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CONFIRMATION NO. 8081

22045
BROOKS KUSHMAN P.C.
1000 TOWN CENTER
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FILING RECEIPT



OC000000034985670

Date Mailed: 03/16/2009

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Early Publication Request: No

**** SMALL ENTITY ****

Title

Method and system of object tracking and telemetry

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011509
17691 U.S. PTO

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

U.S. PTO
61/205146
01/15/2009

Atty. Docket No. BRTN 0102 PRV

INVENTOR(s)

FIRST NAME & MIDDLE INITIAL	LAST NAME	RESIDENCE (CITY & EITHER STATE OR FOREIGN COUNTRY)
Bruce	Burton	Grosse Pointe Farms, MI

Additional inventors are being named on the separately numbered sheets attached hereto.

TITLE OF THE INVENTION (500 characters max.)

METHOD AND SYSTEM OF OBJECT TRACKING AND TELEMETRY

DIRECT ALL CORRESPONDENCE TO:

CUSTOMER NO.

22045

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ENCLOSED APPLICATION PARTS (check all that apply)

☒ Specification - Number of Pages <u>244</u>	☐ CD(s), Number
☐ Drawing(s) - Number of Sheets	☐ Other: Specify
☐ Application data sheet. See 37 CFR 1.76.	

METHOD OF PAYMENT OF FILING FEES (check one)

☒ Applicant claims small entity status. See 37 CFR 1.27.	PROVISIONAL FILING FEE AMOUNT(S)	SIZE FEE (if applicable) for each additional 50 sheets that exceeds 100 sheets	AMOUNT SUBMITTED OR TO BE CHARGED TO DEPOSIT ACCT.
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Respectfully submitted,

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DATE 01/15/2009
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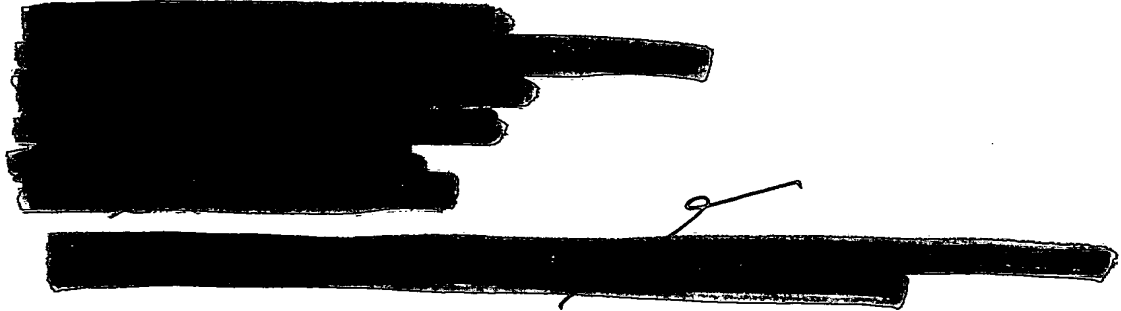
Amy C. Page
(Name of Person Signing)

[Signature]
(Signature)

Section 1: Overview

This document specifies the test setup for the PerforMax Infrared (IR) Locator subsystem. The prototype will demonstrate basic functionality of the IR swimmer location subsystem. Test results acquired during this workshop will be used to improve and refine the IR location system, with the stated goal of returning for a follow-up workshop.

1.1 Participants



1.2 Background

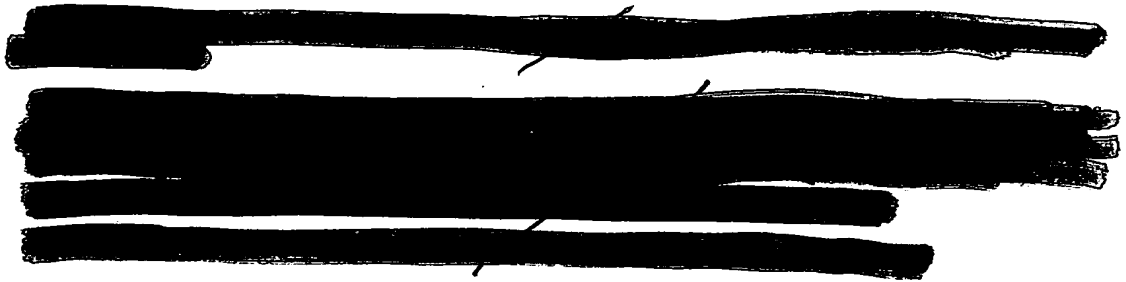
The PerforMax system is being designed to provide significant advantages to the pool-side coach, to the swimmer, and to an entire competitive swimming program. It targets performance-related aspects of the sport by capturing and enabling analysis of data about specific elements of each swimmer's performance and past performances, with support for as many as 100 simultaneous swimmers. It should be as non-invasive as possible, freeing swimmers and coaches to do what they do best, but with a very powerful new tool.

1.2.1 Phase I Prototype Test

 Prototype was implemented to demonstrate the proposed system design, including these important functions:

1. Identify each swimmer's location in the pool.
2. Record a video log of all swimmers in the pool, retaining the video captured for future viewing and analysis.
3. Time the athlete's performance.
4. Acquire basic physical measurements (e.g. stroke, amplitude, motion) from accelerometers in telemetry devices worn by the swimmers.
5. Provide a basic user interface to support the prototype's constrained feature set.

1.2.2 Phase I Test Results



1.3 IR Locator Prototype System Features

The IR Locator Prototype shall consist only of the minimal set of system components required to provide sufficient proof-of-concept of this subsystem implementation.

This system harnesses the two-way RF capabilities of the Swimmer Device, adds an IR LED to it, and uses a camera to look for the LED in a field of interest (i.e. the region of the pool within the view of the camera). It is expected that multiple cameras will be required for a full implementation of this system. This test will be limited to a single camera over part of the pool surface. Image processing software determines the location of the LED within the frame of the image captured from the camera and converts it to real-world (pool) coordinates. This location information will be time coded and saved along with telemetry data and motion video for later review and post processing by the coach or other end user.

Section 2: System Components

The PerforMax IR Locator prototype system consists of the following major blocks:

- Server computer
- Imaging computer
- IP cameras
- Swimmer device and/or swimmer locator device
- Master station radio transceiver
- Wireless access point
- Ethernet switch (PoE)

The following sections describe each of these blocks.

2.1 Server Computer

The prototype system is built around an HP ProLiant ML110 G4 server, running the Ubuntu Linux operating system (server version). Figure 1 shows a typical server computer. The physical appearance of the unit used in this prototype system might vary from the photo.

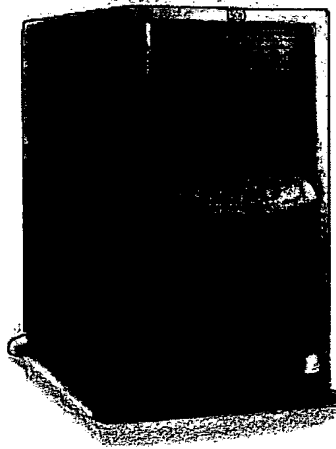


Figure 1. HP server computer

Specialized application software for the IR Locator demo was implemented with the SwiftForth-Linux Interactive Development Environment from FORTH, Inc.

2.2 Imaging Computer

The software responsible for processing the images from the camera and determining the location of the illuminated IR LED on the SD is implemented using the National Instruments LabVIEW Vision Development Module. This module was chosen for its ease of use in rapid prototyping of vision applications and its rich set of built-in features to support image processing.

The vision module requires the Microsoft Windows operating system, so it resides on a separate CPU from the server. The machine dedicated to this task is a small form factor HP Pavilion Slimline desktop computer as shown in Figure 2. The server and vision machines coordinate their functions via Ethernet communication.



Figure 2. HP Pavilion Slimline desktop PC

2.3 IP Cameras

The Mobotix D22 and M22 IP (Internet Protocol) cameras have very wide angle lenses and high sensitivity to infrared (IR) light. Each camera has an onboard CPU to off load processing from the host (server) computer. Two versions are being evaluated as part of this test.

The D22 (Figure 3) is a ceiling-mounted dome camera. The M22 (Figure 4) is a wall-mounted version.

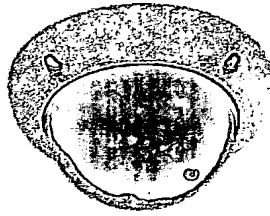


Figure 3. Mobotix D22 IP camera

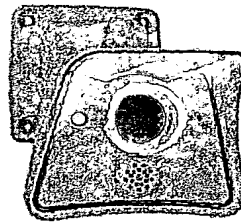


Figure 4. Mobotix M22 IP camera

Each of the cameras can be fitted with optional IR optical filters to block visible light while passing light in the IR end of the spectrum.

2.4 Swimmer Device

A fully equipped Swimmer Device (SD) has the following components:

- Microcontroller
- RF transceiver
- Antenna
- Three-axis accelerometer
- Infrared LED and driver circuit
- Power source (battery)

The locator prototype implements a subset of the full SD and adds some extra features for evaluation and test purposes. The SD board is not equipped with an accelerometer¹.

The Swimmer Locator Device (SLD) is a special prototype equipped with multiple LEDs that can be turned on in any combination under command of the Server (by way of the Master Station).

These LEDs are available on the first SLD prototype board:

¹.The capture of accelerometer telemetry data was demonstrated in a previous in-pool test and is known to be working reliably.

- OPTEK OP200 880nm flat lens 0805 (this is the smallest LED)
- Lite-ON HSDL-4420 2X2mm DOME 875nm
- OPTEK OP 290a 5mm 890nm
- OPTEK OP291A 5mm 890nm
- OPTEK OP294 5mm 890nm

The firmware resident on these devices was implemented with the SwiftX-MSP430 Interactive Development Environment from FORTH, Inc.

2.5 Master Station

The Master Station (MS) provides an interface between the network and the swimmer devices via an RF link. The MS consists of the following blocks:

- Freescale M52235 EVB microcontroller board
- CC2500EM radio transceiver
- Hyperlink HA2401FGI-250 bi-directional 2.4 GHz amplifier
- SMC ANT-DIFP11 flat-panel antenna
- Power converter

The M52235EVB (Figure 5) features a 60 MHz MCF52235 ColdFire microcontroller with a 10/100 BaseT Ethernet and is powered by PoE.

The firmware on the M52235EVB was implemented with the SwiftX-ColdFire Interactive Development Environment from FORTH, Inc.

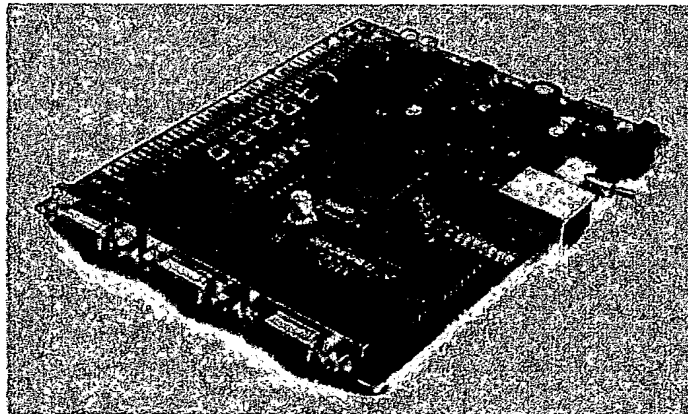


Figure 5. M52235EVB CPU board

The microcontroller communicates with a CC2500EM radio transceiver via a high-speed synchronous serial interface. The CC2500EM radio interface is connected to the SMC antenna (Figure 6) via the Hyperlink bi-directional amplifier (Figure 7). A

power converter takes the 48V PoE supply from the M52235EVB and converts it to 12V to power the amplifier. Figure 8 shows the polarization pattern of the SMC ANTDFP11 antenna.



Figure 6. SMC ANTDFP11 antenna

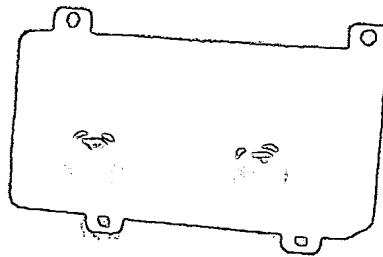


Figure 7. HyperLink bi-directional amplifier

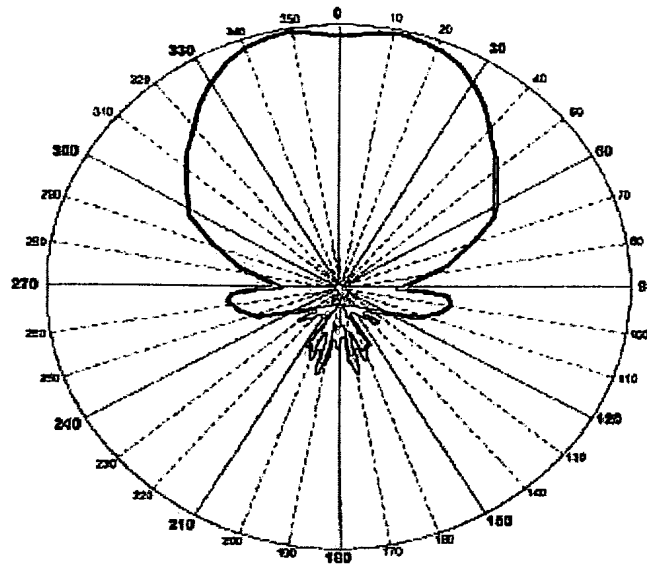


Figure 8. SMC ANTDFP11 antenna polarization

2.6 Wireless Access Point

A Wireless Access Point (WAP) provides a secure WiFi link between portable computers and the Server. In the final PerformMax application, the coaches' computers will access the server database and video via the WiFi link. In the prototype test system, the WAP is provided primarily for diagnostic purposes.

2.7 Power over Ethernet Switch

Power over Ethernet (PoE) technology describes a system to transmit electrical power, along with data, to remote devices over standard twisted-pair cable in an Ethernet network. This technology is useful for powering IP telephones, wireless LAN access points, network cameras, remote network switches, embedded computers, and other appliances where it would be inconvenient, expensive or infeasible to supply power separately. The technology is somewhat comparable to telephones, which also receive power and data through the same cable. PoE works with existing Ethernet cabling infrastructure.

There are several PoE implementations, including ad-hoc techniques, but the devices used in this system adhere to the IEEE 802.3-2005 standard for supplying power over Ethernet. The following devices in the PerformMax system are connected to (and powered by) the PoE switch:

10 System Components

- Master Station
- Cameras
- Wireless access point

The switch used in the prototype system is the Netgear FS116P, shown in Figure 9 below. It has eight PoE ports and eight non-PoE ports, for a total of sixteen.

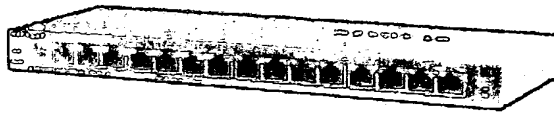


Figure 9. Netgear FS116P PoE switch

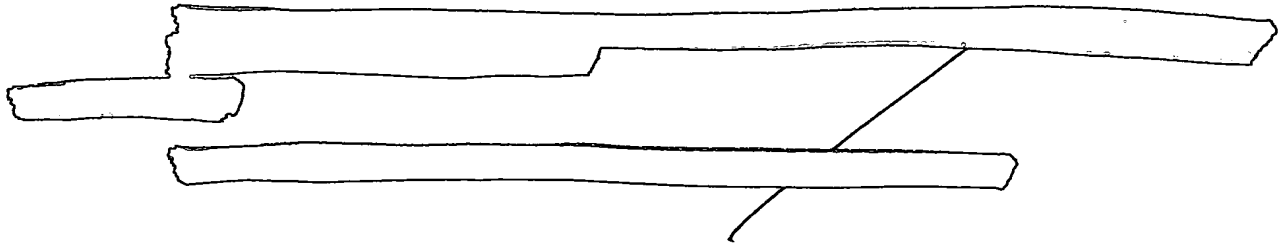
12 System Components

Section 3: Test Workshop

This section gives the planned timeline for the in-pool test workshop of the IR Locator subsystem.

3.1 Agenda

[illegible]



SECTION 1: EXECUTIVE SUMMARY

1.1 Overview

This report presents the status of the development of technologies to enable PerforMax to determine swimmer location in real time.

Two methods of determining swimmer location in the pool on demand were considered, and prototypes were developed and tested. Details of each method are presented later in this document.

The method [REDACTED] used a pair of lasers to scan the pool, combined with detectors and precision counters on the *swimmer devices* (SDs). Related findings are presented in Section 2.5.

The [REDACTED] method uses an infrared light-emitting diode (IR LED) on the SD and an IR sensor outside the pool. The LED is triggered by a command from the host computer, using the radio frequency (RF) communications link developed in Phase I of the PerforMax program.

When comparing the two methods, the IR method shows the following distinct advantages:

- cheaper
- easier
- fewer parts
- no moving parts
- calibration of the sensor can be done in software
- less engineering effort to produce this product

1.2 Test Summary

The initial proof-of-concept for the IR-based locator was successful, with the detection algorithm working properly about 99% of the time.

1.3 Continuing Work

With the success of the initial proof-of-concept, we are now refining and improving the technology. [REDACTED] ordered new cameras for the locator that are expected to provide performance superior to equipment used so far. When they arrive, [REDACTED] will begin testing with them.

4 Report

SECTION 2: TECHNICAL DETAILS

This section discusses details of implementing the location-acquisition strategy. Section 2.2 describes issues concerning cameras, geometry and the pool area; Section 2.3 introduces details concerning image-processing algorithms; some of that discussion is based on preliminary tests using a prototype optical locator.

2.1 SD-to-Host Data Streams

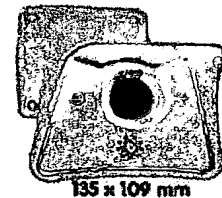
Data streams transmitted from each swimmer may include such information as accelerometer output or, perhaps, physiological information, and will be encoded to identify the particular person. Gyroscopes might be added to each swimmer device to provide the orientation references needed to permit accurate integration of the accelerometer data to obtain velocity and position, but these could add significant cost to each SD unit, and it may prove more cost effective to instead provide an independent locating system that can also be used to identify each swimmer in movies made for near-real-time and/or delayed viewing.

2.2 Camera Projections

This section discusses cameras, equipment placement and important tradeoffs. A laser-based approach that has been superseded is discussed in Section 2.5. The preferred configuration, as of the date of this report, is shown in Section 2.2.7.

2.2.1 The cameras

Vision will clearly play a major role in the system operation, and cameras must be properly chosen and located to achieve complete pool coverage with acceptable resolution. Mobotix cameras (B&W for the locator, color for movies) have been chosen because of their standard super-wide-angle lenses (900 x 670), power-over-Ethernet capability (PoE) and proven record in the field.



The model shown here will be used during the development phase because of its ease of adjustment, but it is likely that a dome camera (probably incorporating both monochrome and color) will ultimately be chosen for aesthetic value. A wide field of view is particularly important because of the large area to be observed and the relatively short distance available between the pool and the cameras.

This is illustrated in Figure 1 and Figure 3, where ideal (no optical distortion) pool projections have been calculated for the given cameras. The camera is located at the origin, and the projections are shown for various incidence angles measured from

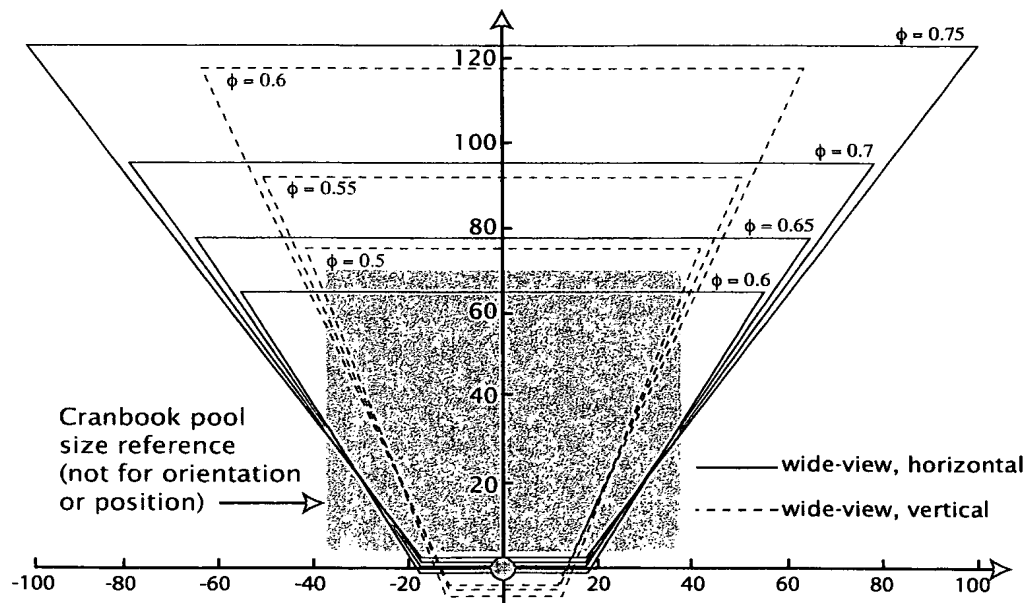
vertical and for horizontal and vertical orientations of the sensor.

Figure 1 applies to a camera mounted 22' above the pool (on the ceiling of the Cranbrook facility), while Figure 3 is for a camera mounted 12' above the pool (e.g., on the Cranbrook balcony.) The relative size of the Cranbrook pool is superimposed on the plots for convenience, and can be rotated and translated to study coverage, but such plots are otherwise quite general, and would be used for the design of any installation. The plots are quite similar in appearance, but it is important to note that *the projections near the camera are wider for the higher camera*, and that will generally favor such a mounting.

2.2.2 22' ceiling mount

Figure 1 shows a full range of reasonable projections from a Mobotix super-wide-angle camera mounted 22' above the pool surface (i.e., a ceiling mount at Cranbrook.) ϕ is the tilt angle in radians of the camera from vertical. The [redacted] pool is shown for size only, not for position or orientation. The projections can be applied to any pool with the camera at 22', and the *pool projection* can be moved to determine the best location for the camera.

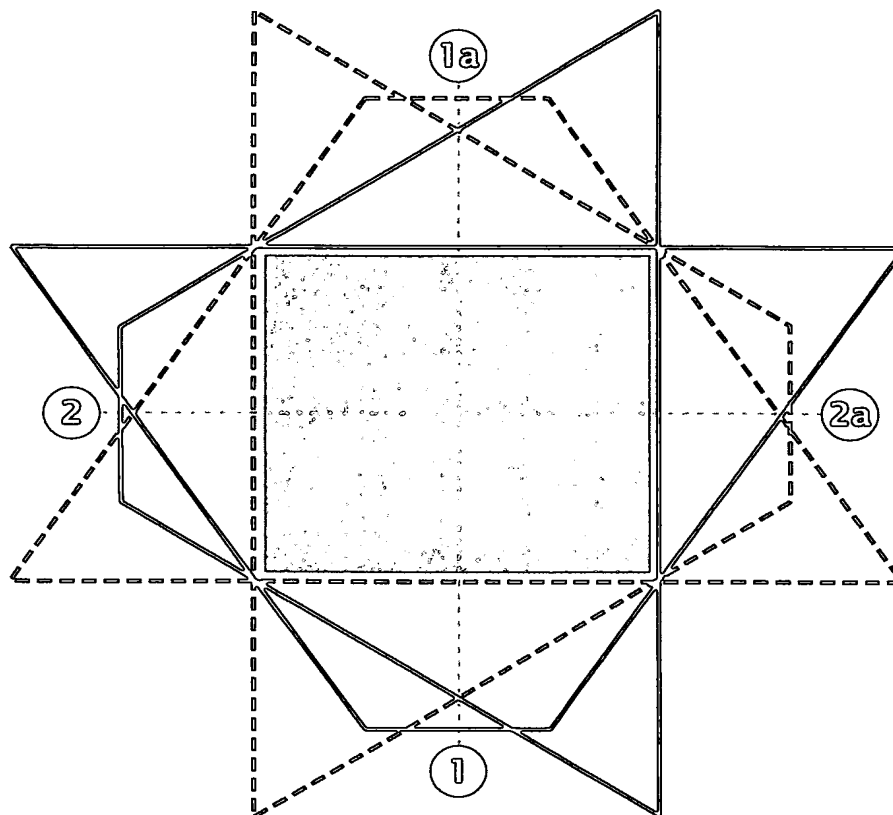
Figure 1. Ceiling-mount projection, 22' high



2.2.3 35.5' offset mount

Figure 2 shows several ceiling-mount arrangements for which a single camera will view the entire pool. A second identical camera can be added, facing the first, to improve imaging and location accuracy. The 35.5' horizontal distance from the camera to the side of the pool may, however, be too large for the building, or the view may be partially obstructed by the balcony.

Figure 2. Ceiling mount, 35.5' offset



Camera is 35.5' from pool edge,
distance may be too great.

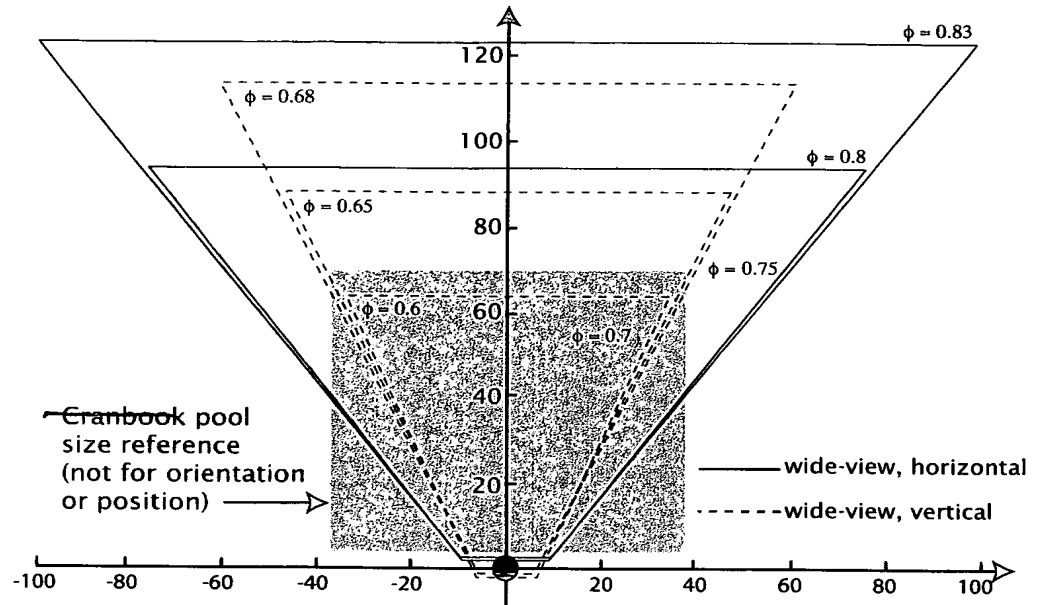
Observations:

- super-wide-angle lens enables full viewing with ceiling-mounted Mobotix camera at 42 degrees from vertical
- orientation can be based on viewer preference, not camera limitations
- cameras and layouts suitable for both locator (B&W) and movies (color)
- selectable 10 fps with 1080 x 960 resolution, or 30 fps with 640 x 480 resolution

2.2.4 12' side-mount

Figure 3 is equivalent to the layout shown in Figure 1, but applies to a camera 12' above the pool (a side mount XXXXXXXXXX). The narrower width of the projection near the camera is a major disadvantage of lower height.

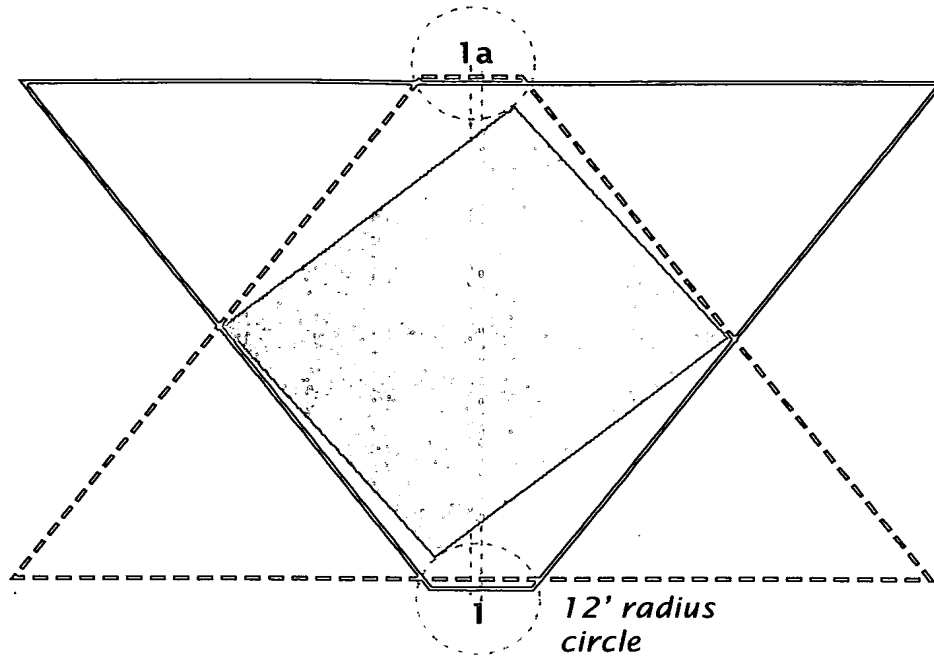
Figure 3. Side-mount, 12' high



2.2.5 12' side mount

Figure 4 shows a side-mounted arrangement that provides full pool viewing with a single camera and meets all the building constraints ~~(*Figure 4. Side mounted, 12' offset*)~~. The diagonal viewing angle may not be a desirable aspect and may actually reduce resolution.

Figure 4. Side mounted, 12' offset



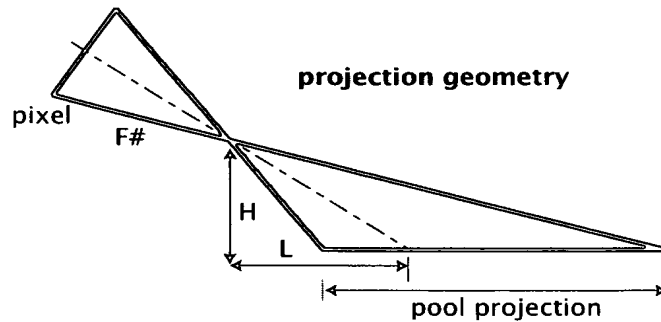
This configuration, with a super-wide-angle lens positioned 12' above and 12' from the side of the pool, at 47 degrees from vertical, gives an unobstructed, diagonal, full-pool view.

2.2.6 Resolution & accuracy versus distance from camera

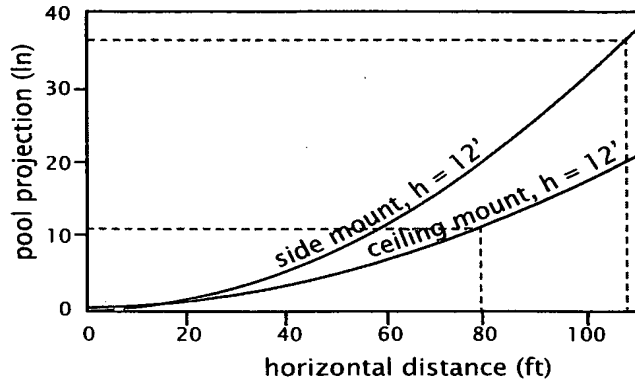
Figure 5 demonstrates the loss of image resolution and location accuracy that occurs with increasing distance from the camera. The ceiling mount will give considerably better performance. A second camera facing the first will further improve matters, and the cameras will achieve 2X better resolution with MEGA operation — but at reduced frame rate.

The resolution issue is a very important consideration because of the distances and angles involved with pool viewing. The projected size of a single pixel for the side-mounted camera in VGA operation will be 36" at the furthest corner of the pool at 108' from the camera, whereas it is only 11" for the ceiling-mounted camera at the most distant corner at 80'.

Figure 5. Projection resolution



worst cases to
furthest corner with
Mobotix SW lens and
VGA operation



Observations:

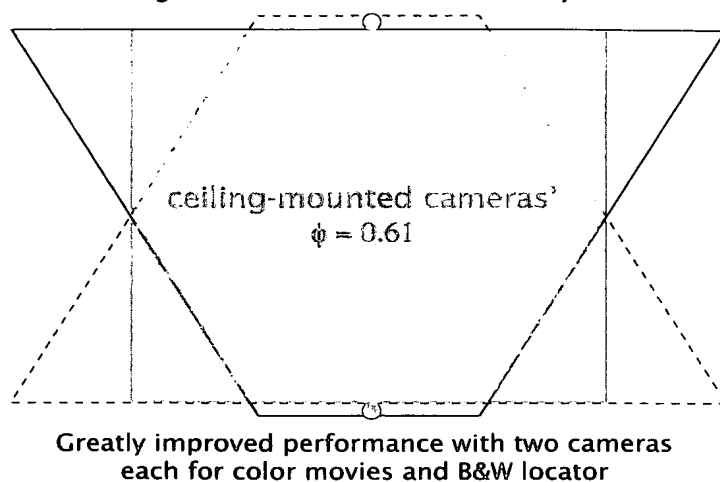
- pool projection and location error increase rapidly with distance from camera
- ceiling mount offers significantly better performance
- second camera will help considerably with both accuracy and imaging

- MEGA camera operation would decrease the projected pixel size by 2X, but that would be obtained at the cost of lower frame rate.
- The projected pixel size decreases dramatically nearer the camera, suggesting a better alternative in the form of a well-located second camera. Figure 6 shows a recommended arrangement with ceiling-mounted cameras, two each for both monochrome locating and color movies. The four corners would have reduced resolution in this case, but images of the rest of the field (the majority of viewing area) could be software-selected to provide the best-available combination of properties.

2.2.7 Preferred configuration

Figure 6 shows a two-camera, ceiling-mounted layout for which each camera would essentially cover 50% of the pool surface after rejecting “waste” and redundant pixels. This, the preferred arrangement, would use a total of four cameras with separate color and monochrome ones for movies and the locator. Separate color and B&W cameras could be mounted side-by-side, but Mobotix does offer dome units with the two cameras at a somewhat lower price. Separate cameras were purchased for use in the development phase for ease of use.

Figure 6. Preferred multi-camera layout



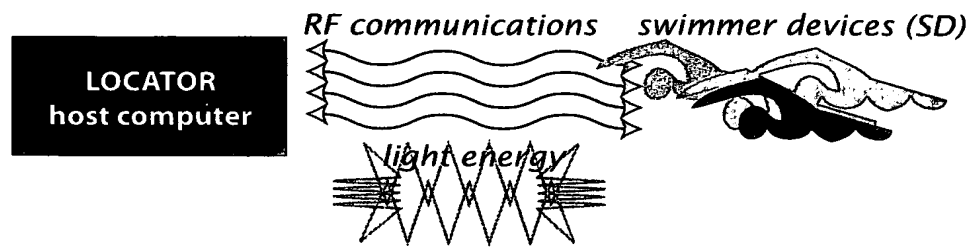
2.3 Optical Locator Principles

The optical locator is a query-based location system in which light is used to excite a light sensor. The RF link [REDACTED] of the Performax program passes commands between host computer and SDs.

The measured data result of the location event, along with the known geometry of the environment (the pool), are used to calculate the SD's location. This system has a host computer (the *locator*), an SD (the object being located) and a fully calibrated camera to detect the SD.

The host computer always initiates the location process. This ensures that the host can synchronize the location data with all other data inputs to the system (e.g., video and telemetry).

Figure 7. RF link for communication between host computer and swimmer devices



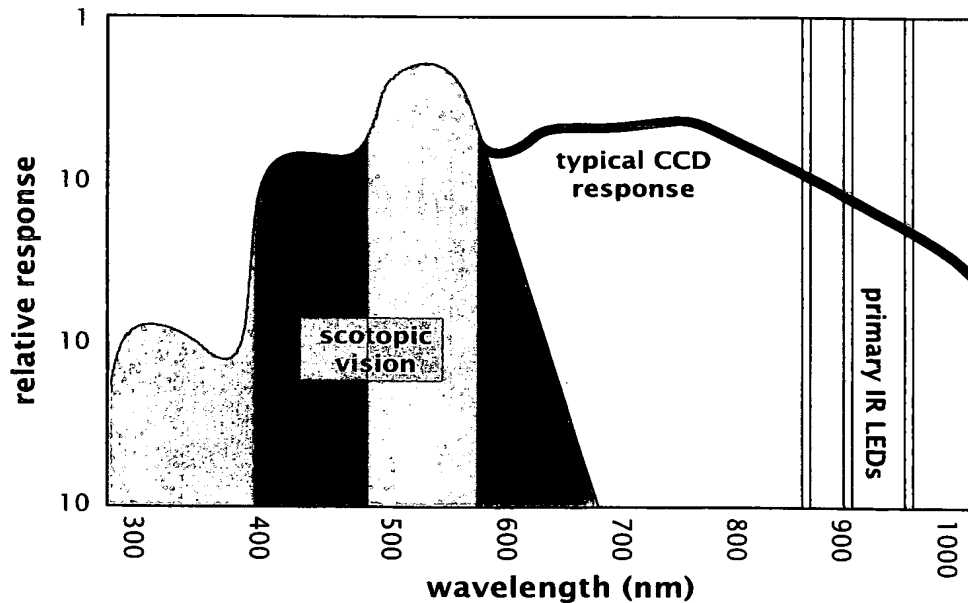
2.3.1 Location by IR Detection

The infrared (IR) approach to position determination utilizes the same basic principles—using a light energy source and light energy receiver—as the scanning laser light method; the direction of the light is just reversed. The remainder of this report discusses how this method works and presents the data collected during the initial proof-of-concept testing.

The host sends a request to a swimmer device to flash an LED that is, in turn, recognized by a calibrated camera system that registers the pool coordinates of the LED and sends that data to the host computer. Powerful infrared LEDs that operate outside the range of the human eye (Figure 8) but which can be readily detected by conventional CCD cameras are readily available commercially. An IR LED was tested (Figure 8) to prove the concept that SD-to-host light location is possible; the process took about 1/30th of a second.

Proof-of-principle tests have been successfully conducted with a home movie camera. Of particular interest is the 850 nm LED, and tests are underway to identify the best model and to reach a satisfactory compromise between the power requirements and the number of LEDs needed for each SD to provide unambiguous location data.

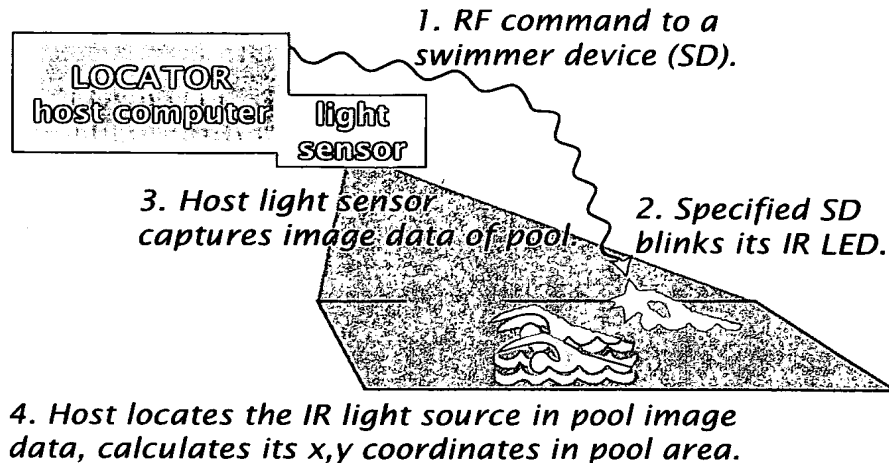
Figure 8. Visual and CCD frequency response



Illumination beyond 700 nm is invisible to the human eye.
LED output must be weighed against CCD response.

The swimmer devices all have unique addresses that identify each swimmer individually. The host computer uses the RF communication channel to contact a specific SD and command it to flash its LED. While it is illuminated, the host computer captures an image of the pool. The host computer can then filter and analyze the image to locate the light spot that has the wavelength of the LED's light output.

Figure 9. Infrared LED approach



When the light spot is located in the image, the image's pixels can be assigned specific lengths based on the geometry of the environment and the resolution of the CCD. As an example, if the area in the image is 25' x 18.75' and the CCD imager has a resolution of 640 x 480 and the image was acquired at an angle normal to the pool, then every pixel will represent an area that is 0.46875" x 0.46875". With these distances known, it is a simple measuring exercise to calculate where the swimmer is in the pool. An advantage to this approach is that the host computer is in charge of the whole process and there are no tight timing constraints.¹

As shown in Figure 5, pool projection and location error increase rapidly with distance from the camera. A ceiling-mount camera offers significantly better performance, and a second camera will help considerably with both accuracy and imaging (Figure 6).

¹. Pixel transformations have been simplified in this discussion for clarity of principle.

2.3.2 Pros and Cons of the IR Approach

Advantages:

- components are commercially available
- components are substantially less inexpensive — \$1-2K host side and (single dollars) SD side, plus two monochrome cameras at about \$1K each — than with the laser-scanner approach
- specialized CCD imagers make IR detection easy
- environmental calibration (bumping) can be fixed in software
- little impact on SD battery life (LEDs are on for a small fraction of a second)
- simple geometry design: based on accelerometer, multiple LEDs can be used and the accelerometer will tell which LED to turn on
- simple concept makes the required engineering easier and will take less time

Disadvantages:

- line-of-sight location (this will be improved with multiple LEDs)
- may be visible to a very small percentage of people (they may notice the LEDs blink from time to time)
- number of locations per second is limited to the CCD imager's frame rate (the location between locations will be extracted from accelerometer data)

2.3.3 Testing the IR Approach

Here we describe the tests performed on IR detection; these tests will be refined and expanded as development continues. In particular, test protocols to address angular dependence (spatial resolution as a function of distance from the camera and camera positioning) or the visibility of the SD LED (to determine if multiple LEDs will be required to reliably determine SD location).

A prototype board was created containing eight visible-light LEDs and eight IR LEDs. The thought process here was that one could use visible LEDs to do this, as well; the only difference is that the people may notice the LED blinking on the heads of the swimmers.

A series of pictures was taken in frequent succession. The first pictures are with the IR LEDs off, and the second with the IR LEDs on, in order to simulate the command being sent from the host to the SD.

These pictures were then processed in several different ways in order to determine the best method for processing images to extract the location of the illuminated IR LEDs. The following pictures (edited here for clarity) are an example of how this process worked. Figure 10 shows the IR LEDs off; Figure 11 shows the IR LEDs on.

Figure 10. LEDs off

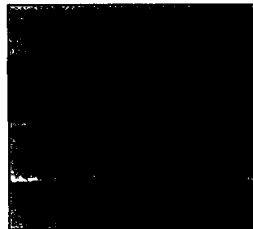
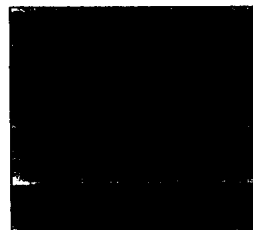


Figure 11. LEDs on

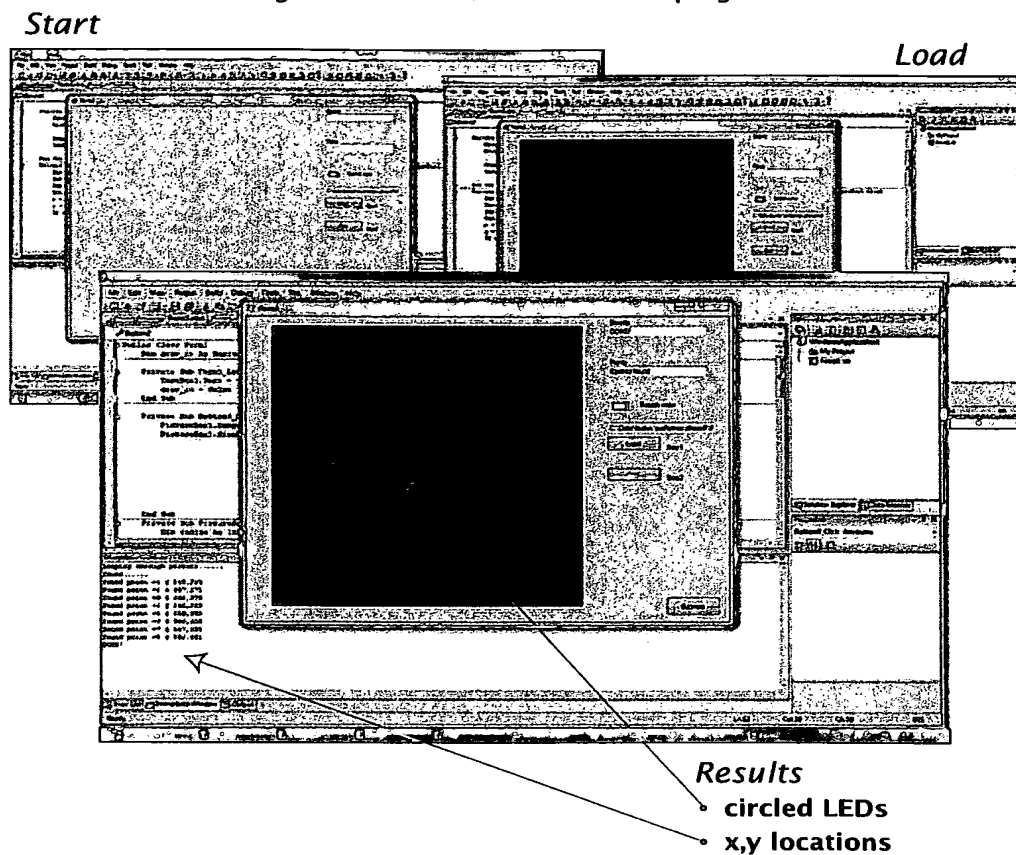


Data and images were captured representing eight swimmers in close proximity. A simple prototype program was then developed to process the images to locate the "swimmers" and return their x,y positions in pixel units within the picture.

2.3.4 The “detection” program

A program was created to test algorithms for finding the IR LEDs in an image. The program is very simple to use: load an image and press “Find” to locate the IR LEDs. The program searches the image using two algorithms (discussed later) to find the LEDs, then draws a circle around the LEDs. When all the LEDs have been found, the program prints the x,y location, in pixels, of each of them.

Figure 12. Demo of LED-detection program



2.3.5 The algorithms

Subtraction:

The test pictures shown in Figure 13 and Figure 14 were processed using a subtraction algorithm, to produce the result shown in Figure 15.

1. The image in Figure 13 is captured with the LEDs off.
2. The host commands the LED on.
3. The image in Figure 14 is taken.
4. The two images are then subtracted pixel by pixel.
5. The resulting image in Figure 15 is mostly black.
6. That image is stripped of its blue and green components.
7. The Red component is cubed and averaged.
8. The Red component is then normalized to 100%, using the average and the max as bounds.
9. The image is searched pixel by pixel.
10. The largest red values are circled and recorded.

Figure 13. Image processing: frame 1, LEDs off

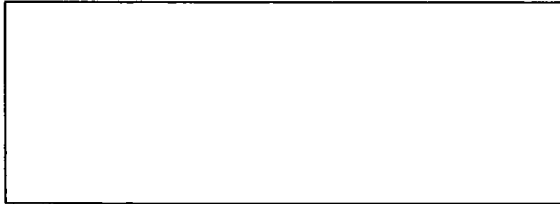


Figure 14. Image processing: frame 2, LEDs on

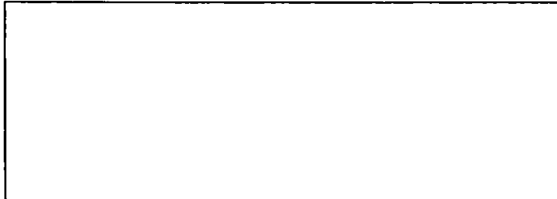
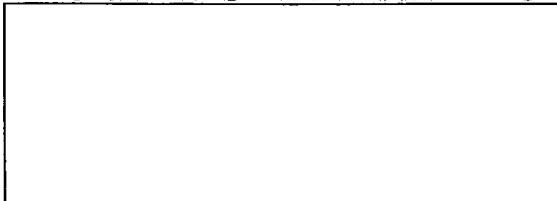


Figure 15. Image processing result: after subtracting #2 from #1



Deviation from mean:

The image in Figure 16 was processed using a deviation-from-mean approach with calibrated LED color, producing the result shown in Figure 17.

1. 6 x 6 pixels of data are averaged around a central pixel.
2. The neighboring pixels are averaged the same way.
3. The 6 x 6 pixel blocks are subtracted. This gives a smoothed error signal from pixel to pixel.
4. The resulting image is cubed. This isolates pixels that are very different from each other.
5. The resulting image is then normalized. This brightens the picture and grays the similar pixels.
6. The pixels of the original image are checked to see if they match the *search color*, a calibrated color based on what color the IR LED appears in the CCD imager.
7. The closest values to the search color are circled and recorded.

Figure 16. Image processing: original

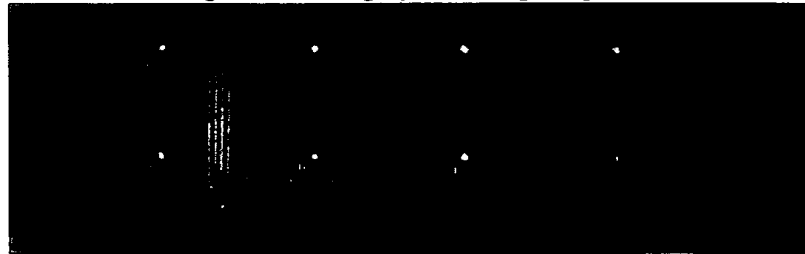
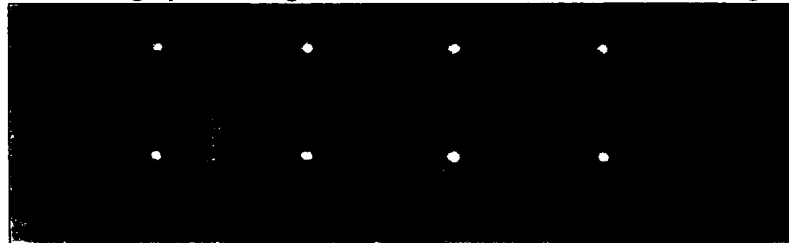


Figure 17. Image processing result: deviation-from-mean with target color



The ending image, in which to search for the search color, is basically converted to a grayscale image except where large differences in color originally existed. The IR LED appears in the 800-850 nm range. As is evident in Figure 17, vivid colors show where the largest differences were: the IR LEDs and PCB traces.

This procedure works very well but is math- and time-intensive.

2.4 Continuing Work

[REDACTED] Illuminated markers be temporarily placed at the corners and midpoints of the sides of the pool to calibrate for image rotation, skew, perspective, and distortion. Even if this proves to be essential to the system's operation, calibration should only have to be performed once, as long as the cameras aren't moved.

Two Mobotix cameras and a PoE (Power over Ethernet) switch have been ordered. The PoE switch has been received; we expect the cameras by March 12. Assuming there are no delivery delays, and [REDACTED] is able to provide [REDACTED] with LED sources on schedule, we expect to complete preliminary testing with the cameras. [REDACTED]

A Mobotix monochrome camera has been purchased for the locator, and will be tested within the next month over interesting distances with candidate LEDs. The camera can operate at 30 fps at 640 x 480 VGA resolution or at 10 fps at 1280 x 960 MEGA resolution, but the rate at which swimmers can actually be recognized will depend upon a variety of hardware and software factors and remains to be determined. Calibration and operational software is being written in MatLab for development and test purposes, and will ultimately be translated to Forth for commercial use.

2.5 Discarded Location Methods

This section is included for the purpose of providing background on the laser-scanner method of position-location. [REDACTED]

Location-determination methods investigated [REDACTED]

[REDACTED] included Doppler sounding (excessive echoes from the pool walls), underwater RF (excessive attenuation loss), and atmospheric RF "triangulation" [REDACTED] synchronize signals using a master clock and to handle multiple swimmers).

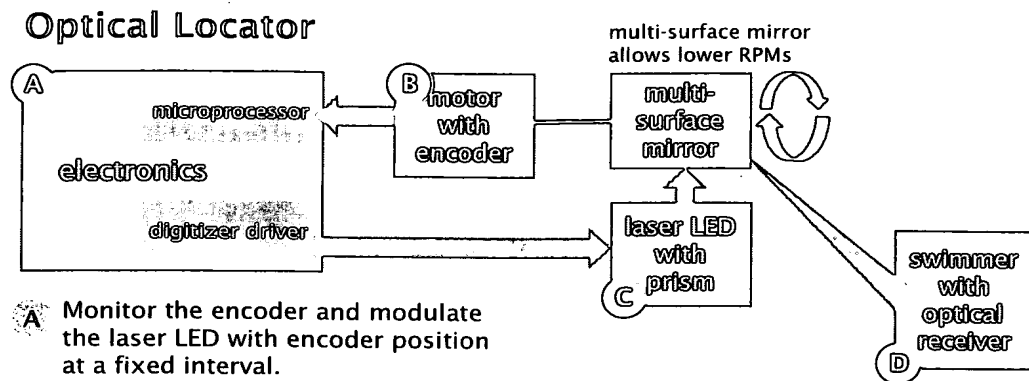
[REDACTED] optical locating techniques, the first of which used a commercial DLP to project a time and spatially encoded pattern that would be recognized and translated by the SD to give the swimmer's location. [REDACTED] a concept offering higher-resolution and improved data rate by scanning two laser beams across the pool and using the SD to measure their times of arrival. The two-beam approach would work [REDACTED] but the hardware components proved to be very expensive (well over \$10,000 per installation), and there are [REDACTED] issues with the rapidly moving mirrors; see Section 2.5.1 for [REDACTED]

2.5.1 Location by Laser Scanner

This approach to the locator is flexible and can be configured to work from host-to-SD or SD-to-host. In either situation, the host is always in charge and completely controls the communication channels.

This method uses a pair of scanning laser light sources controlled directly by the host computer. The host initiates a sync pulse over the RF, which starts a high-precision counter on the SD used to measure the elapsed time between the sync pulse, beam-one sweep, and beam-two sweep.

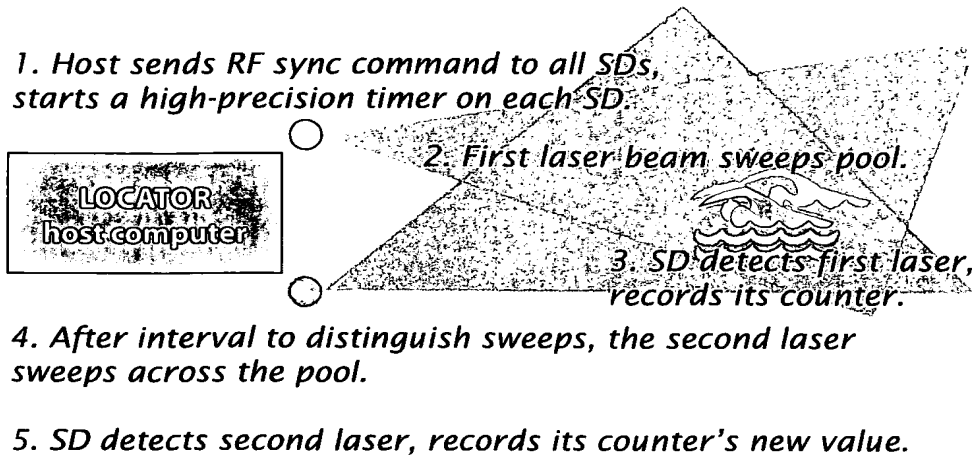
Figure 18. Locator process and hardware



The laser sweeps across the pool, and the SDs monitor their light sensors looking for the laser beam to sweep across them. When the laser beam is detected, the high-precision timer count is logged. These logged times, in conjunction with the known geometry of the system, resolve a unique pair of x,y coordinates in the pool area.

Although the details of execution have been simplified since the inception of this concept, the laser-based optical locator proof-of-concept completed successfully and was documented in a previous presentation titled "Optical Locator1.pdf."

Figure 19. Laser-sweep approach



2.5.2 Pros and cons of the laser-sweep approach

Advantages:

- components are commercially available
- laser technology allows for precision beam sizes and good resolution

Disadvantages:

- components are expensive — \$7–9,000 per module (two modules)
- rapidly moving parts (the scanner motor)
- for good signal-to-noise, the laser has to be very bright; could be troublesome getting certification for this product
- laser modules are very susceptible to bumps and vibrations
- requires servo-motor controls and associated overhead
- the battery life of the SD is reduced because the SD must monitor the beam sensor for long periods of time
- effective sensor-geometry design and placement is difficult
- engineering time to design this into the system is sizeable
- location method is line-of-sight only (adding multiple sensors in different directions adversely affects SD battery life, sensor design, and cost)

INTRODUCTION

Overview

This report presents the results of preliminary PerforMax system in-pool testing [REDACTED] as well as follow-on work and analysis of test results in the weeks following the test.

The tests performed [REDACTED] were very successful. The highlights are given in a bulleted list below. Subsequent sections of this report go into detail about each of the subsystems tested or demonstrated. It is important to note here that even though some of our tests indicate more work and/or investigation is to be done, none of them can be considered a failure. We find this very encouraging as proof of concept.

Please refer to the *PerforMax Prototype Preliminary Test Plan* dated [REDACTED] for the details and goals of this [REDACTED] system test.

Test Summary

Our tests utilized a Swimmer Device (SD) board mounted inside a protective case, all of which was wrapped in a waterproof plastic bag inside the cap (see Figure 1) as well as strapped to the wrist and ankle of a volunteer swimmer.

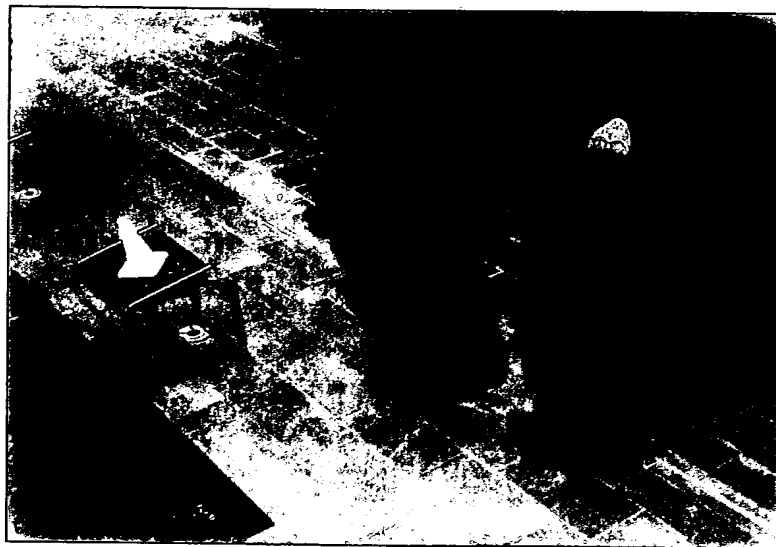


Figure 1. Testing SD inside swim cap

The SD was in two-way data communication with a fixed transceiver (a modified SD) on the balcony just above the edge of the pool. The data from this transceiver was stored by the server computer for later analysis. Multiple SD tests were performed, both with and without a swimmer.

Multiple sets of accelerometer data were acquired during the swimmer tests. The data were later displayed graphically to demonstrate the potential for use by coaches in technique and stroke analysis. See Appendix A for plots of accelerometer data.

The Radio Frequency Time of Flight (RF TOF) system is one of two generic candidates for measuring the position of every swimmer. The other is a scanning optical beam method. It is important to understand that the method or methods that are ultimately utilized in the final product will need to perform three distinct functions: (1) Uniquely identify each swimmer, (2) Uniquely establish the coarse location of each swimmer to an accuracy sufficient to track the swimmer with the video system, and (3) precisely determine the location of each swimmer device to a few inches to enable competitive performance evaluation. Because our RF TOF system is much more mature and was a central focus of the tests performed, it receives the lion's share of attention in this report. For completeness, a version of the optical method is separately discussed in Appendix B.

RF TOF uses the measured times of receipt of SD poll responses from fixed location receivers positioned around the pool to determine the location of the transmitting SD. For this initial test, the transmissions of raw data were captured and analyzed on a high-speed oscilloscope. Subsequent followon tests were also performed after the conclusion of the in-pool testing. See Section 2 for details on the RF Subsystem test results.

The server computer and associated infrastructure (PoE switch and Wireless Access Point) provided a robust platform upon which all the other tests were supported.

Up to six video cameras were tested in simultaneous operation. The number and configuration of the cameras were subject to much experimentation during the Cranbrook test.

Candidate components of the eventual user interface were demonstrated with varying amounts of integration with the server computer.

Highlights

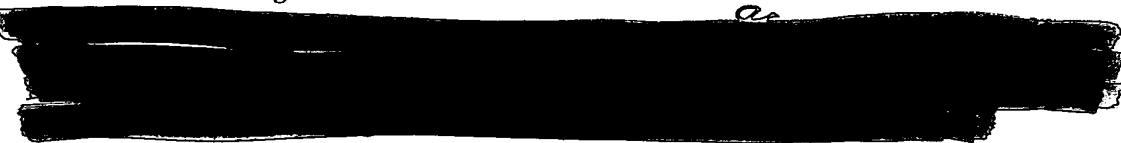
The following items from our test plan were completed successfully:

- The server and IT infrastructure (switch, wireless access point, cabling, etc.) performed flawlessly.
- The Swimmer Devices (SD) used to acquire telemetry data worked well during the in-pool swimmer tests. Our goal was better than 90% poll response and in fact we received 100% of the data with no data loss. Battery issues on the SD prevented very long runs of data acquisition, but this is a relatively minor detail to be worked out in the next hardware revision of the SD.
- Post-test graphical plots of the accelerometer data showed great potential to assist coaches in stroke and performance analysis.
- Measurements taken with a high-speed oscilloscope indicate that using RF Time of Flight (RF TOF) is a viable technique for relatively coarse (about 2 feet) swimmer location. Some caveats are noted in Section 2.
- Continuous coverage of the entire pool with multiple cameras has been achieved using two camera positioning techniques as detailed in Section 3.
- Massive data storage for acquired video and telemetry data was supplied by the server computer.
- Streaming video from multiple cameras to the server computer for long-term storage was successfully achieved.

Continuing Work

The remaining items require further work or investigation as noted below.

- A method to timecode and synchronize the telemetry and video data is still to be developed.
- The actual calculation of coarse swimmer location from RF TOF measurements requires additional hardware and software development to implement.
- An optical alternative to RF TOF has been proposed and is still pending peer review and subsequent refinement. See Appendix B for details.
- Precise tracking of swimmer movement may require the addition of a gyro to the SD. Further investigation is needed.



- Implementation of streaming video delivery from the server to client computers (coach's console, remote users via net connection) is under development but was

1.Ohgi, Y. 62.3: Microcomputer-based Acceleration Sensor Device for Sports Biomechanics, IEEE 0-7803-7454-1/02, 2002.

not ready to demonstrate due to time constraints.

- Power consumption by the SD will need to be addressed when its final configuration is agreed upon.
- Add Low-Noise Amplifier (LNA) on the receive side and High-Power Amplifier (HPA) on the transmit side of the Master Station transceiver.

SECTION 1: SERVER AND INFRASTRUCTURE

Our server and network infrastructure performed reliably, with continuous availability and no failures of any kind throughout the test period.

The deployment [REDACTED] was done in essentially the same fashion that a production installation would be, with cables run and terminated on site using standard termination (Keystone jacks and patch cables.) The Nortel Business Wireless Access Point (WAP) performed flawlessly, as did the PoE (Power over Ethernet) switch. If we use similar camera technology, the installation should be no more technically challenging than a typical surveillance camera installation.

We know that the prototype server's disk capacity will be inadequate for a production system, but the final storage requirements will depend on the video encoding used (MPEG-4, motion JPEG, FLV,) and the resolution the video is stored in. The four-year data (including video) retention requirement guarantees that the storage requirements will be immense no matter what we do. However, we may be able to substantially reduce the storage requirements if we can either selectively reduce the resolution of stored video, or perhaps eliminate stored video altogether after less than four years.

1.1 Server

[REDACTED] prior to [REDACTED] test, the server was configured and tested in the lab and was fully operational. The server computer used for this test has the following attributes:

- Hewlett-Packard Proliant ML110 G4 mini tower
- FreeBSD 6.2 operating system
- Dual-core Intel Xeon 3050 2.13 GHz 64-bit CPU, 1 GB RAM
- Two 500 GB SATA2 disk drives, for a total storage size of 1 TB (about 900 MB of which is set aside for data storage)
- Dual 100/1000 Gb network interfaces (one for a "local" or "private" network and one for Internet connection during lab testing)

The total hardware cost of the server computer as configured was just under \$1,500.

1.2 Switch

Our test system used a fairly generic and inexpensive Netgear 16-port Power over Ethernet (PoE) switch with a list price of under \$200. The switch features 8 PoE ports and 8 non-powered ports.

The switch requires a single AC power supply; it supplies power to the WAP and cameras via PoE. The server was connected to a standard (non-PoE) port.

In spite of its low price and limited feature set, the switch performed well throughout the test period.

1.3 Wireless Access Point

The Nortel Business Access Point 120 (list price \$345) provides secure connections from multiple wireless computers. Video feeds viewed on laptop computers, developers accessing server data files, as well as the coach's console user interface development and testing were all supported concurrently and with no down time.

SECTION 2: SWIMMER DEVICE AND RF SUBSYSTEM

This section summarizes the test results found for the RF Data Communication Link (DCL) and Time of Flight (TOF) concept for transferring data and locating the Swimmer Device (SD) using the CC2500 SD prototype system developed for the Phase I pool tests.

The primary goals that must be met for the system to perform are as follows:

1. The DCL must provide error-free communications between the Master Controller and each of the SDs, no matter what the polarization orientation is, and be able to function with a thin film of water. A hydrophobic radome plastic would be interesting to use. The term "error-free" of course is subject to interpretation; for our purposes we would like to see a 99.0% success rate for maximum length data packets.

The in-pool tests carried out showed no data loss, though there were periods where real-time information was unavailable due to submersion of the SD. The SD firmware was coded to use SRAM internal to its MSP430 microcontroller to buffer up to one minute of samples until a successful DCL transfer could take place.

2. The Radio Frequency Time Of Flight (RF TOF) must provide enough signal margin so that we can recover a sufficient pulse slope to accurately delineate the end of a packet transmission or the end of a bit pulse in the case where we elect to use on/off keying (OOK) TOF mini-packets. Again the system must be insensitive to polarization rotation and must be able to receive transmissions from the entire coverage area.

In-pool tests were limited, however signal levels were sufficient to allow an RF TOF solution to remain in the running with some caveats, as described in Section 2.1.

Battery life on the SD must be conserved as much as possible, so a single packet transmission is desirable.

If it proves necessary to include a gyroscope in the SD, the current consumption will be raised to something on the order of 35-40 mA, which pretty much rules out standard LiMnO_2 (lithium-manganese dioxide) coin cell chemistry. Candidates in the running are standard alkaline AAA or rechargeable Li-ion batteries, or NiMH rechargeables. The primary reason for higher current draw is that some of the subsystems must be run in a near continuous mode in order to capture accurate data and transmit it back to the Master Station.

2.1 In-Pool RF Test Results and Comments

Results of the  tests show that the SD DCL is reliable when mounted on the wrist and head. However, no data was gathered from a unit mounted on the ankle due to continual underwater immersion. Ankle data was later recovered when the device broke through the waterline. In all cases, the DCL was only established when the SD broke through the waterline during the swim stroke. Water beads and splashing water made no noticeable difference to the DCL reliability. The most con-

tinuous RF link during any swim stroke was with the SD placed underneath the swim cap at the top of the head as shown in Figure 2 below. The effectiveness of other mounting positions varied depending on the stroke mechanics. In every case, a complete dataset was recovered from the swim tests, though real-time updates were interrupted while the SD was below the waterline.



Figure 2. Testing DCL with SD inside swim cap

The Master Station used for these tests was a simple SD modified with the appropriate firmware, transmitting its results to the Server through an RS-232 serial port. As such, this device had no external gain on either receive or transmit, yet was still able to communicate with a swimmer-mounted SD for the length of the pool. An external front end that provides a 23 dB gain on transmit and 16 dB gain on receive was procured, but was not tested due to time constraints.

The front end is a bidirectional LNA (Low Noise Amplifier) for receive functions and an HPA (High Power Amplifier) for transmit functions. The device amplifies any signals from the Master Station by about 23 dB, corresponding to an output of about 250 mW, when not sensing a signal from the Master Station is in a receive mode, amplifying the incoming signal by about 16 dB. Other gain combinations are available if necessary, and the final Master Station product would simply incorporate this function into the RF board. Mathematically, a doubling of transmit and receive distance equates to 3 dB of additional power required, so the front end would provide more than adequate coverage of the pool surface for both transmit and receive operations.

With respect to RF TOF testing, signal levels from the SD were sufficiently strong to be able to recover a usable power reading above the ambient noise floor. With respect to the quality of the signal for RF TOF purposes, there are several things found for consideration:

1. As suspected, the signal cutoff slope of the RF power signal starts to flatten out as the signal strength gets lower and closer to the noise floor of the system. The signal level as the SD transmits is relatively steady with a voltage variation within the oscilloscope measurement range. While the DPO4014 oscilloscope used during the test is one of the few on the market that has both the acquisition speed and deep memory storage available for this work, it does have some dynamic range limitations regarding the data. The offset function has limited range when used on low (50 mV and below) signals that ride on top of a large DC offset. Post-processing the data will have to be done to gather the statistics necessary to fine tune any future design iterations.
2. Multipath propagation causes the signal to exhibit either a dip or peak in the voltage output as the primary signal stops transmitting. This occurs because multipath propagation is a coherent interference phenomenon and may make the signal stronger or weaker, depending on the phase relationship. There is a secondary effect due to the modulation used on the signal. However, the data rate in this application is so low that for all intents and purposes both signals are at the same modulation state at the end of the received packet. Interestingly, the multipath effect was not seen in the majority of the measurements done (usually only when the SD was next to a metallic object such as a handrail or other structure). However, a statistically significant sample of signals was not gathered due to equipment and time limitations. One could simply design the end-of-pulse detector to trigger on both positive and negative changes in the signal amplitude. Such signal quality and data extractions are discussed in Section 2.2.
3. One of the other criteria for an RF TOF system is its immunity to noise and concurrent transmissions by other devices. In doing the in-pool testing, it became quickly evident how much 802.11g traffic was going to be seen by the RF TOF receiver when the coach's wireless 802.11 data link is active. Without an adequate method to qualify and filter out extraneous signals from the system, the RF TOF computation engine will suffer from too many false readings. Even if the 802.11 link were moved to the 5.8 GHz range, RF TOF would still need to deal with a myriad of other 802.x devices operating in the 2.4 GHz frequency range (e.g. Bluetooth, ZigBee) and worst of all the infamous microwave oven. Most modern ovens operate at a nominal 2450 MHz, which happens to be right in the middle of our radio band (ISM). Our current filter will not exclude this noise. The details of remedies are discussed below in Section 2.2.
4. Finally, the real issue is how accurate the ultimate position determination can be from a system such as this. Given the raw data values measured on the oscilloscope, the comfortable answer is 2 to 4 feet under good signal conditions, whereas under low signal conditions, the answer is closer to 5 to 10 feet, primarily due to the decreased and noisy slope of the signal cutoff waveform. The driver amplifier system as designed does a very good job of maintaining signal fidelity through the RG-58 cable, so central processing of the TOF data is viable as originally envisioned. A central processor allows a more complicated signal extraction process, which can be used to increase the accuracy of the system. In addition, the relatively large number of polls to each SD allows a measure of statistical sampling to be invoked. As in the

case of the DCL, this system is a worst case prototype, so any optimizations should be able to meet the 2-4 foot case.

2.2 RF TOF Signal Extraction and Analysis Issues

The first item that was noticed was the amount of active noise seen by the RF TOF system especially due to the tablet wireless video link. The current prototype has a full 100 MHz bandpass so that any signal seen in the entire 2.4 GHz ISM region is visible to the power detector. The reason for this was for flexibility in determining frequency of operation. The RF TOF subsystem does not require the full bandwidth of the 83.5 MHz ISM band, however if a very narrow filter is chosen, it may be that a particular facility has a noise problem particularly at that frequency and an alternate filter would have to be installed in the Station Receivers as well as the Master Station. Such interference may be intermittent or may not show up for weeks or months after installation, causing quality perception problems. Such noise may also cause the DCL to fail. However, that system can also adapt by updating the frequencies it uses. The other option is to go with a superheterodyne receiver system and filter the frequency at the IF portion which is not terribly expensive but a fast response will need to be maintained to keep the resolution of the system.

The other solution is to develop a smart version of the RF TOF power receiver that gates all except a narrow time slice of the incoming signal and uses the CC2500 SYNC WORD strobe as a qualifier to examine only a certain subset of the incoming signal. Measurements indicate that the CC2500 sync strobe to inbound RF signal loss has a jitter of about 100 ns and takes about 8 us to react to the end of the packet. In this situation a high speed ADC converter would have to be used to store about 8 or 9 us of data, which corresponds to roughly 8 KB of high speed FIFO memory per SR. This system would also enable the use of higher level intelligent signal extraction techniques by the processor, as opposed to the simple analog conditional decision circuits that were envisioned at the outset. This would help considerably in improving the accuracy of weak signals as new algorithms could be devised as opposed to new circuits. The penalty paid is that it significantly increases the cost of the Master Timekeeper (MT) by several hundred dollars (compared to a simple analog circuit with counters) given today's high speed ADC market.

A third option is to use an RC voltage ramp to charge up starting from the first TOF pulse incidence and then stop each charge ramp as the subsequent pulses come in. The advantage here is that there is no need for fast counters, only an accurate ADC and well characterized voltage ramp. The design caveats are charge injection during the start and stop charge steps, and the slope of the charge. The other advantage is that it is possible to get sub-nanosecond resolution with this technique, something that is not possible with just the counters. A hybrid design would be to use the counters as the 1ns positions, but then interpolate with a charge ramp to get sub-nanosecond resolution again, resetting the ramp at each clock count. To reduce costs the counter could also be run at a slower speed and the analog interpolation could be in terms of several nanoseconds.

A cost effective technique would be the superheterodyne receiver coupled with a relatively simple analog circuit with counters as originally envisioned. Such a solu-

tion would not have the full processing power necessary to perform sophisticated signal analysis and may suffer degraded accuracy at low signal levels but would not suffer from the noise issues as the wideband design.

Regarding multipath signals, it was found that they had the effect of changing the signal level at the end of the packet by either shifting the signal up for a time instead of down. This makes sense since the phenomenon is coherent at the time scales and modulation rates we are using. When the primary signal is removed the remaining (secondary path) signals are no longer being interfered with. Since the system relies on a change in the signal level to signify the end of the RF envelope, it is a relatively simple matter to make that function happen on either a positive or negative shift in the signal.

2.3 RF TOF Granularity and Geometric Uncertainty with Algorithm Solutions

Assuming we can get a signal that truly represents the actual TOF from a particular location in the pool, we need to know how accurately it represents a specific point in the pool, and what algorithm can be used to extract that location without being sensitive to mathematical truncation errors.

three algorithms have been presented for extracting information from the TOF data. The first was a hyperbolic solution set and was complicated, which led to a second algorithm of simply generating a precomputed solution set that would be updated as calibrations from fixed transceivers are processed. Using a table-lookup algorithm, a 25x25 yard area at one square foot resolution only requires 5,625 unique points, which is trivial in today's memory costs. The third algorithm was a considerable mathematical improvement as opposed to the first, however it is sensitive to very small errors in TOF measurements. These three techniques have come down to this fundamental question: given a set of overlapping annuli from the SD to each station receiver, what is the maximum geometric uncertainty that can be guaranteed by TOF measurements restricted to 1 ns resolution? Figure 3 shows the isotemporal lines in the TOF setup for a 25 foot square. The differences are not generally significant when scaled to a 75 foot square, but this makes for a very busy plot.

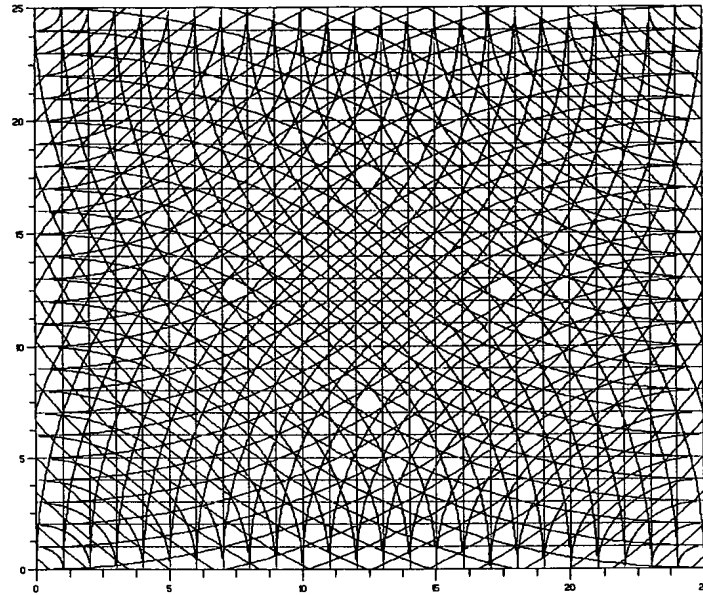


Figure 3. Isotemporal lines, 25-foot square

A 10x10 example is shown in Figure 4 for better visual clarity.

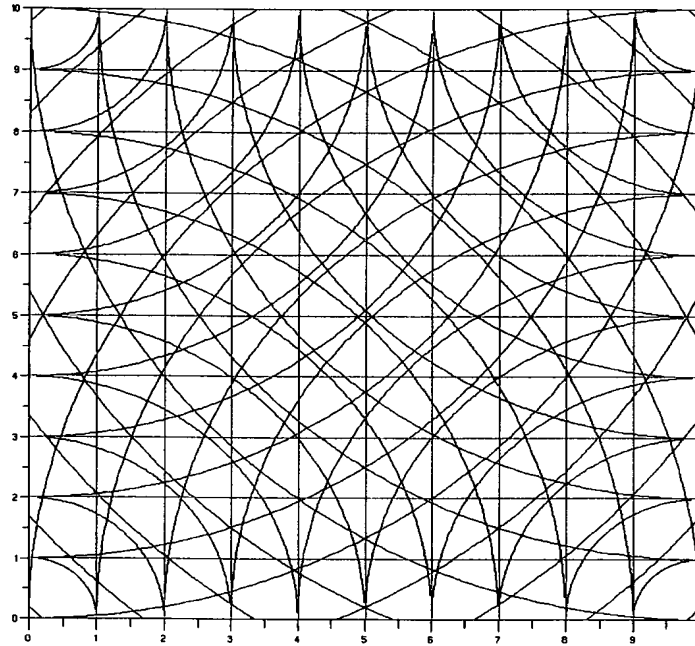


Figure 4. Isotemporal lines, 10-foot square

The immediate thing that strikes one is that the RF TOF mapping at a 1 ns resolution does not map into our customary X-Y Cartesian grid conveniently.

As an example, Figure 5 has colored highlights where the RF TOF would follow a swimmer through successive 1 ns time of flight differences and how they undulate on the 1x1 foot Cartesian grid. Note that the graph does not show individually colored tiles representing specific combinations throughout the movement of the swimmer. This mapping could be generated but given the time and budget constraints it is relatively easy to see that each geometric pattern generated by the RF TOF 1 ns data can be considered to be a unique area. In some cases the area is small, but in most cases it approximates 1 square foot. Naturally one would expect that the path would likely follow the largest tiles, as those are the statistically likeliest to be occupied by the SD at any particular time. Errors of 1-2 ns in any direction do not cause the mapping to jump to completely erroneous values, so the geometry doesn't have any problems locating the swimmer. However, it would be difficult to generate a rectilinear velocity vector from these data which would require the preci-

sion of an inertial measurement unit (IMU) on the SD itself.

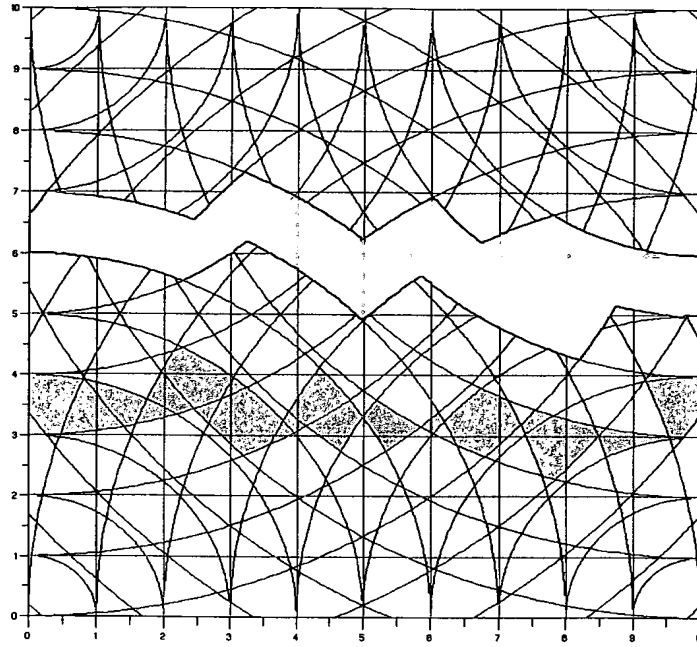


Figure 5. Colored highlights follow swimmer

SECTION 3: CAMERAS AND VIDEO

3.1 Camera Positions

It became clear during the tests [redacted] that the discontinuities between camera images that we had originally allowed can be very disconcerting in practice when swimmers suddenly disappear between images or appear simultaneously in multiple ones. The coach would prefer one camera to smoothly view all of the swimmers, but this would require a very wide field of view (FOV) with associated distortions.

Continuous coverage of the entire pool with multiple cameras has been achieved using two camera positioning techniques.

The next best and easiest alternative is to use two cameras mated to seamlessly bring the adjacent images together. The best two-camera results [redacted] were achieved with Camera # 1 viewing the left half of the pool from about 6" to the right of center, and Camera #3 viewing the right from the same distance to the left of center. The cameras were located about 12 feet from the pool edge and about 13 feet above the water, and were tilted significantly about their optical axes to produce symmetrical distortion above the horizontal image centerline. The net effect is to produce a merged image like that which would be obtained with a panoramic camera. See Figure 6 for the two-camera view.

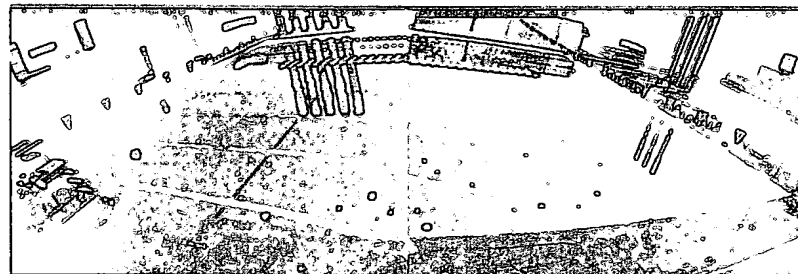


Figure 6. Two-camera view of entire pool

There is significant overall distortion with two cameras, and the FOV across the pool is much larger than necessary, so three cameras were arranged to produce three merged images. The result shown below in Figure 7 was obtained with the left-viewing camera located 30 inches to the left of the center one and the right-viewing camera 30 inches to the right of center. This is probably near optimum because the horizontal centerline of the pool and the nearest edge just fit within the picture, and the cameras view essentially all of the nearest edge. Three additional cameras on the opposite side of the pool would obviously provide full coverage when merged with the nearer three, but the image junction at the pool horizontal centerline should then be close to a straight line, and that would cause greater distortion

near the edges.

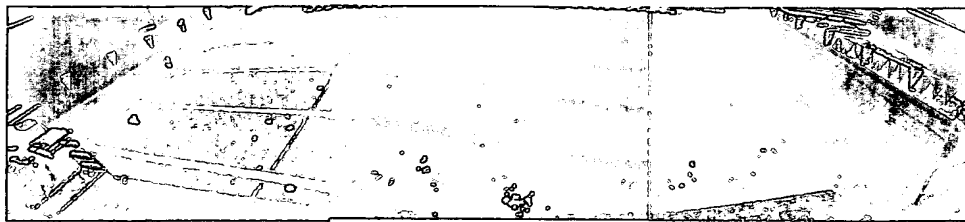


Figure 7. Three-camera view of entire pool

The black lines along the length of the pool are lane markers, and most of their curvature is due to the contour of the bottom. Curvature of the pool edges and the float lines in the far half are due to distortion, a combined consequence of the lens quality and the use of a short focal length with a flat sensor array. Also, it should be noted that the adjustable lenses on the Axis cameras are difficult to accurately zoom and focus. That would not be a problem for the surveillance applications for which the cameras were intended, but it complicates setup and operation for Performmax.

3.2 Video Data Storage

For the prototype system, adequate storage for continuous video coverage of the pool was available. However, due to logistics and great amounts of time spent on camera placement experimentation, actual capture time during the test period was significantly less than planned. In fact, after capturing only 2 hours of pool coverage, duplicating some of these files for conversion tests and analysis, and preserving some videos from previous tests of the system, only 8% of the capacity of the server was used.

Although the final system will need to include data storage capacity magnitudes greater than that used in this test of the prototype, given our test data and the usage of the resources available, the stated test goal of "Massive data storage" has been obtained successfully as predicted.

We know that the prototype server's disk capacity will be inadequate for a production system, but the final storage requirements will depend on the video encoding used (MPEG-4, motion JPEG, FLV,) and the resolution the video is stored in. The four-year data (including video) retention requirement guarantees that the storage requirements will be immense no matter what we do. However, we may be able to substantially reduce the storage requirements if we can either selectively reduce the resolution of stored video, or perhaps shorten the time frame for the stored video..

3.3 Timecoding and Synchronization

Due to time constraints, a time-code system and method for synchronizing video with telemetric data was not available. This is an element that needs further development. We do not see any great technical challenge to achieving this goal.

3.4 Streaming Capabilities

Implementation of streaming video on the server was underway at the time of the [REDACTED] test, [REDACTED]. Streaming video is to be processed and assembled from any of the available video sources based on selected view, targeted swimmer, swimmer position, and best camera views of the targets that are available.

SECTION 4: USER INTERFACE PROTOTYPE

We believe the UI met all the criteria outlined in the Test Plan document.

Following discussions with, and observation [REDACTED] we confirmed that the general interface concept is understandable to the user, and we can confidently proceed to a beta test with it

We believe the four functional groupings we have proposed correctly subsume all the system's intended uses and data displays. We also verified the general usability and acceptability of basic UI component concepts.

In the course of our on-site testing, we reprioritized and refined the intended use of one of the proposed displays (the graphical aerial view of all swimmers in pool).

[REDACTED] in order to better plan the "Workout Manager" utility¹, which Scott considers critical.

[REDACTED] performance comparisons via line graphs should show the best performance as the topmost line (intuitive to users at a glance).

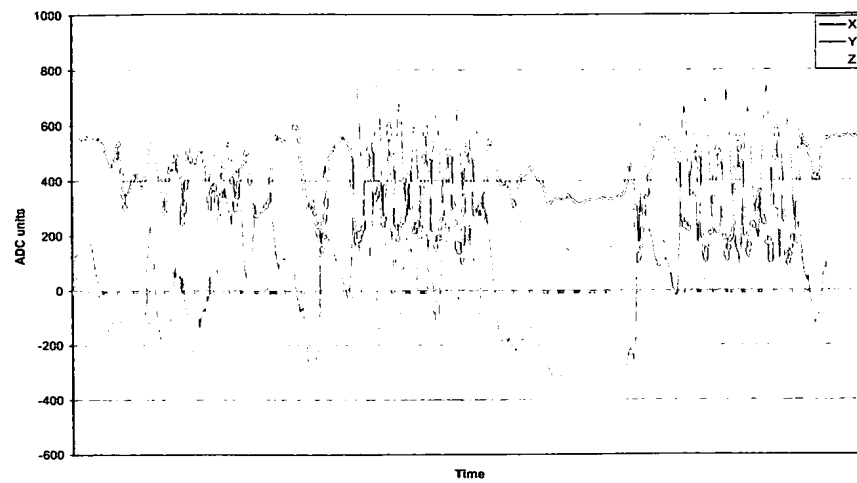
The form factor of the Fujitsu Lifebook Tablet PC may be too confining [REDACTED] [REDACTED]; the interface layout [REDACTED] reasonably adaptable to changes in user hardware (especially display size and aspect ratio).

Handwriting is only a plus to the user if it is fast and reasonably accurate. This likely pertains mostly to the Workout Manager and is subject to user testing later in the UI development process.

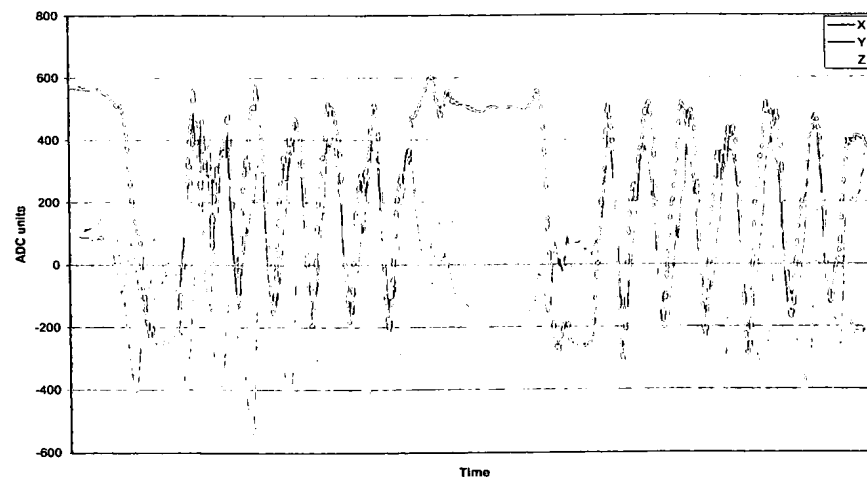
1. On-the-fly definition of custom workouts with near-zero constraints on the coach but retaining maximum ability to compare same or similar workouts.

APPENDIX A: ACCELEROMETER DATA PLOTS

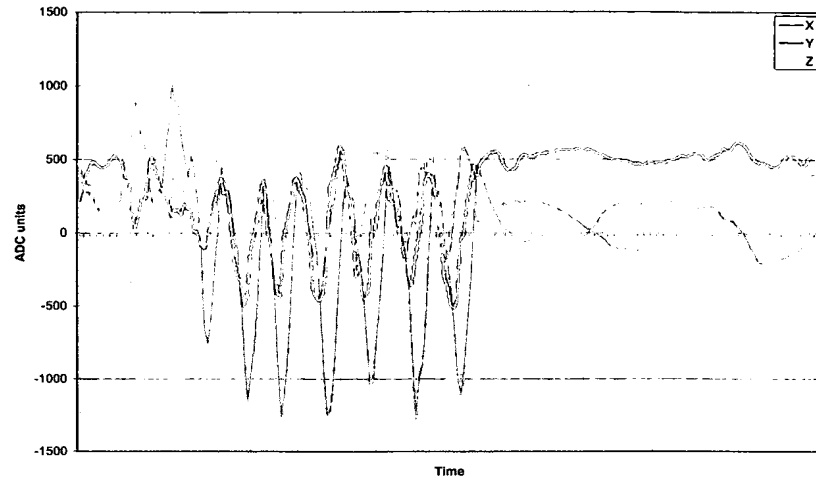
Freestyle (14 strokes down, 12 back)



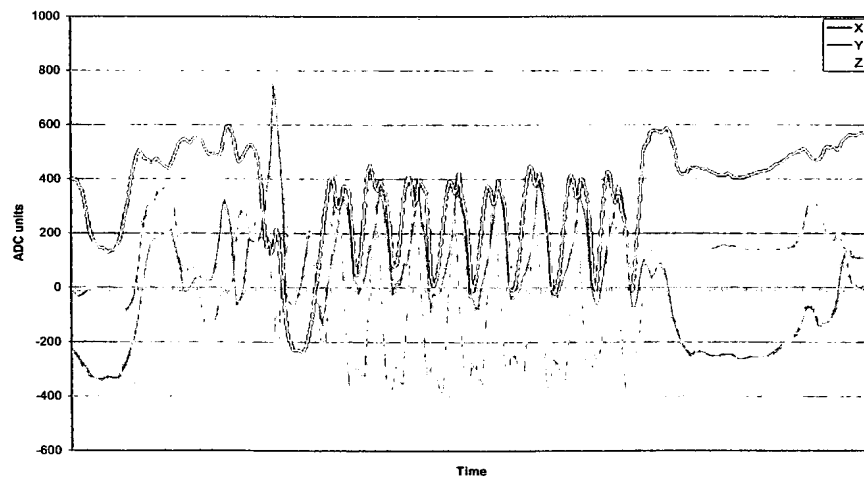
Backstroke (14 strokes down, 12 back)



Butterfly (9 strokes)



Breast stroke (8 strokes)



As the Swimmer Device reports X, Y, and Z coordinates, we decided to generate some X,Y,Z coordinate charts to examine the results visually. Unlike the Excel charts, where each component (X, Y, Z) is graphed with respect to time, in this combined graphic technique, time is represented by the distance between each point along the connecting vector in the X,Y,Z plot

Because this report is presented as still images on paper and is therefore not capable of showing the moving 3D graphic charts or allowing interaction, we have included snapshots of the 3D graphs at a near-center point (X, Y axes standard orientation as in excel, and Z axes into and out of the printed medium, visually adjusted) and again with the graph rotated to give a better perspective of what is going on with the Z axis, and where appropriate, a slight rotation to view the X and Y data trends.

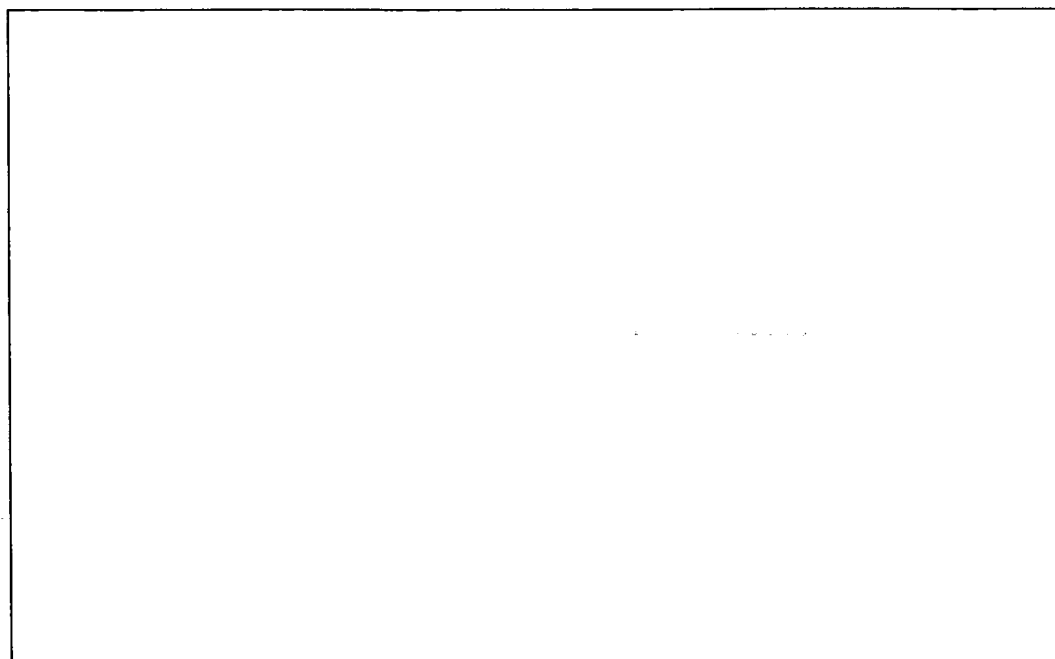


Figure 8. 3-D butterfly view #1

For instance, in the Butterfly plots in Figure 8 and Figure 9, the corrected X, Y, and Z values the Swimmer Device reported at time 2330 were 32.6276, -38.7724, and 532.6276. This point is plotted and connected to the next point at the next time, 2331, where the values were 153.0276, -59.5724, and 515.6276.

Using the 3D graphing application, live viewing including pan/zoom and rotation is possible, and provides the ability to trace through a visual 3D simulation of the Swimmer Device's location in reference to the origin (0,0,0).

Perhaps more important than the graph as a whole is the ability to examine a spe-

cific set of points (10 to 20, for example) where a specific movement or stroke element is under scrutiny. Also, limiting the displayed data points eliminates visual clutter during analysis.

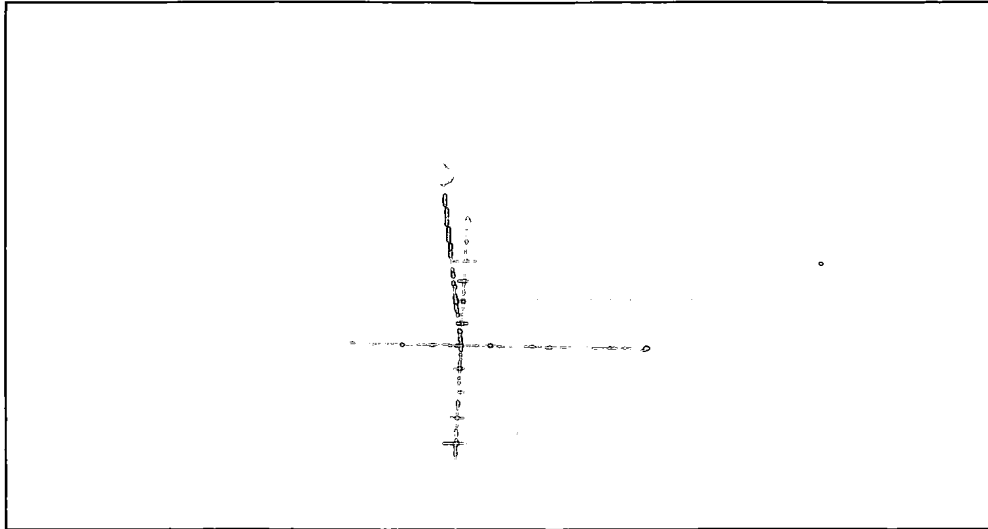


Figure 9. 3-D butterfly, view #2

APPENDIX B: OPTICAL ORTHOGONAL LOCATION SYSTEM

The system for swimmer location presented in this Appendix is an alternative to RF TOE



B.1 System Components

The Optical Orthogonal Location System uses a timed sweep of two dissimilar laser diode sources to locate swimmer devices. A block diagram is shown in Figure 10.

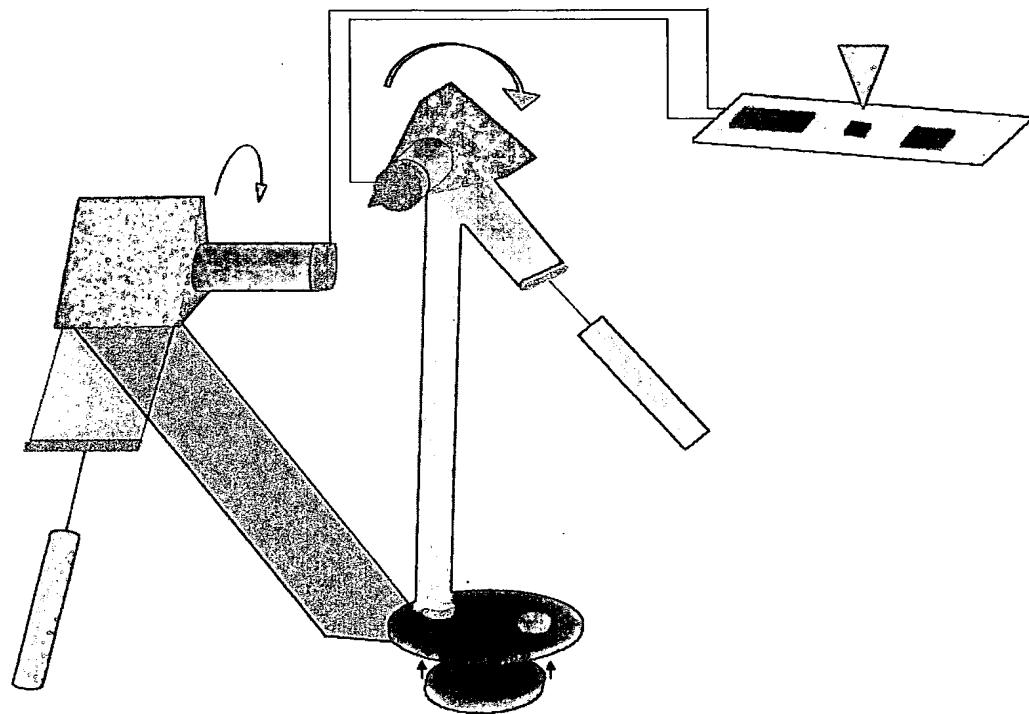


Figure 10. Block diagram of optical location system

There are three modules that comprise this system:

1. The swimmer device. Battery-powered microprocessor-based device that incorporates an accelerometer to collect relative motion data, a 2.4GHz transceiver, and two

- optical sensors. Each of the two optical sensors is sensitive to a specific color.
2. The motor mirror system. There are two of these positioned perpendicular to each other. The motor mirror system is a simple yet precise low RPM motor with a three-sided mirror is mounted to its shaft. A 16-bit position encoder with a zero pulse is attached to the shaft of the motor.
 3. The Master Interface card. This is a microprocessor-based subsystem that incorporates a 2.4GHz RF transceiver, motor drive circuits, and a communication interface for transmitting data to the server.

B.2 Theory of Operation

The motor mirror system uses a motor to turn a three or more sided mirror. The two motor mirror systems are positioned orthogonal to each other. Each of the two diodes transmits a different wavelength of light. This allows the swimmer device to differentiate the two axes. The motor of the mirror system has an encoder attached to the motor shaft. This encoder has 65,535 counts per revolution allowing precise motor speed and location reporting back to the master interface board. A laser diode is offset from the axis of the rotating mirror transmitting through a prism. The prism spreads the light from the laser diode into a stripe. This dispersion reduces the density of the energy from the diode¹.

The spinning mirror reflects the stripe across the pool at a constant rate. The encoder is aligned with face turns of the mirrors. The whole assembly is then aligned with the edges of the pool. Once the system is aligned the motors spin at a speed set for location of the swimmer 5 times per second.

The swimmer device has two optical sensors that each have unique color filters enabling it to differentiate between the two axis sweeps. When the mirror edge (zero pulse) is detected, the master interface board broadcasts an RF message to all swimmer devices to reset their position counters.

As the stripe of light passes over the swimmer's optical sensor, it interrupts the SD's CPU, latching the timer value. The latched timer values (corresponding to X and Y) are passed along with the other telemetry data when the SD is polled and are converted to a coordinate location based on the known beam positions at those times.

¹. Testing will have to be done to see if the intensity of the light is lowered enough to fall within the safety limits of eye exposure.

APPENDIX C: GLOSSARY

Table 1: List of Acronyms

Acronym	Definition
DCL	Data Communication Link
FOV	Field of view (camera image)
ISM	Industrial, Scientific, and Medical radio bands
Li-ion	Lithium ion battery
LiMnO ₂	Lithium-manganese dioxide battery
MS	Master Station
MT	Master Timekeeper
NiMH	Nickle metal hydride battery
OOK	On/off keying
PER	Packet Error Rate
PoE	Power over Ethernet
RF TOF	Radio Frequency Time of Flight
RSSI	Received Signal Strength Indication
SD	Swimmer Device
SR	Station Receiver
ST	Station Transceiver
SYNC	Strobe generated by CC2500 transceiver
WAP	Wireless Access Point

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SECTION 1: OVERVIEW

1.1 Prototype system features

What is the vision? The PerforMax system is being designed to provide significant advantages to the pool-side coach, to the swimmer, and to an entire competitive swimming program. It targets performance-related aspects of the sport by capturing and enabling analysis of data about specific elements of each swimmer's performance and past performances, with support for as many as 100 simultaneous swimmers. It should be as non-invasive as possible, freeing swimmers and coaches to do what they do best, but with a very powerful new tool.

What will be in the prototype? The [REDACTED] prototype must demonstrate the proposed system design's fundamental ability to:

1. Identify each swimmer's location in the pool.
2. Record a video log of all swimmers in the pool, retaining the video captured for future viewing and analysis.
3. Time the athlete's performance. In the prototype, this may be constrained to lap times and finish time only. Turn times, breaks, etc. will be deferred to the next phase of the project, after basic functionality is established.
4. Acquire basic physical measurements (e.g. stroke, amplitude, motion) from accelerometers in telemetry devices worn by the swimmers.
5. Review an event, displaying captured data (e.g., lap times) in sync with video replay.
6. Provide a basic user interface to support the prototype's constrained feature set.

1.2 Prototype Design Constraints

The purpose of the [REDACTED] Prototype is to demonstrate the fundamental principles of the system under design: swimmer position and telemetry data correlated to video footage.

Limited proof of concept testing has been performed for discrete system components. One of the primary goals of the prototype system is a proof of concept of the integrated system.

1.3 System components

Figure 1 shows the layout and relationship of the system's components.

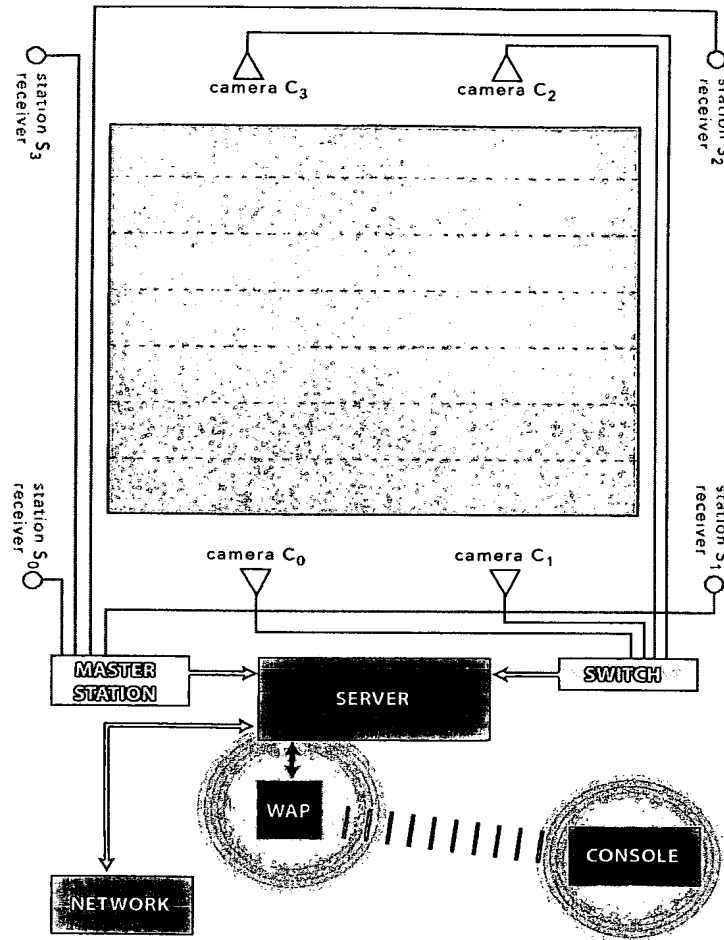
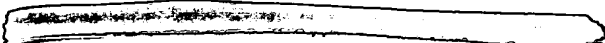


Figure 1. System block diagram

The Swimmer Device (not shown in the system block diagram), is a small RF transceiver and associated electronics, affixed to each swimmer's cap¹. The transceiver provides a two-way communication link with the Master Station and is also used to determine the swimmer's location. See Section 2 for details about the Swimmer Device.

1. A version of the Swimmer Device to be worn on each wrist (and possibly also each ankle) will not be part of the Phase I Prototype, but is planned for a future phase of system development.



Video cameras are positioned along the sides of the pool to provide complete coverage of the pool surface, including the start/finish area. Video is routed through a switch to storage on the system's dedicated server. See Section 4 for details about the video subsystem.

Station Receivers are positioned at diagonal opposite setbacks from each of the pool's corners. Each receiver detects the transceiver's signal and sends it to the Master Station for resolving swimmer locations. The Master Station correlates data received from all four receiving stations to a common timecode, uses its own transceiver to communicate with Swimmer Devices, and routes the resulting position and telemetry data to the Server. See Section 3 for details about the Location system, including Station Receivers and Master Station.

The coach's Console is a lightweight tablet PC that provides the coach, via a secure WiFi connection, with a control and monitoring interface to the server. This will be the primary User Interface (UI, see Section 5) to the Phase I Prototype system.

The dedicated Server (see Section 6) receives video from all cameras along with synchronized telemetry (accelerometer data from the Swimmer Devices) and position data from the Master Station, and stores the correlated video and data so it can be replayed with video in sync with position and other captured data.

A Wireless Access Point (WAP) provides a secure WiFi link between the coach's console and the Server. The Internet (or a secure private network) may provide additional ways to view data and to replay events. Remote access to the Server is outside the scope of the Phase I Prototype.



6 Overview

SECTION 2: SWIMMER DEVICE

The Swimmer Device (SD) is a small (1.75" diameter), battery-operated printed circuit board responsible for acquisition and radio transmission of uplink² telemetry data to the Master Station (MS) and for receiving commands and downlink telemetry data from the MS. This section details the components of the SD and their individual functions. The schematic for the Swimmer Device is in Appendix A.

The Swimmer Device (see Figure 2 below) consists of the following main components:

- Microcontroller
- RF transceiver
- Accelerometer
- Memory
- Audio output device
- Pushbutton input (optional)
- Battery.

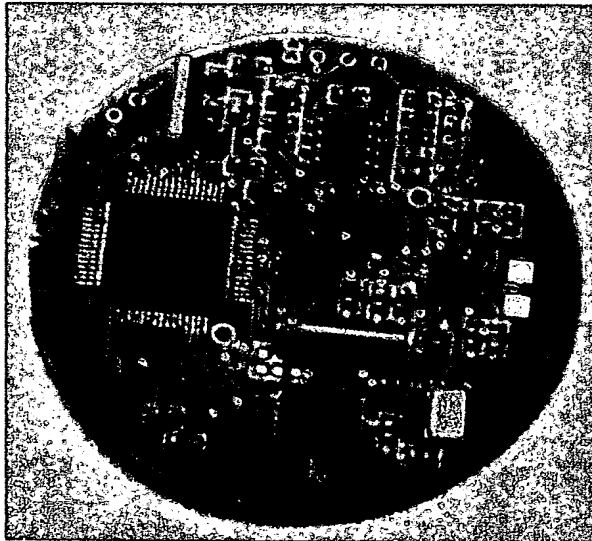


Figure 2. Swimmer Device Circuit Board

²The MS is deemed "superior" to the SD, so data flowing from the SD to the MS are in the "uplink" direction. Likewise, data flowing from the MS to the SD are in the "downlink" direction.

2.1 Microcontroller

The Texas Instruments MSP430F1611 mixed-signal microcontroller supplies the “brains” of the Swimmer Device.

Figure 3 shows a block diagram³ of the MSP430F1611 microcontroller. The microcontroller has 48kB of reprogrammable flash memory to hold the firmware and calibration data plus 10kB of SRAM for temporary data storage, stacks, etc.

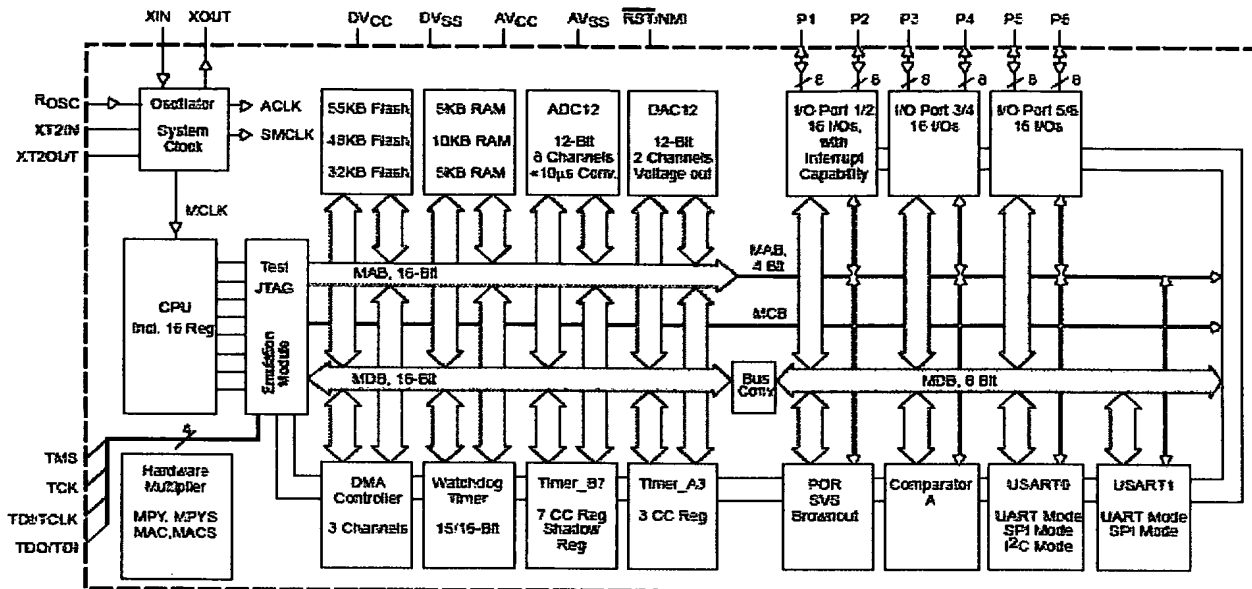


Figure 3. MSP430F1611 Block Diagram

The Texas Instruments MSP430 family of ultralow power microcontrollers consist of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low power modes is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that result in maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6µs. The MSP430F1611 features two built-in 16-bit timers, a fast 12-bit A/D converter, dual 12-bit D/A converter, two universal serial synchronous/asynchronous communication interfaces (USART/SPI), I2C, DMA, and 48 I/O pins. In addition, the MSP430F1611 offers extended RAM addressing for memory-intensive applications.

³Block diagrams in this section are copied from their respective data sheets. Some image quality degradation is a result of re-scaling these images.

2.2 RF Transceiver

A Texas Instruments CC2500 single-chip 2.4 GHz transceiver provides two-way communication between the Master Station and the Swimmer Device. Figure 4 shows a simplified block diagram of the CC2500 transceiver. Note the standard SPI signals for communication between the microcontroller and the CC2500.

The CC2500 is a low-cost single chip 2.4 GHz transceiver designed for very low power wireless applications. The circuit is intended for the ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency band at 2400-2483.5 MHz.

The RF transceiver is integrated with a highly configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 500 kbps. The communication range can be increased by enabling a Forward Error Correction option, which is integrated in the modem.

This device provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication and wake-on-radio.

Output power ranges from -30 to 0 dBm into a 50-ohm load.

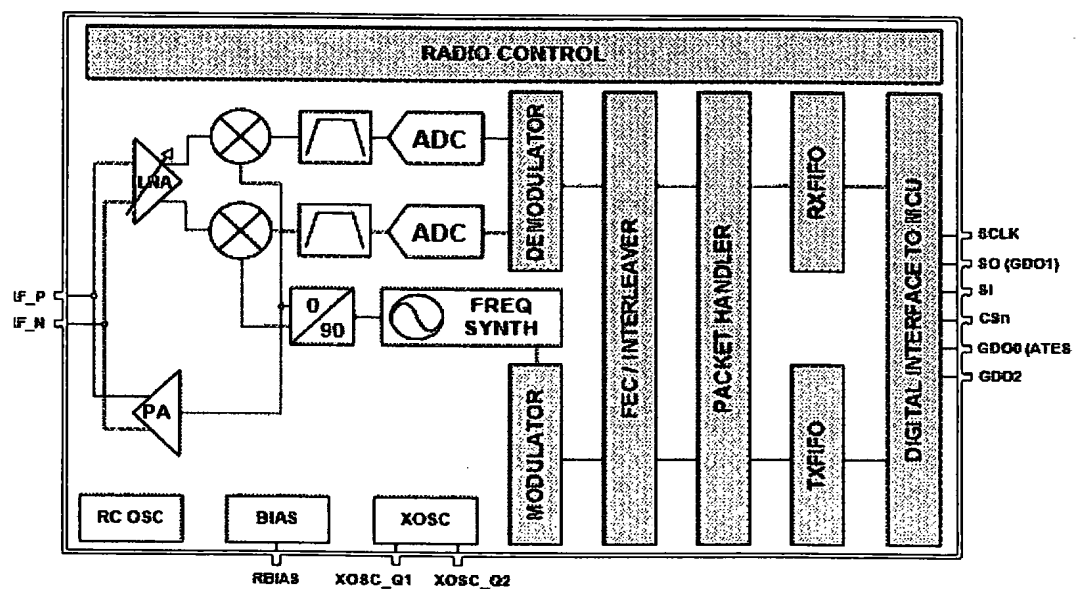


Figure 4. CC2500 Block Diagram

2.3 Accelerometer

An Analog Devices ADXL330 accelerometer is connected to the microcontroller's analog inputs, supplying data on motion in three axes. Figure 5 shows a block diagram of the ADXL330.

The ADXL330 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs, all on a single monolithic IC. The device measures acceleration with a minimum full-scale range of ± 3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration.

Capacitors CX, CY, and CZ select the bandwidth of the accelerometer at the XOUT, YOUT, and ZOUT pins.

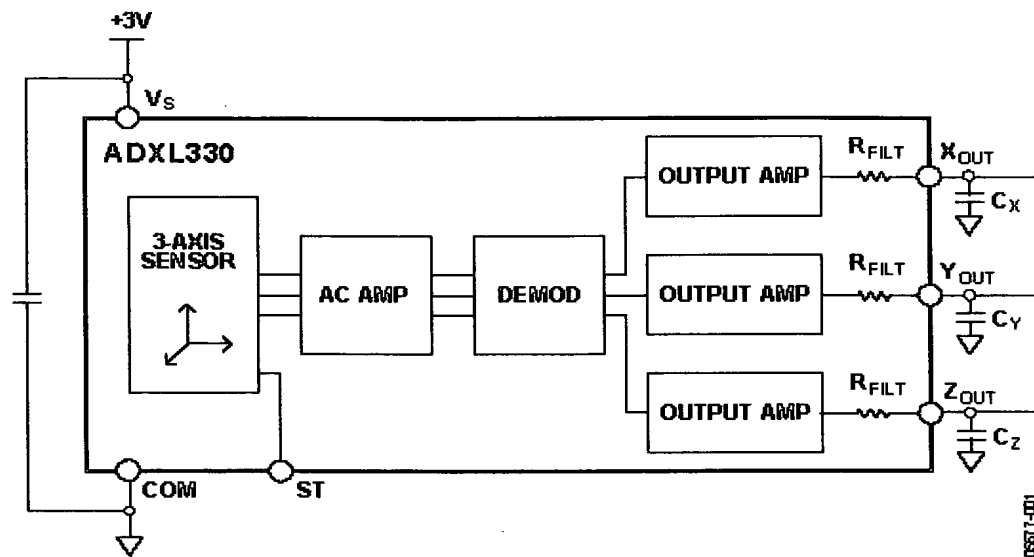


Figure 5. Accelerometer Block Diagram

2.4 Memory

A FM25L512 ferroelectric nonvolatile RAM (FRAM) chip is connected to the microcontroller's serial peripheral interface (SPI) bus provides backup storage of telemetry data to be held between poll cycles by the Master Station. Figure 6 shows a block diagram of the FM25L512.

The FM25L512 is a 512-kilobit nonvolatile memory employing an advanced ferro-

electric process. A ferroelectric random access memory or FRAM is nonvolatile and performs reads and writes like a RAM. It provides reliable data retention for 10 years while eliminating the complexities, overhead, and system level reliability problems caused by EEPROM and other nonvolatile memories.

Unlike serial EEPROMs, the FM25L512 performs write operations at bus speed. No write delays are incurred. The next bus cycle may commence immediately without the need for data polling. The next bus cycle may start immediately. In addition, the product offers virtually unlimited write endurance. Also, FRAM exhibits much lower power consumption than EEPROM.

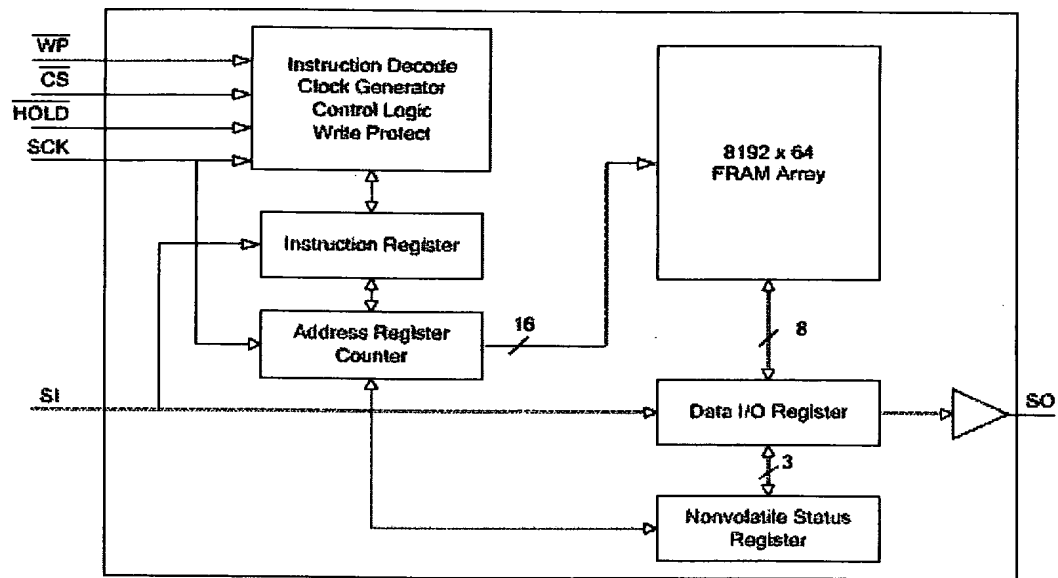


Figure 6. FRAM Block Diagram

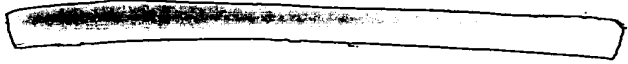
2.5 Audio Output

A TPA611A2D audio power amplifier provides optional audio output to the swimmer's earphones. This feature is reserved for future use and will not be implemented in the Phase 1 prototype.

The TPA611A2D is a stereo audio power amplifier capable of delivering 50 mW of continuous RMS power per channel into 16-ohm loads. The TPA6100A2D is optimized for battery applications because of its low supply current, shutdown current, and THD+N. When driving a 16-ohm load with 45-mW output power from 3.3 V, THD+N is 0.04% at 1 kHz, and less than 0.2% across the audio band of 20 Hz to 20 kHz. For 28 mW into 32-ohm loads, the THD+N is reduced to less than 0.03% at 1 kHz, and is less than 0.2% across the audio band of 20 Hz to 20 kHz.



12 Swimmer Device



SECTION 3: RF COMMUNICATION AND LOCATION

The prototype system will use a Radio Frequency Time of Flight (RF TOF) system to determine the location of each swimmer by accurately measuring the time each transmitted frame from the CC2500 transceiver in the Swimmer Device takes to reach multiple known locations surrounding the pool.

This section details experiments performed to determine if RF TOF could be used in this application to determine location of swimmers based on the reception of messages from their Swimmer Devices. Based on the results of these experiments, we go on to propose an RF TOF system and its integration into the overall RF communication scheme.

3.1 Preliminary proof of concept

Some preliminary tests were performed to determine if the transmitted frames from the CC2500 transceiver would be suitable for use in a Radio Frequency Time of Flight (RF TOF) location system. The CC2500 has various modes of modulation, including Frequency Shift Keying (FSK), On-Off Amplitude Keying (OOK), and Minimum Shift Keying (MSK) with various sub-modes of each.

3.1.1 Transmitted frame characteristics

For RF TOF in its simplest form to work, we need to detect a fast (1-5 ns) edge from the transmitting device. First measurements were done to see if this is indeed the case for the transmitter. We initially looked at OOK due to scope triggering issues, and because in the end it gave us both start and stop times for the oscillator.

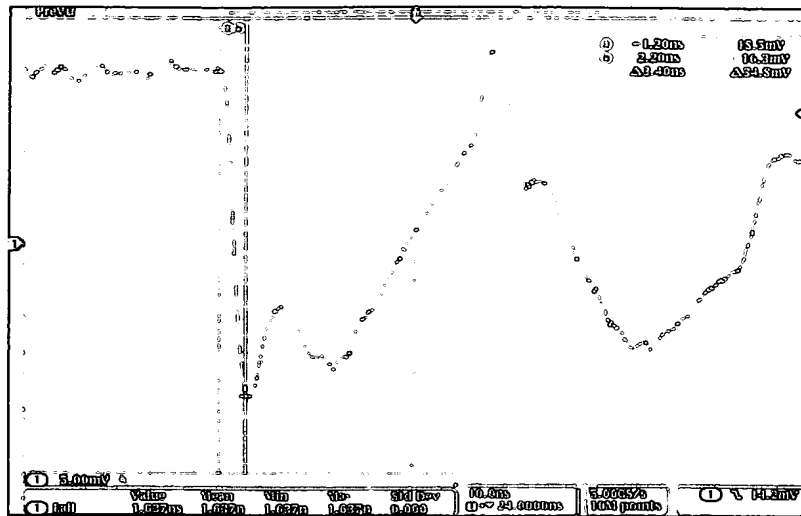


Figure 9. Pulse fall time

Figure 9 shows the pulse fall time. Note the considerably faster drop, which caused us to decide to concentrate on the trailing edge for further testing.

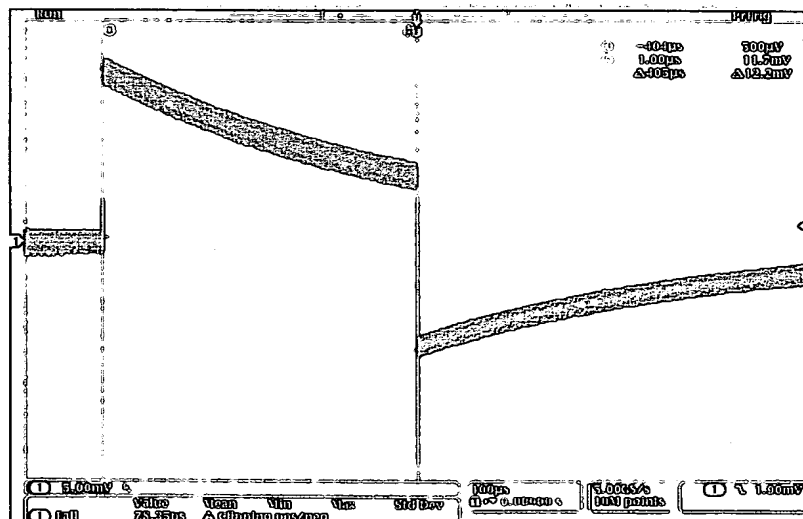


Figure 10. MSK modulation envelope

Figure 10 shows some details of the MSK modulation envelope.

From the above scope images, it is apparent that the trailing edge is better to use than the leading edge for an RF TOF comparator trigger. Further, we note that OOK

modulation gives us the ability to measure multiple edges from a single packet in case we need to do some kind of statistical averaging due to as-yet undetermined factors. The various FSK and MSK modulation formats give us a single rising and falling edge due to their constant amplitude characteristics.

3.1.2 Received frame characteristics

The next step was to measure the modulation envelopes after going through the antenna and being received by a low-noise amplifier (LNA) coupled to the oscilloscope with a high pass (1700 MHz cutoff) filter to see if any problems developed.

Figure 11 shows the rising edge of the received signal. Note that the rise time is on the same order as Figure 8, confirming that this is indeed a characteristic of the CC2500 and not a loading or mismatch artifact of the previous test.

Unfortunately the oscilloscope used for this test was unable to trigger on the falling edge of the pulse to determine the RF fall time, and the memory depth was insufficient to record the entire packet in the detail required.

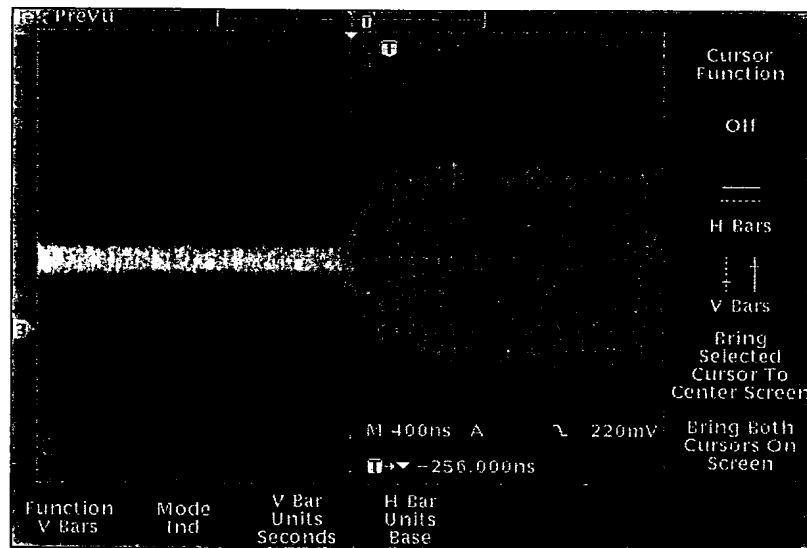


Figure 11. Received rise time

At this point we decided to procure some RF power detectors as these signs still pointed to success using a comparator type function for determining pulse edges.

A Mini-Circuits ZX-47-60-S+ detector was used, with the caveat that the stated rise and fall times on the detector were 400 ns and 10 ns respectively. We decided to forge ahead with this device for three reasons:

- [REDACTED]
1. The oscilloscope would still show a differential shift in the time domain no matter what the slope of the curve was.
 2. These detectors were in stock for next day delivery which was critical due to the time constraints of the project.
 3. Detectors with 1 nanosecond to 100 picosecond response times are available but with longer lead times.

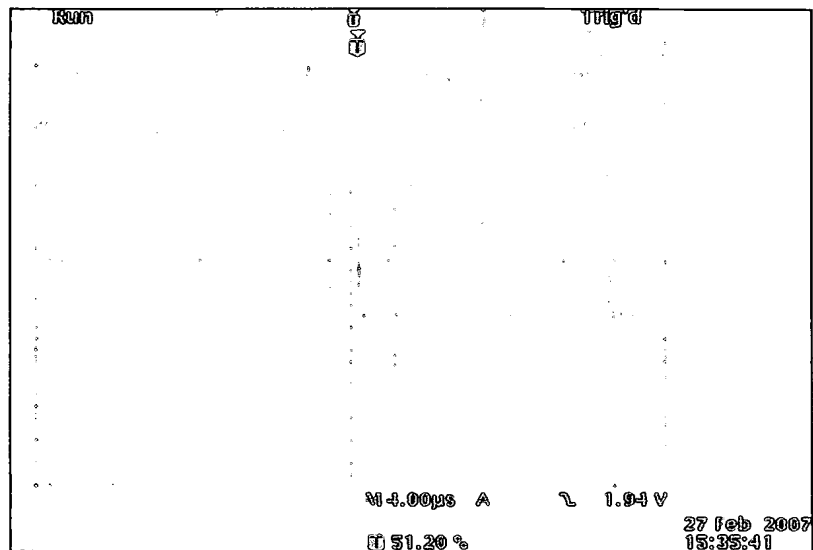


Figure 12. Typical pulse train from ZX-47 detector

With this in mind, we performed some additional tests using the ZX-47 devices. Figure 12 shows a typical pulse train measured with the ZX-47 device.

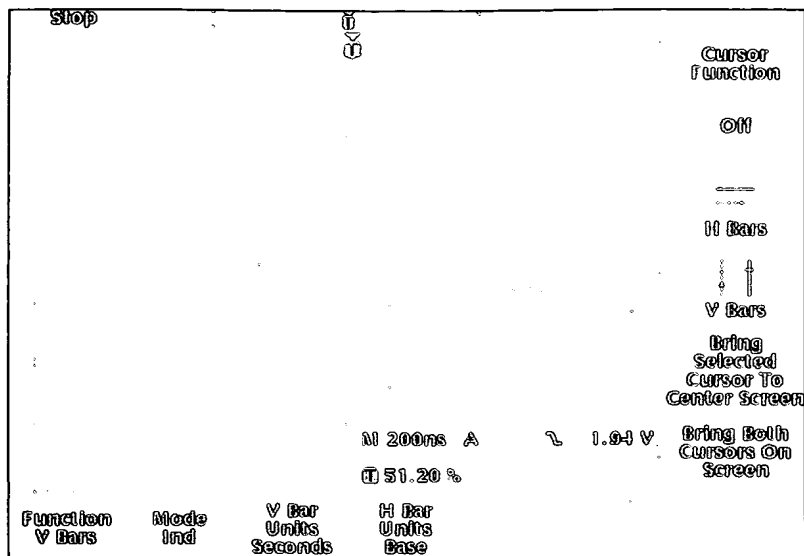


Figure 13. Received pulse rise time (negative polarity)

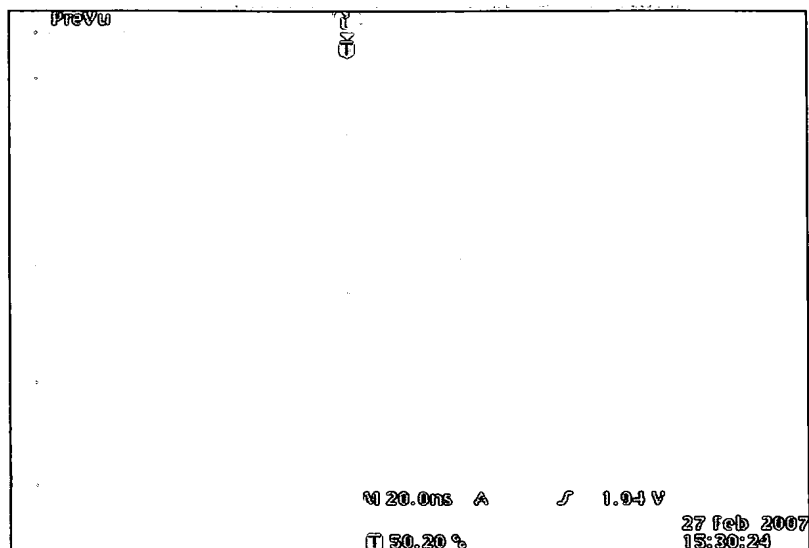


Figure 14. Received pulse fall time (negative polarity)

Figure 13 and Figure 14 show the rise and fall time of one of the pulses (note that the detector polarity is negative).

This was the first result that challenged our original thinking that a relatively sim-

ple comparator would work well. The main issue is that the detector is a logarithmic device so that even low power levels (such as trailing RF turn-off bleed through) will cause the slope to exhibit an exponential decay, which is something that we are seeing in Figure 14. The falling pulse edge did exhibit some of that behavior, as shown in Figure 9, although it looked like a cable reflection at first glance (we will need to confirm the source of the tail now).

Nevertheless, we pressed on and did some actual RF TOF testing given the room confines and this is shown below.

3.1.3 Time of flight measurements

The test setup was comprised of two receiving antennas, one stationary (the “reference” antenna) and one moving, each connected to an amplifier/detector circuit as described above, along with a stationary transmitter sending packets.

Figure 15 shows a baseline measurement of about 60 ns with both antennas within about a six-foot radius of the transmitting antenna. This shows some of the delays on the transceiver antenna, primarily due to cable length and oscilloscope channel-to-channel lag.

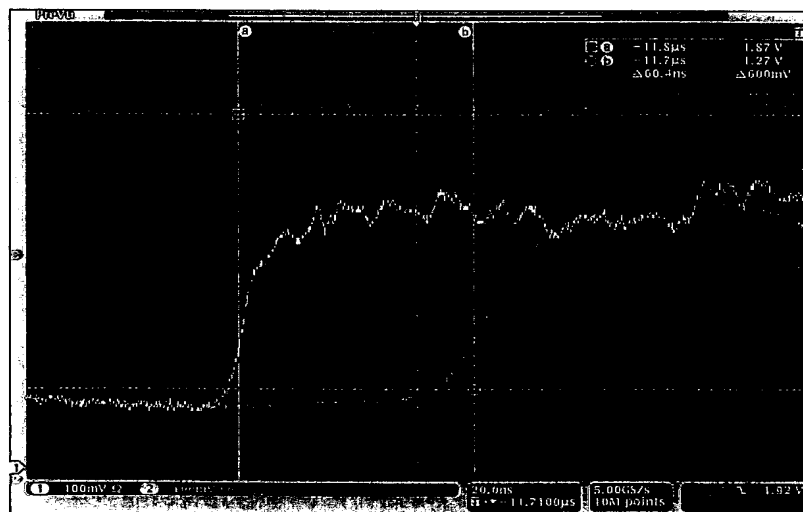


**Figure 15. Baseline distance measurement
(~6 feet, 60.4 ns)**

Figure 16 and Figure 17 indicate the moving antenna located further from the transmitting antenna, with the reference channel still in its starting position as described above. Note the increased time lag on the system, but with a relatively well defined pulse. The added delay can be seen in the measurements between cursors ‘a’ and ‘b’ which shows the difference between the rise of the yellow and blue traces denoting the same end of transmission (negative polarity) as seen by the two receivers.

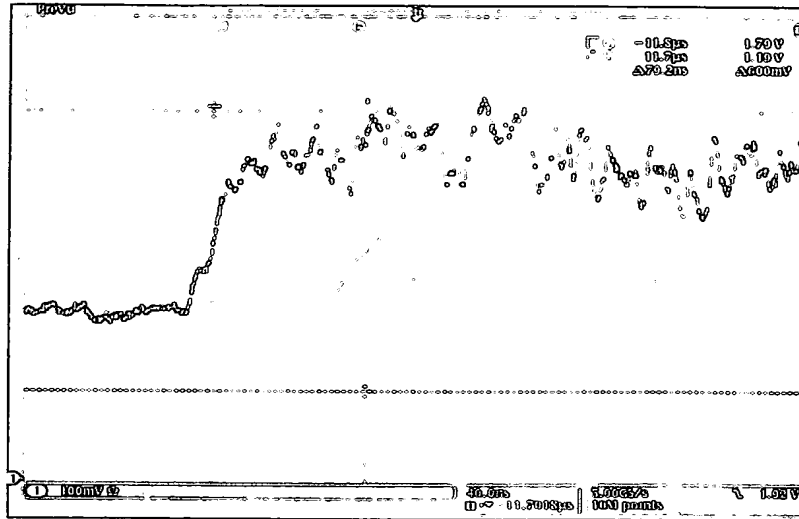


**Figure 16. First distance measurement
(21 feet, 79.2 ns)**

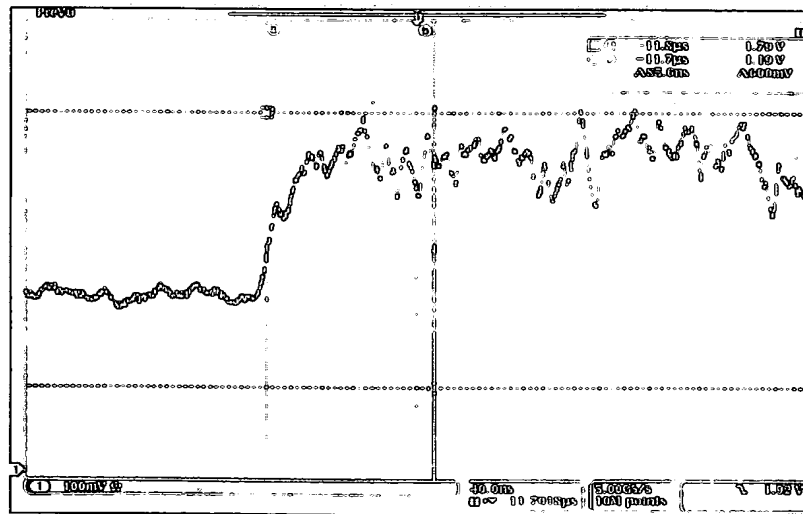


**Figure 17. Second distance measurement
(26 feet, 85.6 ns)**

3.1.4 SYNC pulse characteristics

The next set of tests we did was to investigate the use of the "SYNC received"

strobe, a programmable output signal from the CC2500. In the scope images below, the yellow and magenta traces are the outputs of the ZX-47 detectors, which have a negative voltage response to input RF power, so the lower the voltage the higher the RF power. The green trace is the CC2500 SYNC output.

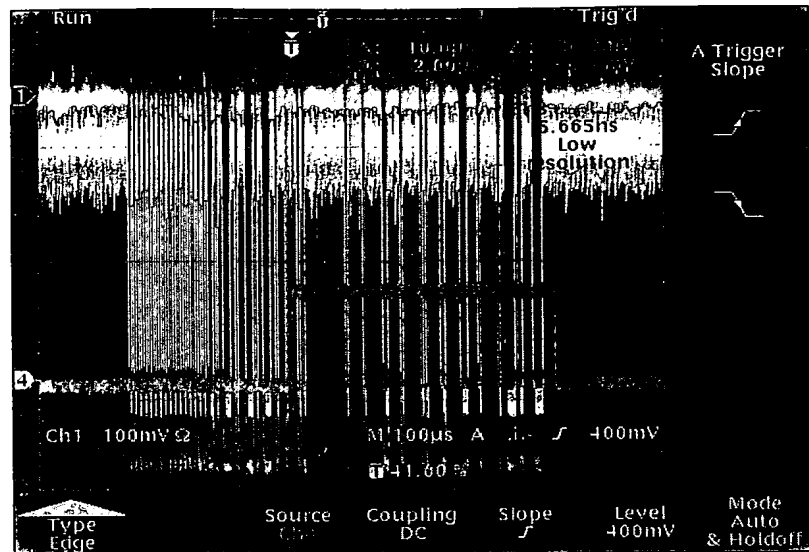


Figure 18. OOK packet with SYNC strobe

Figure 18 shows a full OOK packet and where the SYNC strobe comes into play. Figure 19 and Figure 20 show a more detailed look at the timing between the RF transmission and the processing delay in asserting and deasserting the strobe. Figure 21 is an MSK packet with the SYNC strobe shown.

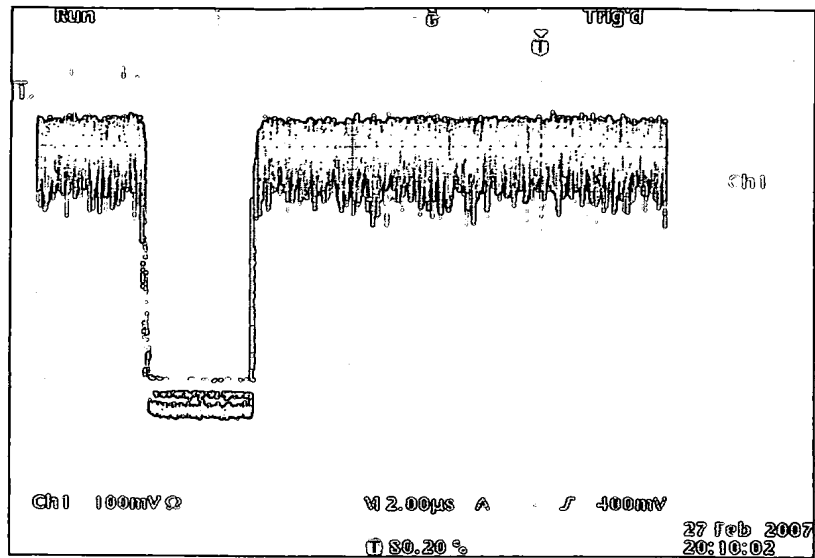
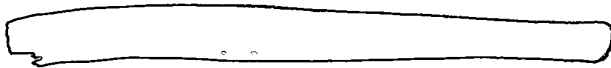


Figure 19. SYNC strobe detail

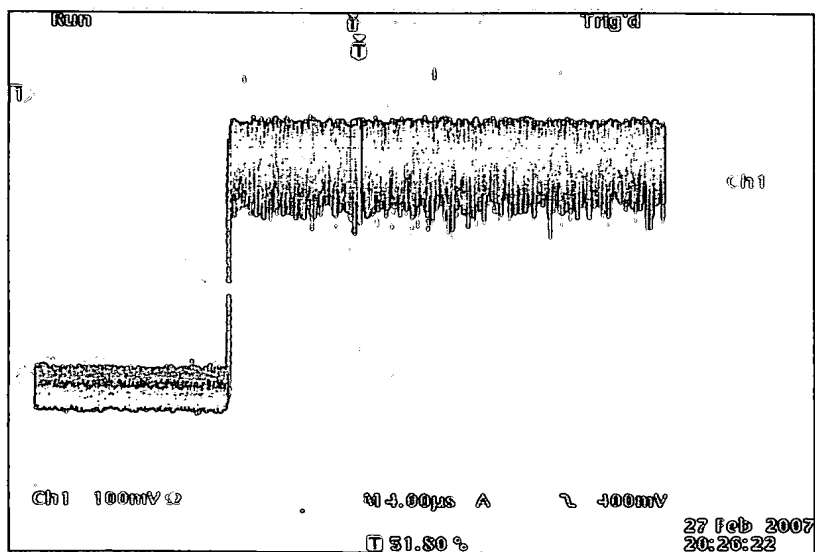


Figure 20. SYNC strobe detail

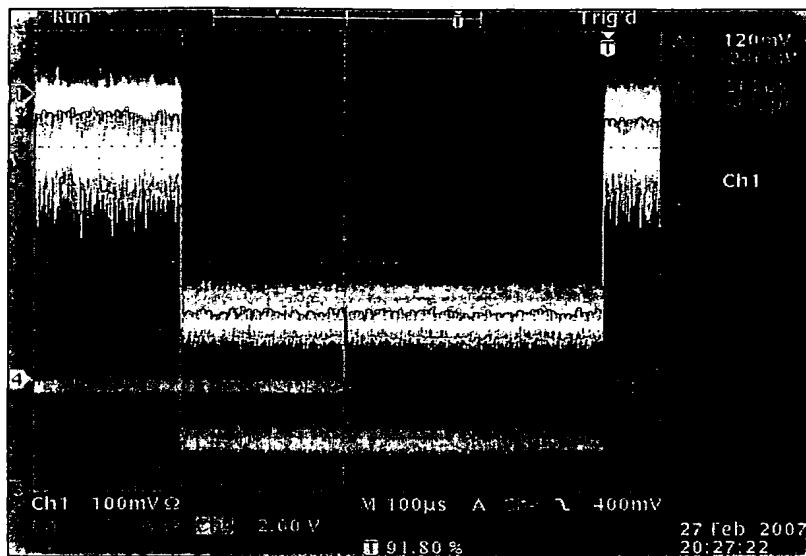


Figure 21. MSK packet with SYNC strobe

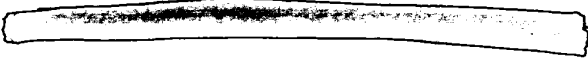
From these pictures we can see that the trigger could be from several to tens of microseconds ahead of the next RF pulse in the case of OOK, and can be hundreds (if not thousands) of microseconds ahead of the trailing edge of the RF pulse in the case of MSK. Recall that we have variable length packets due to the store and forward burst mode, and we may have to drop the transmission bit rate depending on the carrier-to-noise (C/N) performance of the system.

3.1.5 Proof of concept summary

We've shown that the system can recover RF TOF information, however we may need a faster response from the RF power detector. This should not pose a problem technically, but a faster detector may have a long lead time for procurement and will take some research. Another approach may be to modify the ZX-47 modules and lower the load impedance, which will help, but will also reduce the sensitivity of the device. Absolute worst case would be to just run a 1 GHz ADC system on the output of the detector and compute the differences using a more advanced algorithm to do a best fit between the various pulses. These are expensive at around \$300, but available.

The OOK modulation format can provide the RF TOF system with multiple pulse edges so that if necessary an averaging technique can be used to reduce noise effects. We should also procure an ISM band cavity filter set to further reduce interference effects (at about \$100-\$150 each). They are relatively inexpensive and will help in reducing some of the bounce in the pulses.

Unfortunately, OOK is least efficient from a BER (bit error rate) versus output power



perspective. MSK is the most efficient, but only provides us with one shot at getting an accurate distance reading (this may be moot if the system has enough margin).

The other issue is using the SYNC strobe on the MSK will lead to pretty long arming triggers, and since we don't know the actual length of the packet beforehand we will have to count through that entire interval. That may not be an issue if the oscillator tolerances between multiple receivers will hold over that time frame, but it will be more difficult than the OOK scheme.

Perhaps a solution would be to send out a micro packet using OOK to get a fix on the position, followed by the data packet in MSK.

3.2 Proposed implementation

In this section we discuss what the final system geometry should be for the proof of concept system, with the rationale included. This includes the location algorithm, as well as some additional tweaks for the baseline receiver system.

Improving the pulse fall time of the existing ZX-47 detectors is not feasible so we have sent out RFQs to several companies that should be able to provide them to us in the 1-3 nS range. This is probably not critical; the fall time of the CC2500 is on the order of 5 nS. The detectors will add a fraction of the 10 ns since we expect to trigger early in the pulse, certainly in the 50% region. The main criterion for the trigger point is to exclude noise contributions, so filtering (cavity filters) and S/N are the prime issues here. We have procured two full band ISM cavity filters to decrease the amount of noise present in the power detectors.

The timing circuitry design, along with the algorithm used to reconstruct the location based on TOF values, will be addressed later in this section. For an effective design we must first digress to the location algorithm itself.

3.2.1 Theory of operation

For the following discussion, please refer to Figure 22 for the appropriate geometrical interpretation.

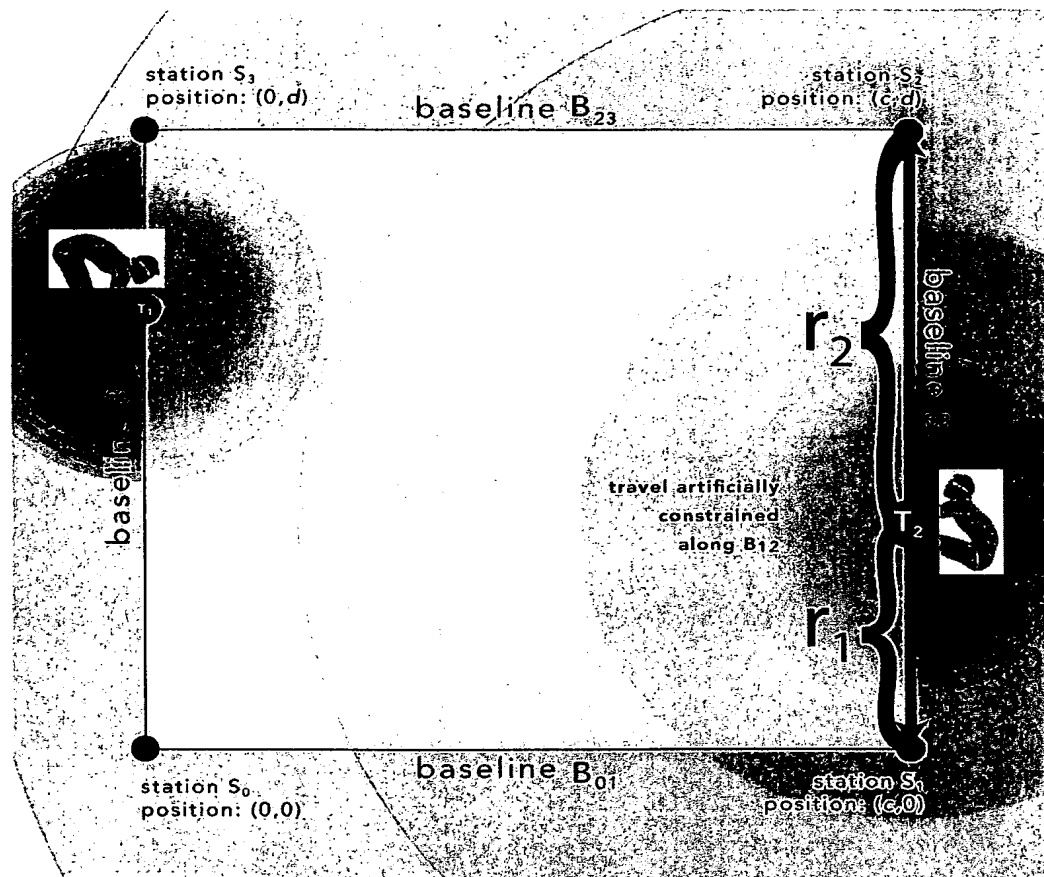


Figure 22. Station receiver baselines

We start with four (4) Station Receivers designated S_0 , S_1 , S_2 , and S_3 , located on four perpendicular baselines named B_{01} , B_{12} , B_{23} , and B_{30} .

Consider the simplest case where the target T_1 is located on one of the baselines, in this case B_{30} . If the target sends out a pulse, the energy travels equally fast in a semi spherical fashion. The first station receiver to detect the incoming pulse is S_3 , followed by S_0 , then S_2 , and finally by S_1 . If we use the first pulse falling edge received to mark a continuously running master clock/counter, then it is easy to see that the following two reception time stamps by the other Station Receivers will represent the expanding "sphere" of RF energy travel time, minus the time it took to travel from the target to the first Station Receiver.

In this sense there is no difference what pulse reference we use to start the time count, whether it is the first detected pulse edge, or a SYNC word pulse or any other RF based trigger because any receiver will always have that blank period (travel time to first receiver). All that happens is that an additional constant is added to the time

count. The only way to solve for the blank is to use multiple stations with a known geometrical setup and solving a set of simultaneous equations, the difficulty of which depends on the number of Station Receivers and their relative locations.

As a simple illustration, consider the artificial situation of target T2 being restricted in its movement along the baseline B12. If it sends out a pulse it will be received by S1, followed by S2 after a time (which corresponds to distance) of r_2 . The only unknown in this system is the flight time r_1 , but as we know the baseline length B12 we can calculate the following:

$$r_1 = B12 - r_2$$

Unfortunately, this simple situation rapidly becomes intractable with only two Station Receivers if the target is no longer restricted to the baseline. The solution becomes a locus where the difference of arrival times between r_1 and r_2 is some constant k . We can only start the reference point for the count as the first Station Receiver gets a pulse edge, thus the second receiver can only count the difference in the arrival time. In simple terms we now have:

$$r_1 - r_2 = k$$

Thus we can identify the locus as a hyperbola, where k is half the distance between the vertices of the hyperbola, and the two Station Receivers are at the foci. Note that if $r_1 = r_2$, then the solution lies on a transverse line between the foci and that both receivers will get the signal at the same time. This case shows that at least one more uniquely located station receiver is required to solve for the point.

In order to generate a unique solution consisting of a point, a third station receiver has to generate an orthogonal hyperbolic locus with either one or the other of the first two receivers. If we place the receivers on the vertices of a rectangle, then having four receivers simplifies the mathematics, as we don't have to rotate the third hyperbolic axis. Note that depending on which station receiver gets the initiating edge, the solution has to permute the hyperbolas with respect to the one that receives the first (reference) pulse.

Consider the four receivers (foci) S0, S1, S2, and S3 located on the rectangular baselines B01, B12, B23, and B30. The four (we are not for the moment going to consider the diagonal baselines) hyperbolas with the four possible TOF values of k_{01} , k_{12} , k_{23} , k_{30} , are determined as shown below.

For baseline B01 we have receivers S0, S1 located at (0,0) and (c,0), so:

$$a_{01} = \frac{k_{01}}{2}$$

$$\frac{\left(x - \frac{c}{2}\right)^2}{a_{01}^2} - \frac{y^2}{(c^2 - a_{01}^2)} = 1$$

For baseline B12 we have receivers S1, S2 located at (c,0) and (c,d), so:

$$a_{12} = \frac{k_{12}}{2}$$

$$\frac{\left(y - \frac{d}{2}\right)^2}{a_{12}^2} - \frac{\left(x - \frac{c}{2}\right)^2}{(d^2 - a_{12}^2)} = 1$$

For baseline B23 we have receivers S2, S3 located at (0,d) and (c,d), so:

$$a_{23} = \frac{k_{23}}{2}$$

$$\frac{\left(x - \frac{c}{2}\right)^2}{a_{23}^2} - \frac{\left(y - \frac{d}{2}\right)^2}{(c^2 - a_{23}^2)} = 1$$

For baseline B30 we have receivers S3, S0 located at (0,d) and (0,0), so:

$$a_{30} = \frac{k_{30}}{2}$$

$$\frac{\left(y - \frac{d}{2}\right)^2}{a_{30}^2} - \frac{x^2}{(d^2 - a_{30}^2)} = 1$$



3.2.2 Location algorithm

The algorithm would proceed as follows:

Each Station Receiver monitors the ambient incoming RF energy and if it detects the rising edge of a pulse, proceeds to charge a comparator reference voltage which is used to decide if the falling edge of the pulse has been detected⁴. Upon detection of a falling edge, the Station Receiver sends a Change of State (COS) to the Master Timekeeper (most likely via a cable), and goes back to monitoring the ambient RF waiting for the next pulse⁵.

The Master Timekeeper (MT) looks for falling edge indications from all four Station Receivers while maintaining a 1GHz clock and counter. There are four latches, each associated with a particular Station Receiver. When a COS signal is received from a particular Station Receiver, the MT latches the counter value into a FIFO buffer for that Station Receiver and latches succeeding COS signals from the other three Station Receivers into their own respective buffers. The first incoming COS signal also resets the count to 0 before latching and starts a 400 ns window⁶ to receive the following COS signals from the other three Station Receivers; if the window is exceeded without one or more succeeding COS receptions, the MT will transmit all available data, with the unavailable data set to some NaN (Not a Number) equivalent for the Location Engine to recognize. The delays associated with each receiver chain and its associated signal backhaul circuitry can be calibrated out using fixed position transmitters, possibly co-located with the Station Receivers.

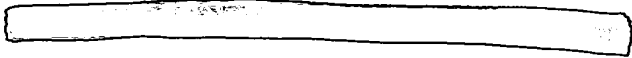
The Equation Solver (ES) does several things. Its primary purpose is to solve for the location of the transmitter, based on the differential timestamps given to it by the Master Timekeeper. The timestamps received may be complete data sets from all four Station Receivers, or may be partial. The ES decides if a particular partial data set is usable for location purposes, and take the appropriate course of action. It also keeps a running log of data set dropout statistics in order to resolve site problems such as poor S/N, antenna alignment, failed equipment, etc. The ES passes the solved location to the calling routine as an X,Y data set, or if the calculation cannot be performed due to missing data, will pass an error code and the reason for the failure (missing data from Station Receiver S3, for example)⁷. As one issue, one can

4. A more complicated detection scheme can be used using a correlation filter or bit-slicer technique, however they are designed to work with a particular modulation and data rate. Due to the dynamic length of the data packet(s) and the MSK preference for Bit Error Rate (BER) performance, they are considerably more complex than the initial proposed schema.

5. A COS signal can be either DC or AC coupling, a DC coupling could provide additional information such as approximate length of pulse when combined with the falling edge timestamp (with our variable length MSK modulated packets, this information is of little use for noise discrimination). It may be more difficult to achieve a fast edge for DC coupling. Some quick performance tests can decide this.

6. The 400 ns window is an example, assuming a 25x50m pool, the longest transit time for an RF signal would be about 170 ns across the diagonal of the pool, plus another 30 ns of receiver processing time followed by perhaps 100-200 ns of COS backhaul link delay, depending on the medium and associated signal processing circuitry.

7. There are several ways that a partial data set can still reconstruct the transmitter's location, however ideally all four Station Receivers should pick up the signal. A miss by a single receiver still leaves three receivers as a necessary requirement to get the location, albeit with possible degradation of accuracy in some situations.



see that there is an exception that has to be processed if the transmitter is equidistant from more than one of the Station Receivers. In this case the time difference between reception at each receiver is 0 ns. A signal from the center of the pool would calibrate out to simultaneous 0 differential counts for each of the four receivers.

3.2.3 The third dimension

The discussion up until now has assumed the simple 2-dimensional case for solving location based on TOF. But we must also consider the third dimension introduced by positioning the receivers above the surface of the pool. For the ensuing discussion, please refer to Figure 23 for the appropriate geometrical interpretation.

We start with four (4) Station Receivers designated S0, S1, S2, and S3, located on four perpendicular baselines named B01, B12, B23, and B30 located on the z=h plane, and the transmitter located on the rectangle bounded by B01, B12, B23, and B30.

Consider the simplest case where the target T1 is located on one of the baselines, in this case B30. If the target sends out a pulse, the energy travels equally fast in a semispherical fashion, the first station receiver to detect the incoming pulse is S0, followed by S3 then S1 and finally by S2. This so far is pretty much the same situation as the original 2-dimensional problem, however in this case the RF pulse edge also has to travel the hypotenuse of the triangle formed by the T1 S0(0,0,z) S0(0,0,0) triangle. This will cause the signal delay to increase by as much as the time it takes the RF pulse to travel distance z (transmitter directly under S0 or S3). This would cause the 2-dimensional solver to fail as the vertex would appear to be past the focus of the hyperbola, causing a complex number to be the 'solution'. The range of the error is:

$$h = \sqrt{z^2 + r_{xy}^2}$$

where z is the height of the Station Receivers above the reference xy plane and r_{xy} is the xy plane distance between the transmitter and the xy plane projection of the Station Receiver.

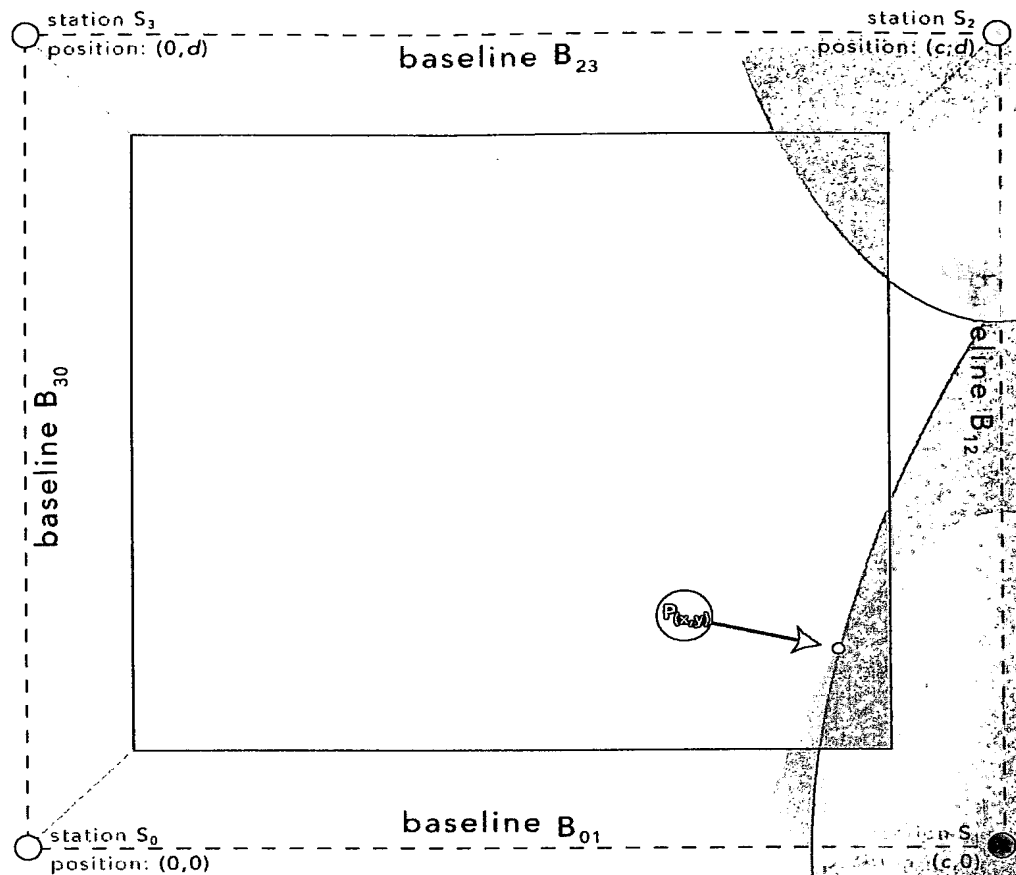


Figure 23. Station receiver geometry

From this it is easy to see that the error is:

$$\Delta_{ERR} = \left(\sqrt{z^2 + r_{xy}^2} \right) - r_{xy}$$

Note that the error term is in units of distance/time as opposed to percentages, as the former is more useful to us than a percentage. As an example, suppose that we try to ameliorate the error due to height by moving the Station Receivers whose height is 8 feet, back from the vertices of the rectangle by 8 feet. We can see that a transmitter at the vertex of rectangle having an original (purely vertical) error of 8 feet now has an error of about 3.3 feet, which isn't very bad. The problem with this mechanical approach is that it is unlikely that we will be able to use convenient heights and set-off distances in real world applications. The worst case scenario is where we have to mount one or more Station Receivers at different offsets and

heights, so it would be best if we could construct a coordinate system that takes these issues into account from the outset.

We start once again with the standard definition of the hyperbola locus, but this time we add the z component to the equation. As long as all of the receivers are at the same height, the equation actually comes out pretty well as shown below. If receivers are mounted at different heights then a tilt or rotation will have to take place, significantly complicating the results- hence we should discourage that practice if possible, though we can write the code for it.

A quick derivation of the relevant equations follows:

$$\begin{aligned} |r_1| - |r_2| &= \pm 2a \\ |r_1| &= \pm 2a + |r_2| \end{aligned}$$

We now square both sides to obtain:

$$|r_1|^2 = 4a^2 \pm 4a|r_2| + |r_2|^2$$

For a 3-dimensional Cartesian distance we have:

$$|r|^2 = (x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2$$

The point P(x,y,z=0) is located on the x-y plane, while the station receivers are set at P(-c,0,h) and P(c,0,h).

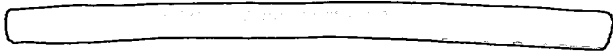
Expanding the terms we have:

$$\begin{aligned} (x+c)^2 + y^2 + z^2 &= 4a^2 \pm 4a|r_2| + (x-c)^2 + y^2 + z^2 \\ x^2 + 2cx + c^2 + y^2 + z^2 &= 4a^2 \pm 4a|r_2| + x^2 - 2cx + c^2 + y^2 + z^2 \end{aligned}$$

Collecting like terms we have:

$$\begin{aligned} cx &= a^2 \pm a|r_2| \\ \pm a|r_2| &= a^2 - cx \end{aligned}$$

Squaring both sides:



$$a^2 |r_2|^2 = a^4 - 2a^2 cx + c^2 x^2$$
$$a^2 [(x-c)^2 + y^2 + z^2] = a^4 - 2a^2 cx + c^2 x^2$$

Collecting like terms we have:

$$a^2 x^2 - 2a^2 cx + a^2 c^2 + a^2 y^2 + a^2 z^2 = a^4 - 2a^2 cx + c^2 x^2$$
$$a^2 x^2 + a^2 c^2 + a^2 y^2 + a^2 z^2 = a^4 + c^2 x^2$$
$$a^2 c^2 - a^4 = c^2 x^2 - a^2 x^2 - a^2 y^2 - a^2 z^2$$

Factoring:

$$a^2 (c^2 - a^2) = x^2 (c^2 - a^2) - a^2 y^2 - a^2 z^2$$

Setting:

$$b^2 = c^2 - a^2$$
$$a^2 b^2 = x^2 b^2 - a^2 y^2 - a^2 z^2$$

Dividing by $a^2 b^2$ we have:

$$\frac{x^2}{a^2} - \frac{y^2}{b^2} - \frac{z^2}{b^2} = 1$$

Thus we can identify the locus as a hyperbola from a hyperboloid of two sheets, where k is half the distance between the vertices, a , of the hyperbola, and the two Station Receivers are at the foci, c . Note the two degenerate cases: if $r_1 = r_2$, then the solution lies on a transverse line between the foci (also note that both receivers will get the signal at the same time). This case shows that at least one more uniquely located station receiver is required to solve for the point as the hyperbola has two solution traces on the x - y plane. One unique situation does exist at the centroid, wherein all four receivers would get the signal at the same time, an easy singularity.

In order to generate a unique solution consisting of a point, a third station receiver has to generate an orthogonal hyperbolic locus with either one or the other receiver. If we place the receivers on the vertices of a rectangle, then having four receivers simplifies the mathematics, as we don't have to rotate the third hyperbolic axis. Note that depending on which station receiver gets the initiating edge, the solution

has to permute the hyperbolas with respect to the one that receives the first (reference) pulse.

Consider the four receivers (foci) S0, S1, S2, and S3, located on the rectangular baselines B01, B12, B23, B30, then the four hyperbolas (for the moment, we are not going to consider the diagonal baselines) with the four possible TOF values of k01, k12, k23, k30, are given by:

For baseline B01 we have receivers S0, S1 located at (0,0) and (c,0), so:

$$a_{01} = \frac{k_{01}}{2}$$

$$\frac{\left(x - \frac{c}{2}\right)^2}{a_{01}^2} - \frac{y^2}{(c^2 - a_{01}^2)} - \frac{z^2}{(c^2 - a_{01}^2)} = 1$$

For baseline B12 we have receivers S1, S2 located at (c,0) and (c,d), so:

$$a_{12} = \frac{k_{12}}{2}$$

$$\frac{\left(y - \frac{d}{2}\right)^2}{a_{12}^2} - \frac{\left(x - \frac{c}{2}\right)^2}{(d^2 - a_{12}^2)} - \frac{z^2}{(d^2 - a_{12}^2)} = 1$$

For baseline B23 we have receivers S2, S3 located at (0,d) and (c,d), so:

$$a_{23} = \frac{k_{23}}{2}$$

$$\frac{\left(x - \frac{c}{2}\right)^2}{a_{23}^2} - \frac{\left(y - \frac{d}{2}\right)^2}{(c^2 - a_{23}^2)} - \frac{z^2}{(c^2 - a_{23}^2)} = 1$$

For baseline B30 we have receivers S3, S0 located at (0,d) and (0,0), so:

$$a_{30} = \frac{k_{30}}{2}$$

$$\frac{\left(y - \frac{d}{2}\right)^2}{a_{30}^2} - \frac{x^2}{(d^2 - a_{30}^2)} - \frac{z^2}{(d^2 - a_{30}^2)} = 1$$

3.2.4 RF subsystem design rationale

The primary goals of the RF subsystem are:

1. Establish a reliable link for the transmittal of data to and from the swimmer devices.
2. Reduce the complexity, power consumption, and cost of the swimmer devices.
3. Establish a reliable link for the determination of swimmer device location.

As a result, the burden of signal processing complexity is assigned to the Station Receivers. This includes noise reduction, signal amplification and edge extraction, and transmittal of edge detection events down to the Master Timekeeper system via either wired or wireless pathways, given the need for providing power to the Station Receivers, a wired pathway cannot be ruled out, and it also has the potential for easier signal processing at the Master Station. A wireless pathway always has the issues of obstruction, interference, etc. that a wired connection doesn't have to deal with in most situations.

3.2.5 TOF receiver design

A block diagram of the proposed Station Receiver is given below in Figure 24, with the following commentary on the design process.

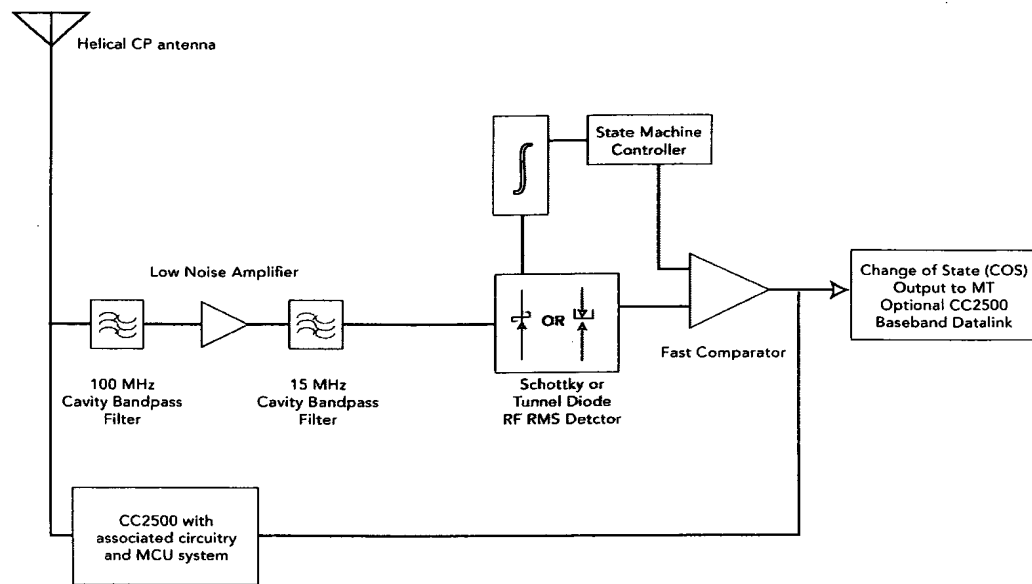


Figure 24. Station receiver block diagram

The first element in the signal processing chain is the antenna. There are several constraints on this element, first that the usable bandwidth should cover the 2400-2458.3 MHz frequency range of the remote swimmer device, the second is that the polarization should be circular, so that the nulls encountered by the moving remote swimmer device are relatively shallow, the third is that it provides some level of gain and directivity so that only the pool area is covered, thus reducing interference from outside sources, and fourth that the aesthetic be pleasing as the device will be viewable in public. Given these four parameters, a suitable design is either a helical or circularly polarized yagi antenna, both of which can be fitted into a plastic cylinder not more than a foot long and perhaps 3 inches in diameter that is made of a suitable RF transparent plastic.

Following the antenna a very low loss medium bandwidth (~100 MHz) cavity filter is introduced to reduce the out-of-band noise coming into the LNA module. Due to the specific construction techniques involved the filter will attenuate by >40 dB any signal that is out of the 2.4-2.5 GHz frequency band, thus reducing the possibility of the LNA saturating, and also reducing the amount of noise that the detector diode has to ultimately deal with.

The LNA module is designed to boost the signal received by the antenna to a level that the detector diode can effectively recognize (typically -60 dBm for a zero-bias schottky detector of the type used in our field trials). If absolutely necessary the LNA can be followed by a narrow band pass filter (NBPF) (15 MHz or less) followed by a secondary amplification stage to further increase the signal and signal to noise level⁸.

Given the proposed RF TOF plan for location, a high bandwidth (250 MHz-2 GHz) RF



process is required to quickly determine that the RF carrier from the swimmer device has been turned off, so a direct RF power level using a schottky or tunnel diode detector is the preferred detector embodiment. While the prototype detector we have used to date has a comparatively slow response time (10%-90% fall time of 10ns), other devices are available such as tunnel diode detectors that have response times on the order of < 50ps, which is well under the actual swimmer device turn-off time.

The output of the detector diode assembly is a DC voltage whose magnitude is proportional to the amount of RMS RF power presented to it. This is the main reason why we want to increase the S/N by both amplification and by reducing the amount of RF bandwidth to ideally just the bandwidth of the swimmer device signal. The more noise power, the smaller the DC step at the detector when the swimmer device is turned on. While there are many ways of doing an ex post facto signal extraction, this is a real-time TOF system and we don't have those luxuries. One possibility is to use an OOK modulation mini-packet to get multiple shots at well defined continuous wave (CW) signals where the possibility of using a correlator does exist.

The output of the detector goes to the edge extraction module, wherein the decision is made to validate the RF pulse from the swimmer device and at what point the Swimmer Device has turned off its carrier. The initial design calls for a comparator that takes a low-pass filtered reference voltage and a state machine that decides when a CW on pulse has been seen. A new state is latched and a new reference voltage set stored, followed by the tripping of the CW off pulse discriminator which fires a COS signal to the Master Timekeeper via a low loss RF cable⁹.

This would complete the description of the Station Receiver module, with the additional mention that a coupled RF path can exist in each to enable a CC2500 to also extract the contents of the received packet. In one way this would enhance the function of the edge extraction module in that a valid SYNC word strobe would be a definitive state change incident, as well as provide diagnostic capabilities such as SYNC received but no edge detected, etc. Such information would be added to the COS signal sent to the Master Timekeeper, or would be sent as a TOF fail-to-measure signal if the edge discriminator did not function. This would be a good diagnostic tool to have, especially since the CC2500 does have an RSSI (Received Signal Strength Indication) function, giving a rough S/N value.

3.2.5.1 Master Timekeeper

The Master Timekeeper (MT) looks for falling edge indications from all four Station Receivers while keeping a 1GHz clock and counter (see Figure 25).

8.The NBPF tends to have a much higher loss (on the order of several dB) so it cannot be placed directly after the antenna, where it would severely reduce the available signal to noise (S/N) to the rest of the receiver.

9.The current embodiment entails a wired connection to the Master Timekeeper, as this reduces the complexity of the prototype system. Obviously other ways to transmit the COS signal exist and can be explored in a pre-commercialization phase of the project.

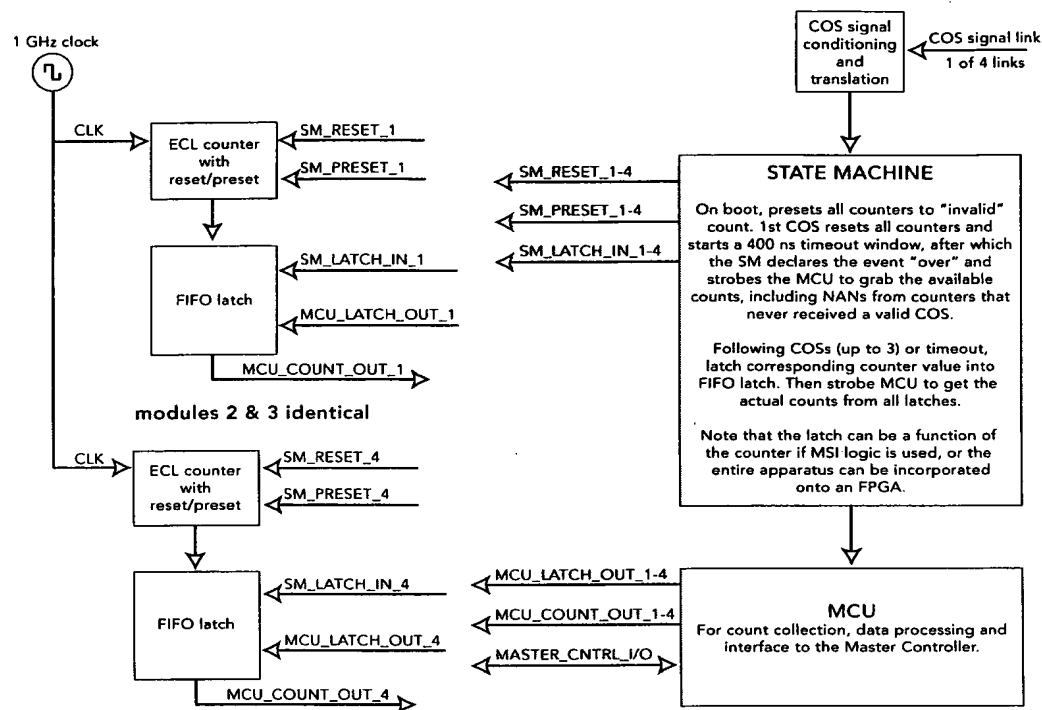


Figure 25. Master Timekeeper block diagram

There are four latches, each associated with a particular Station Receiver, when a COS signal is received from a particular Station Receiver, the MT latches the counter value into a FIFO buffer for that Station Receiver and latches succeeding COS signals from the other three Station Receivers into their own respective buffers. The first incoming COS signal also resets the count to 0 before latching and starts a 400 ns window¹⁰ to receive the following COS signals from the other three Station Receivers; if the window is exceeded without one or more succeeding COS receptions, the MT will transmit all available data, with the unavailable data set to some NaN (Not a Number) equivalent for the Location Engine to recognize. The delays associated with each receiver chain and its associated signal backhaul circuitry can be calibrated out using fixed position transmitters, possibly collocated on the Station Receivers. If the CC2500 is also included in the Station Receivers, then additional diagnostics on the signal strength, etc. can be gathered from each SR.

¹⁰The 400 ns window is an example, assuming a 25x50 meter pool, the longest transit time for an RF signal would be about 170 ns across the diagonal of the pool, plus another 30 ns of receiver processing time followed by perhaps 100-200 ns of COS backhaul link delay, depending on the medium and associated signal processing circuitry.



3.3 Master Station

The Master Station (MS) will consist of the Master Timekeeper (see Section 3.2.5.1), a CC2500 RF transceiver and suitable antenna for polling the Swimmer Devices (see Section 2.2) and a single-board computer with sufficient resources to manage the polling operations, swimmer location mapping, and communication with the database server.

3.4 Link Budget

This section summarizes the details of the link budget between the CC2500 Swimmer Device (SD), the Station Receivers (SR), and the Master Station (MS). The link budget must be broken down into two main components, the data channel, that is both sent and received by the CC2500 device, and the RF TOF channel that is sent by the CC2500 device but received by a custom high bandwidth RF power detection system.

The primary system performance goals that must be met are as follows:

1. The Data Channel Link (DCL) must provide error-free communications between the Master Controller and each of the SDs (no matter what the polarization orientation is) and be able to function with a thin film of water. A hydrophobic radome plastic would be interesting to use. The term "error-free" is subject to interpretation. For our purposes, we would like to see a 99.0% success rate for maximum length data packets.
2. The RF TOF Link (TOFL) must provide enough signal margin so that we can recover a sufficient pulse slope to accurately delineate the end of a packet transmission or the end of a bit pulse in the case where we elect to use OOK TOF mini-packets. The system must be insensitive to polarization rotation and must be able to receive data from swimmers over the entire coverage area.
3. Battery life on the SD must be conserved as much as possible, so a single packet transmission is desirable.

For the following discussion we will again be using our standard four (4) Station Receivers designated S0, S1, S2, and S3 located on four perpendicular baselines named B01, B12, B23, and B30 located on the $z=h$ plane, and the transmitter located on the rectangle bounded by B01, B12, B23, and B30 on the $z=0$ plane.

The first matter to consider is the issue of antenna polarization. Given the fact that the SD will be moving on highly complex paths, it would be most desirable for it to have as isotropic a radiation pattern as possible, so as not to prejudice a particular orientation (this can be of course modified for particular body locations such as the head, etc., however the practical physics of confined antenna design leave little maneuvering room). The most we can really hope for is to have a dipole-like radiation pattern, preferably using a large (in terms of wavelength) loop antenna.

In the same vein, the Station Receiver antenna should have the following:

1. The antenna should be insensitive to polarization orientation; this implies that it should have a circular polarization characteristic. The only performance penalty is

that a 3dB loss is incurred with respect to having two linearly polarized antennas perfectly matched. However this 3dB loss stays the same, whereas a linear mismatch of 90 degrees can easily have a 30dB null.

2. The antenna should have a pattern that is sensitive to the area of the covered rectangle, with minimal back and side lobes. With this will also come a moderate gain, making up for the 3dB loss versus a perfectly matched linear antenna orientation.
3. The bandwidth of the antenna has to cover the intended ISM band (2.4000-2.4835 GHz) used by the CC2500. Using a conservative estimate of 100MHz, this implies a 4.2% bandwidth and has some impact on the physical antenna design choice.
4. Given the venue the antenna has to be constructed in a fashion that renders it unobtrusive, mechanically rigid, and easily aligned. Three candidates arise, the first a helical antenna, the second a crossed (CP) Yagi, and the third a patch antenna.

Link budget basics are based on four items, the radiated power from the transmitter, the distance to the receiver, and the sensitivity of the receiver to the particular transmission and the received noise power. Detailed modeling is complicated, however for our purposes it can be relatively simple to evaluate.

We start out with the simple case of using isotropic antennas, a conservative output power level -10dBm on the transmitter, with just free space loss and a conservative receiver sensitivity of -80dBm on the CC2500.

Using the simple path loss formula:

$$P_R = \frac{P_T}{(4\pi R / \lambda)^2} = \frac{P_T}{L_P}$$

We have:

$$L_P = \frac{P_T}{P_R} = \frac{10^{-1}}{10^{-8}} = 10^7$$

Now solving for the distance R:

$$R = \frac{\lambda}{4\pi} \sqrt{L_P} = \frac{0.12\text{m}}{4\pi} \sqrt{10^7} = 30\text{m}$$

Given the more typical case of another 5dB margin on the receiver, 7dB on the transmitter and a conservative 7-12dB on the Station Receiver antenna, it would appear that we have more than enough link margin to make the DCL link meet. Of course there are other complicating factors at play here, namely the additional attenuation caused by the water film, as well as the protective housing. Offsetting these are the Station Receiver antennas coupled with high-power transmitters if necessary coupled with additional LNA receiver front ends. From a practical per-

spective, the limiting factor is likely to be the receiving signal floor on the SD as opposed to anything on the Station Receiver.

If we use the "typical" values found in the datasheet and a conservative 2dBi gain value on the antennae, then the calculations show:

$$L_p = \frac{P_T}{P_R} = \frac{0\text{dBm}+2\text{dBm}}{-82\text{dBm}+2\text{dBm}} = \frac{2\text{dBm}}{-80\text{dBm}} = \frac{10^{0.2}}{10^{-8.0}} = \frac{1.58}{1 \cdot 10^{-8}} = 1.58 \cdot 10^8$$

Now solving for the distance R:

$$R = \frac{\lambda}{4\pi} \sqrt{L_p} = \frac{0.12\text{m}}{4\pi} \sqrt{1.58 \cdot 10^8} = 120\text{m}$$

Both of these numbers indicate that we should have an adequate link margin for exchanging data packets between the Station Receivers and the Swimmer Devices, especially if we drop the data rate to 250 kbps which yields an additional 5 dB.

The primary design tradeoff will be the antenna gain versus directivity pattern. Too high a gain will cause an unacceptably narrow main lobe and cause SDs to drop off when out of the path of the main lobe near the antenna. That the SD is closer to the antenna when this happens mitigates the effect somewhat.

The RF Time of Flight Link (TOFL) budget is a more basic problem, where we are trying to extract a signal amplitude out of the received noise floor with enough clarity that we can (i) detect the existence of the pulse, and (ii) extract the falling edge from it with some degree of confidence in regards to its position in time.

To that extent, we are trying to distinguish from a Gaussian thermal noise distribution over the same bandwidth that we are trying to receive the signal in which is a CW signal for our purposes. The mean-square voltage developed across a resistance is given as:

$$\overline{v}^2 = \frac{2\pi^2 k^2 T^2}{3h} R$$

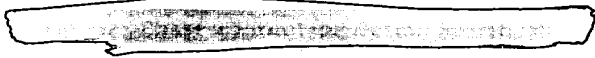
where

$k = 1.37 \cdot 10^{-23}$ W-s/°K (Boltzman's constant)

$h = 6.62 \cdot 10^{-34}$ W-s² (Planck's constant)

T is the absolute temperature of the load in Kelvin

In the case of the CC2500 we have the real part of the ideally matched load at 80 ohms, so the expression calculates out to 13.4 microvolts. For the noise power seen by the receiver, the condensed formula is:


$$P = kTB$$

where B is the bandwidth in Hertz.

In the case of the CC2500, the real part of the input impedance is on the order of 80 ohms, and if we use a conservative bandwidth of 100 MHz (the bandwidth of the cavity filter) we have an equivalent noise floor of 39.7 picowatts, or -94 dBm. Added into this noise floor is the actual carrier wave from the SD, and from the previous section we can assume that the transmitted power is on the order of 0 dBm, with a worst-case distance of 30 meters. Then the power received by the Station Receiver antenna is on the order of:

$$P_R = \frac{P_T}{(4\pi R / \lambda)^2}$$

For the figures of 0dBm and 30 meter distance, the received power is on the order of -70 dBm, which, while comfortably above the -94 dBm noise floor (recall that 20dBm is a linear factor of 100), is below the linear detection region of the proposed diode detector by about 10 dB. Thus an LNA will be required to boost the signal for the detector to work properly. The LNA modules used in the initial RF TOF testing have a gain figure of about 30dB so they should provide us with an adequate level yet not saturate the detector with strong signals near the Station Receiver.

[REDACTED]

SECTION 4: VIDEO CAPTURE

The prototype system will use from four to six fixed position cameras on the sides of the pool to collect video of swimmers. See Figure 26 for a line diagram showing a four-camera configuration.

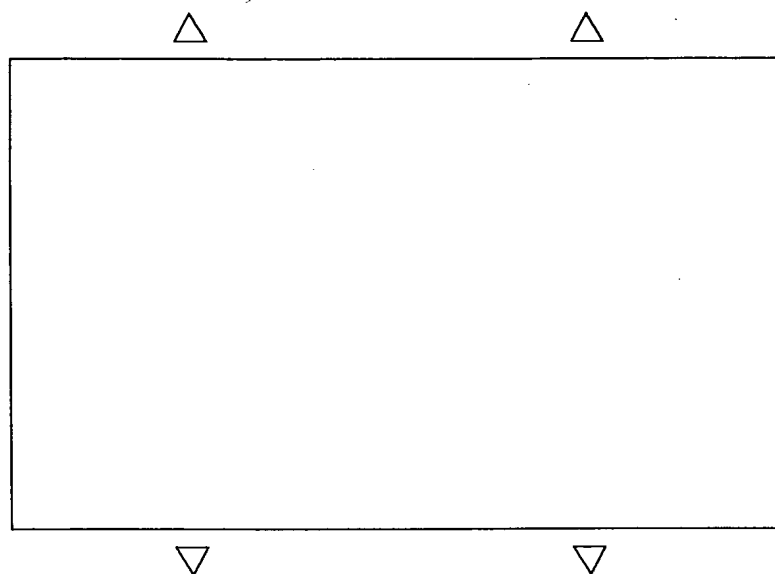


Figure 26. Cameras located on sides of pool

Using post-processing techniques, a video-view tailored to each swimmer's activity can be derived and saved as files on the server (see Section 6), and optionally sent to the coach's view upon selection of a specific swimmer. Video in both an overall view and swimmer-specific views will be available for playback to the coach.

4.1 Initial Camera Testing

We have targeted our initial research on video cameras providing streaming video output via TCP/IP, with Ethernet as the physical layer transport and PoE (Power over Ethernet) to supply power to the camera. This has two significant benefits for us:

1. Cabling is simple and inexpensive. A single CAT5 Ethernet cable connects each camera to a PoE switch.
2. Processing required to digitally encode the video is off-loaded from the server to the camera.

Initial video tests were performed using the Axis 210A Network Camera. This cam-

era was chosen using the following criteria:

1. MPEG-4 and MJPEG compression performed by the camera.
2. Fast Ethernet (100 Mbps) via RJ-45 cable connection.
3. Power supplied by PoE
4. Well documented API for acquiring video stream via TCP connection
5. Readily available
6. Low-cost

However, due to some notable limitations of this camera (poor performance in low-light conditions, slower frame rate at higher resolutions), we are looking at using the higher performance Axis 221 Network Camera (see Figure 27). In addition to the features cited above for the Axis 210A, the model 221 camera provides higher frame rates, a larger CCD element, works well in low-light conditions, is rated for both indoor and outdoor use, and is equipped with a vari-focal lens (which we expect will prove useful for experiments with camera positioning in a multi-camera system).

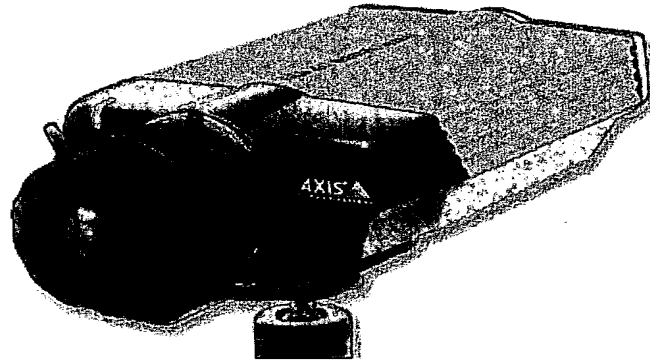


Figure 27. Axis 221 camera

4.2 Underwater Cameras

To date, we have found no commercially manufactured underwater IP cameras. Barring new entries into the market, we'll either have to engineer our own, or use a conventional analog output camera connected to a network video server or PC-based frame grabber board. Due to this added complexity, underwater cameras will not be part of the Phase I Prototype system, but we mention them here as they most certainly need to be added in a future project phase.

4.3 MPEG-4 Capture and Playback Testing

Preliminary tests with the Axis 210A cameras proved challenging, as the MPEG-4



output of the camera was not immediately useful due to the video being sent RTSP-over-HTTP. This limited the availability of software suites capable of recording the stream to a file for later playback.

After much experimentation, we were able to configure the VideoLan Client (VLC) to record this stream format to a file on disk. In attempting to overcome issues with video frame rate and playback rate (addressed below), the libraries of liveMedia (www.live555.com/liveMedia) were found to include several test programs such as openRTSP which proved helpful in the troubleshooting of these issues.

4.4 MPEG-4 Streaming Issues

Once recording and playback of the video was working successfully, we noticed that the playback speed of the recorded video segments replayed at a quicker rate than expected. Further investigation revealed two potential causes for this:

1. Video was being sent from the camera at a lower frame rate (from 21 to 25 frames per second) at its highest resolution (640x480) rather than the 30 fps we were expecting.
2. No stable time-base information (such as the MPEG-4 FlexTime model) is being sent from the camera in its MPEG-4 stream. The MPEG-4 stream from the camera relies on real-time transmission for frame timing.; the camera expects the client application (e.g. VLC, QuickTime) to play frames as they arrive. There is no way the player can display frames at a quicker rate than at that which the frames are sent from the camera. When captured to a file (which lacks a time-base information track) a player does not know how fast to play back video content, other than honoring specified frame-rate information.

Given these two causes for expedited playback, we will devote further research into processing and transcoding software and believe a solution to be within reach.



46 Video Capture

SECTION 5: USER INTERFACE

The product's proposed user interface (UI) for the coach's console is based on a set of intuitive human gestures on a touchscreen display. Certain functions may also make use of natural-handwriting recognition, subject to usability testing.

Figure 28 illustrates a set of concise, tightly integrated functions more akin to the PalmOS concept than to a collection of separate computer applications. The goal should be to feel you can get to anything from anywhere, with the additional philosophical ideal of "no training necessary" when it comes to the portable unit's entire function set.

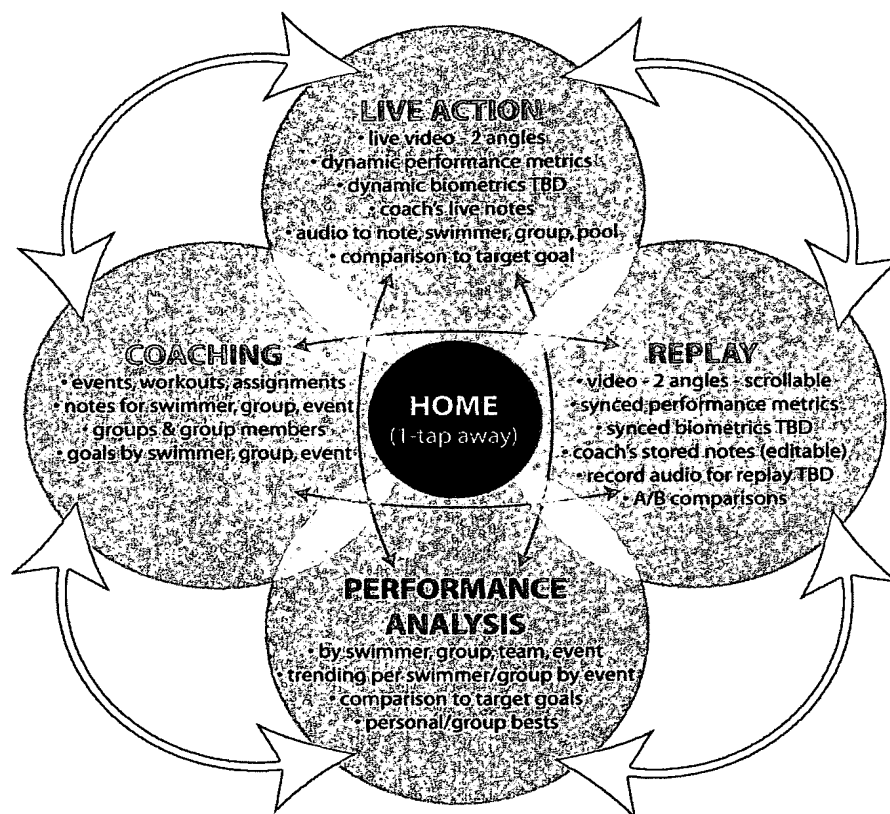


Figure 28. UI architecture

5.1 Coach's Console

The prototype coach's console is a Fujitsu Lifebook P1510 as shown in Figure 29. We chose a tablet PC because its size is almost identical to the coach's notebook (see Section 5.3.1). Unlike most tablet PCs, this model has a touchscreen which allows input both using a stylus (shown to the right of the P1510), or by pressing on the display. This allows the user to navigate the UI using a fingertip to press "buttons" on the display. An integrated microphone provides acceptable audio input even in a fairly noisy environment.

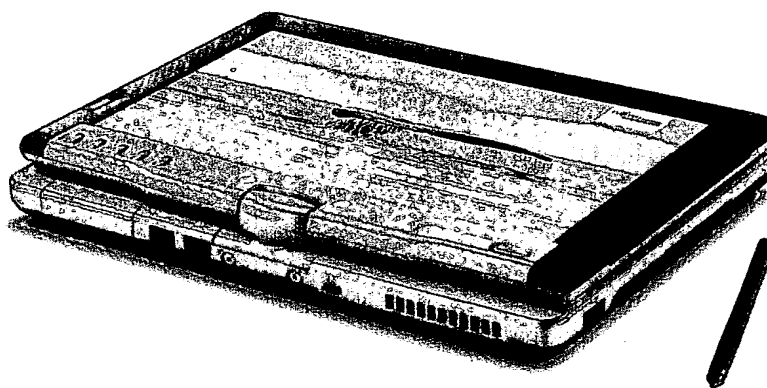


Figure 29. Fujitsu Lifebook tablet PC

The Windows XP Tablet Edition (the OS supplied with the tablet PC) provides excellent handwriting recognition. However, it is poor at individual character recognition. This may prove to be challenging when accepting shorthand such as a coach typically uses when making entries in his notebook.

5.2 Development support

As stated in Section 1, the User Interface (UI) requirement for the Phase I Prototype is to provide a basic user interface to support the prototype's constrained feature set. Delivery of video and swimmer telemetry will be restricted to the coach's console at the pool. The emphasis will be placed on getting data displayed in a fashion most usable to the system developers, as opposed to displaying in a fashion most

[REDACTED]

usable by the coach. This is an important distinction, because in many (if not most) cases, the optimal displays for the system developers and the coaches will not be at all similar.

Along these lines, we will need to provide system-level debugging functionality in the UI to support development of other aspects of the system, such as TOF statistics, RF packet loss, latency, etc. that will not be of use to the end users. However, such functionality will be essential for production system deployment and integration. These will be designed and implemented on an as-needed basis.

5.3 User interface challenges

In this subsection, we discuss some issues that must be resolved for the final product. These were considered for the Phase I prototype, but we have concluded that too much work remains to be done on these issues to resolve them for Phase I.

5.3.1 Coach Interaction

The user interface (UI) for this system is particularly challenging due to the volume and variety of displayed data required, [REDACTED]

[REDACTED] a number of computer-based coaching aids, all of which have been eliminated because they either took too much of his time, or because they weren't flexible enough to provide the results he wanted in the way he wanted them.

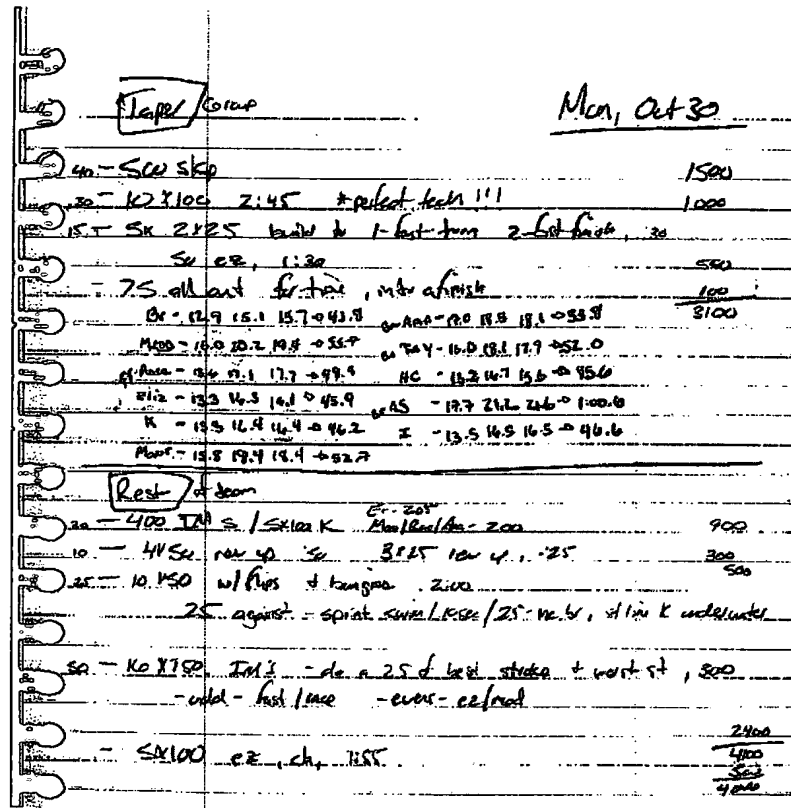
In particular, [REDACTED] reported spending an entire season attempting to manage workouts using Hy-Tek Workout Manager (<http://www.hy-tekld.com>), but abandoned the software because [REDACTED] found it too structured and difficult to use. [REDACTED]

Since then, [REDACTED] has reverted to [REDACTED] Workout Manager (WM), some of which is shown in Figure 30. It's simply a small spiral-bound notebook, but the functionality it provides is far from simple!

Unlike other devices [REDACTED] tried and abandoned in the past, SWM is always in use; [REDACTED] carries it with [REDACTED] almost constantly while conducting, or at least has it within arm's reach. [REDACTED] uses it to keep track of who's supposed doing what and for what duration, to give directions to his two assistant coaches, and to take notes while practice is in session. [REDACTED] will also make modifications on the fly during training: reassign people to different exercises, change exercise goals, etc. However, most of the training plan for the day is written in advance.

It will not be sufficient for the system to capture video and telemetry; [REDACTED] must also get input from the coach to tag date and time ranges as being a particular training event. This is required in order to do quantitative analysis of the data over several training sessions. Without this data entry from the coach, we will have a massive amount of video and telemetry for the swimmers, but no association with training events. This will prevent any sort of useful long-term analysis, as the many different training exercises have different objectives, and thus, will have different perfor-

In order for PerformMax to not be abandoned like the other systems we must get the coach to enter training plan data into our system. Nobody likes to enter data twice, so what we really have to do is to provide a replacement for CWM that (and other coaches) will willingly use.



A careful review of JWM makes it obvious to us that there is no way that we can offer the user a finite number of pre-determined choices of training events and parameters to select from; rather, the coach must be able to enter any data, notes, etc. that he or she sees fit to use as search keys later.

One of the greatest technical challenges we will have to solve is displaying synchronized video and data on the displays. This is critical, as even a slight amount of offset will result in data that obviously does not correspond to the displayed video.

[REDACTED]

with the result being that the integrated display is useless. This is a real-time constraint, as a small misalignment will show results that are obviously wrong; e.g.: taking a breath while the swimmer's head is underwater; forward velocity while the swimmer is in the middle of a turn. The situation is analogous to watching a film dubbed in a different language: it's obvious that the sound is not coming from the actor's lips.

A [REDACTED] solution which requires further analysis to determine its viability is to encode the SD telemetry on the fly as metadata in the video stream. If we can successfully interleave the telemetry with video frames, we will guarantee that the data corresponds to the video frame currently being displayed. Otherwise, the problem will have to be solved by buffering video and telemetry on the coach's console, and synchronizing time references between the two data sources there. This may result in the coach's console requiring more computing power than would be required if this work can be offloaded to the server.

5.3.3 Swimmer interaction

This is closely related to the discussion of removable storage in Section 6.1.2. The method of delivery of the video and data to the swimmers for off-site personal analysis remains to be determined. If it is infeasible to provide this data using removable storage, then the only viable alternative is to provide Internet-based delivery. While bandwidth for video delivery will be problematic, we can take steps to reduce the required bandwidth for analysis, such as providing reduced-resolution video for gross mechanical analysis, then requesting small sections of high-resolution video to download to their PC for detailed analysis.



SECTION 6: DATABASE AND VIDEO SERVER

The prototype system will use a Unix-based server for capture, storage, and retrieval of video and swimmer event data. Figure 31 shows a typical HP Proliant Server. The server (or server array) used in this application may vary.

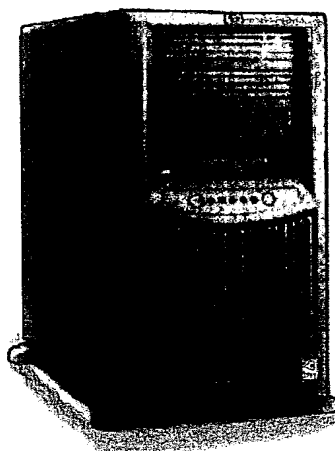


Figure 31. Typical HP Proliant Server

6.1 Video Server

The server will be fitted with adequate processing power, memory, and disk storage to accommodate the requirements of real-time video processing and archival.

The prototype system will use a Unix-based server capable of collecting concurrent video streams from multiple Axis Network Cameras. Captured video will be stored on disk where it will be available to processing applications.

6.1.1 Theory of Operation

The server shall collect video from all video sources and write received video out to files on the server for storage. All of the recorded video will be indexed and catalogued into a database. Information such as Date, Time, Frame, Source, Session, and Status will be recorded.

As the coach selects a swimmer for a more detailed view, the video server will collect relevant information from the database to determine which video sources con-

tained information on the subject swimmer at the requested time. A video stream will be constructed from all available sources to provide a hybrid "best-view" of the subject swimmer for the selection parameters.

This means that as the swimmer passes from one camera view to another, using the swimmer's location data, camera feeds will be "switched" automatically. This hybrid targeted video will be available for storage or streaming to the coach's console.

6.1.2 Removable Storage Considerations

It has been suggested that, for all swimmers, a DVD or CD containing data and footage should be available upon the close of each training session. Alternatively, something along the lines of "thumb-drive" removable storage could be used.

Considerable effort will need to be devoted to the implementation (and maintenance) of periphery capable of meeting the needs of this task. For instance, to efficiently burn fifty (50) separate CDs or DVDs (each of which will require on the order of several minutes to prepare and burn), multiple-drive arrays will be necessary. Multiple-drive arrays are likely to mandate a considerable amount of routine maintenance and repair. Using USB devices such as "Thumb Drives", on the other hand, would require numerous USB ports and a strict guide as to which drives are fully compatible. This is a topic which warrants much further discussion and experimentation in order to produce a fluid and economic solution and is therefore considered to be outside the scope of the Phase I Prototype system design.

6.2 Database Server

The server will maintain a database indexing sessions, video feeds, swimmer-specific views, time indices, and all swimmer data and location data from the Swimmer Device (SD), Location System, and any additional data either collected during sessions or entered by the coach.

This data will be catalogued and stored in the database (and as referenced files as appropriate) and will be available for review on demand, such as from the coach requesting real-time playback of a specific swimmer to analyze performance.

6.2.1 Storage Requirements

It may be important to retain up to four years of data on each swimmer since this is the length of time designated for swimmers to be enrolled in programs where system access is needed. The storage requirements for multiple video feeds operating several hours per week and many weeks per training season will be enormous. The prototype system will not attempt to implement such a massive amount of long-term data storage, but will be limited to a few days or weeks.



6.2.2 Backups

A localized duplicate backup server could be used for all backup purposes if having the data securely located offsite is not a pressing matter. This method of backup should also safeguard against both natural (hardware failure) and accidental (user error) data loss. This is beyond the scope of the prototype system but will be addressed when the production system is designed.



SECTION 7: PROTOTYPE IMPLEMENTATION

7.1 Swimmer Device

The swimmer device PCB has been designed and several have already been fabricated. [REDACTED] The FORTH, Inc. SwiftX MSP430 development system has been ported to the board. The prototype firmware (in Forth, using the SwiftX system) has yet to be written. [REDACTED]

7.2 Antennas

The antennas for the Swimmer Device and Master Station need to be [REDACTED] built, and tested. We have leased the necessary equipment for antenna testing and matching. [REDACTED]

7.3 Location System

The RF TOF receivers and master station (including its master timekeeper) design has yet to be reviewed and signed off on by the team. After this, these components must be built and tested. [REDACTED]

7.4 Video System

Video testing to date has been done using the Axis 210A which, for reasons noted in Section 4.1 has proved inadequate. We will order 4 (or 6) of the Axis 221 Network Cameras for further testing. These units are priced at about \$990 each in small quantities.

We are already in possession of a suitable PoE switch for the [REDACTED] Prototype system and can order an additional one as a backup. [REDACTED]

7.5 User Interface

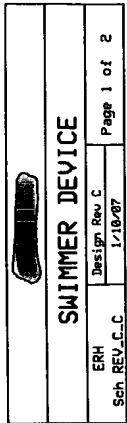
Much prototyping and modeling has already been done on the tablet PC. This needs to be ported to a "live" server environment. [REDACTED]

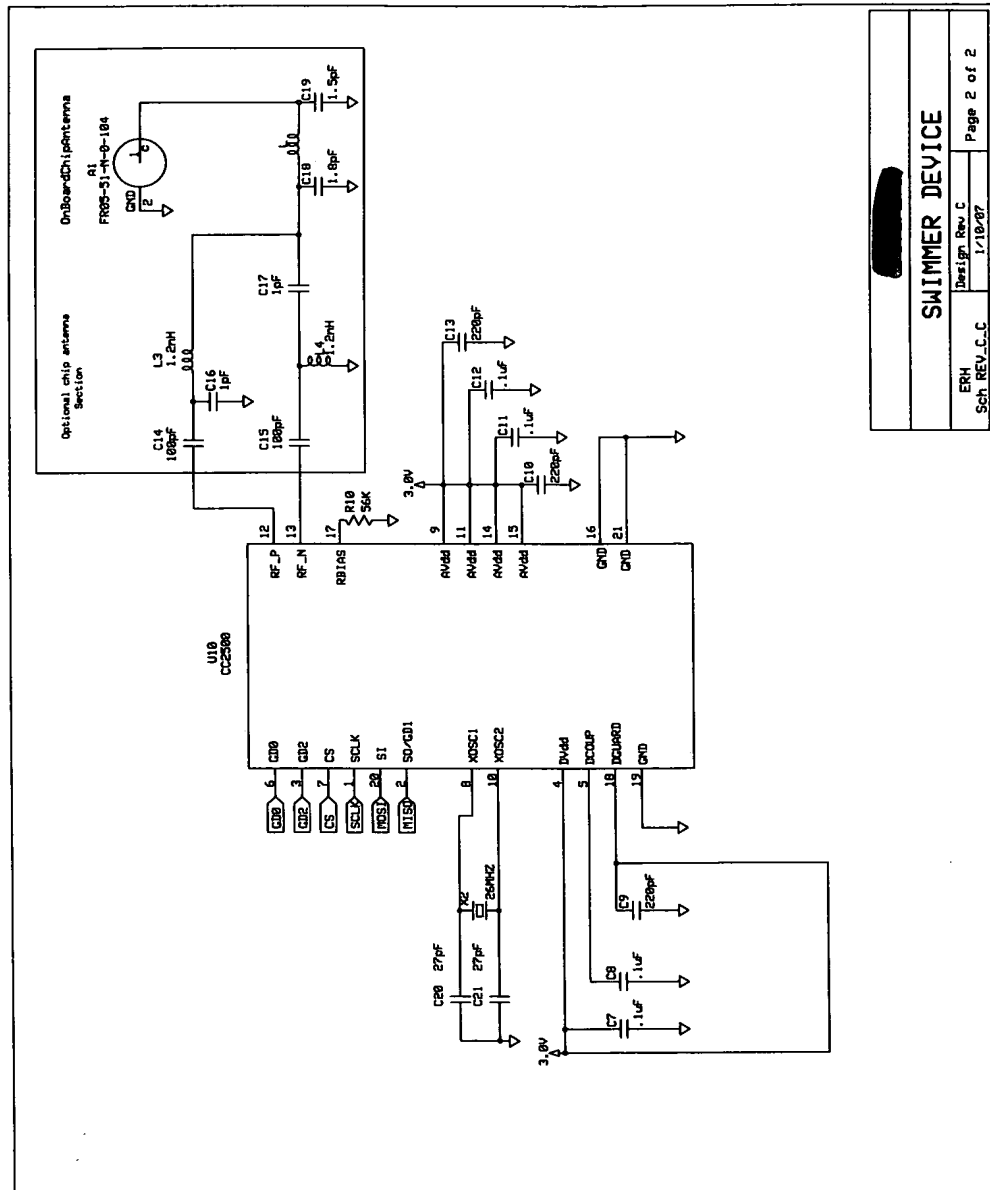
7.6 Server

A server with appropriate features to support the Phase I Prototype needs to be

[REDACTED]

selected, procured, configured, and deployed [REDACTED]





INTRODUCTION

Overview

This document presents a plan for testing the prototype hardware as a system-level proof of concept for the PerforMax system. For each subsystem, it details the test setup, test procedure(s), and the gathering and analysis of results. Much of the results analysis will be done in the weeks that follow this preliminary test.

Test Goals

It is important to understand that this is our [REDACTED] attempt to get everything working together at the level of fundamental subsystems. We are trying to prove that this will lead to a powerful overall system when everything is integrated with more hardware and software to be developed after successful proof of principle of the critical components. [REDACTED]

Our tests will utilize a Swimmer Device (SD) board in a waterproof plastic bag strapped to the cap or wrist of a volunteer swimmer. The SD will be in two-way data communication with a fixed transceiver at the edge of the pool. The data from the transceiver will be stored by the server computer for later analysis. The intent is to have the swimmer swim normally and try to log the transmitted data to show acquisition of usable position and speed data.

The Time of Flight (TOF) system is one of two generic candidates for measuring the coarse position of the swimmer with an accuracy better than 2 feet. (The other candidate is an optical approach [REDACTED]) TOF uses the measured times of receipt of SD poll responses from fixed location receivers positioned around the pool to determine the location of the transmitting SD. For this initial test, the transmissions of raw data will be simply recorded by PCs and oscilloscopes.

There will be six video cameras operating simultaneously. They will stream huge amounts of data for storage and ultimate time synchronization with other performance data.

Candidate components of the eventual user interface will be exhibited. They will not be fully integrated into an operational system, but will show simulated operation.

Several vital components are still incomplete. On the hardware front, [REDACTED] we may not be able to test RF TOF with calculations. He is more concerned that we get RF communication working as it does come first.

There is also a dearth of data relating to what the accelerometers must provide in terms of sampling speed, accuracy and dynamic range in order to integrate to veloc-

ity and position data over multiple strokes. Unless that is done, nobody will know if we are in the right neighborhood of sampling, etc. to calculate accurate velocity and distance vectors.

Figure 1 below shows a block diagram of the test system. Table 1 on the next page summarizes the test goals.

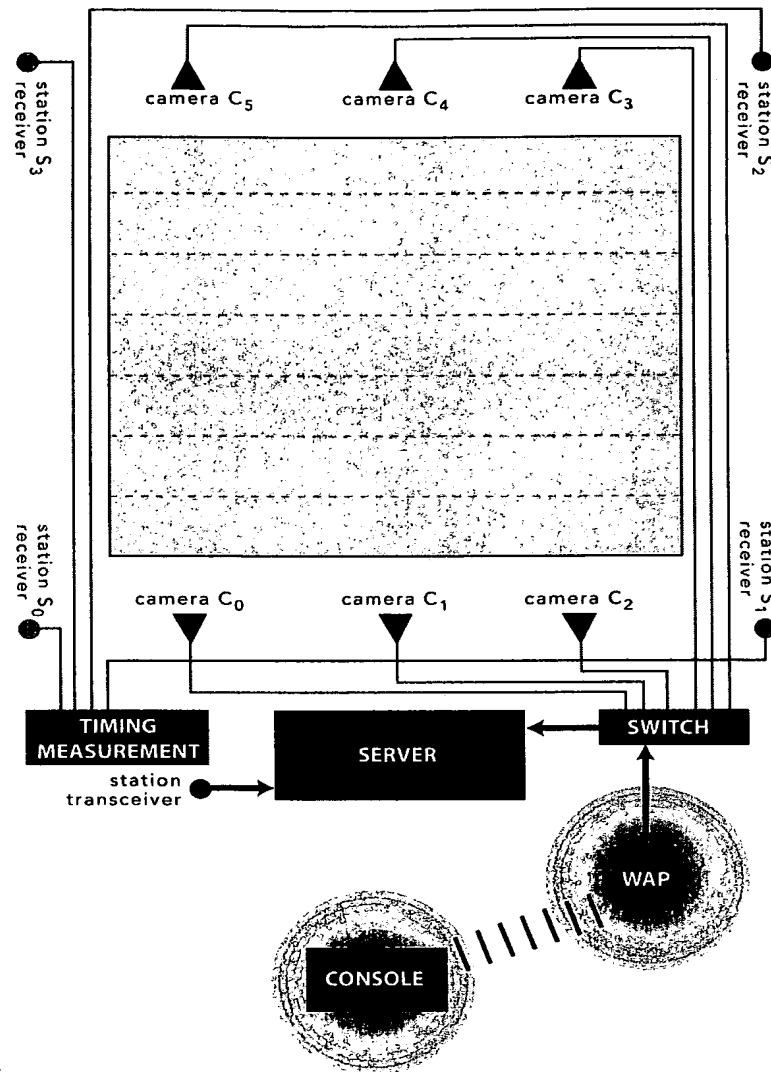


Figure 1. System Block Diagram

4 Introduction

Table 1: Test Goals Summary

Primary Functions	Technical Functions to be Tested	Successful Criteria	Unsuccessful Criteria
Find the Swimmers - Identify Swimmer Device - Determine Location - Show Location Data	- SD responds to poll request from ST with ID data packet - SR receives SD packet across pool - Measurement shows RF TOF adequate for position calculation	≥ 90% poll response when SD is above water - Accepts 75° depointing ≤ 10% PER/RSS > -70 dBm - Measured data for ≤ 2 ft TOF error	- Unreliable link to SD - Unreliable SD to ST link - Excessive MT drift not calibratable for TOF calculation
Measure Position & Speed as Functions of Time - Poll Each Swimmer Device - Display Raw Data	- Continuous repetition of above SD position polling to determine progressive change with time - Data acquired in sequence with small errors	Continuity of data good enough to enable accurate position calculation from accelerometer integration of coarse RF TOF measurements	Inability to maintain position measurement continuity when DCL/RF TOF link is running
Acquire Accelerometer Data - Stroke Rate - Cadence - Raw Data for Energy Calc	- Packets transmission across pool - Reception and logging of 3-axis accelerometer data - Accuracy to integrate to velocity & position	≥ 90% poll response when SD is above water - Accepts 75° depointing ≤ 10% PER/RSS > -70 dBm - Sampling speed 8-10 per second - Dynamic range ? TBD - Overall accuracy 7TBD	- Unreliable link to SD - Unreliable SD to ST link
Acquire Video Data - Continuous coverage of entire pool with multiple cameras - Massive data storage - Timecoding/synchronization - Streaming capabilities	- Capture uninterrupted video from six cameras simultaneously - Ability to accurately synchronize video sources - Deliver streaming video to UI	- Uninterrupted video delivery from camera - Uninterrupted video storage on server - Successful video playback (file and/or stream.) - Synchronization validation	- Camera failure - Network/switch failure - Server fails to capture and store video - Unable to replay file and/or stream - Unable to synchronize
Demo User Interface Goals - Easily Understandable - Interactive Management - Workout Specification - Competitive Evaluation - Touch Screen Control	Using stored and/or simulated data: - Show static and dynamic content - Display graphical and/or video representations of pool activity and swimmer data - Outline of all functional groupings - Interface components interact with and control each other and screen content	- Major functional groupings identified in a usable way - Interaction with display provides consistent, repeatable results - Interface subcomponents communicate with each other	- Unable to display dynamic content - Unable to access major functional group quickly - Unreliable link to Master Console

6 Introduction

SECTION 1: HARDWARE TESTING

1.1 Server

The server has already been configured and tested in the lab and is operational. We have about 900 GB of space available for test data.

1.1.1 Switch

The WAP (wireless access point) and the cameras are all running on PoE (Power over Ethernet) from the switch. The switch is maxed out on power. It probably can't supply power to another camera. Powering on the WAP briefly overloaded the switch, but appears to be okay steady-state. We probably need a heftier PoE switch for production use.

The switch requires power, CAT-5 cables to each of the cameras and WAP as well as to the server. The cameras and WAP must be connected to the PoE ports. The server is connected to a non-powered port.

This is a fairly inexpensive PoE switch, so under heavy loads we may experience some packet loss or other anomalies. We need to watch this closely and be sure we are not attributing switch-related issues to other system components.

1.1.2 Wireless Access Point

After the switch is connected and operational, we will test wireless communication between the server and the Fujitsu tablet PC as well as with other notebook computers equipped with wireless cards for reliable connectivity, bandwidth, and throughput. WAP tests should be performed both with the TOF/telemetry system active and inactive.

If we have interference issues with 802.11b/g, we can try 802.11a, but this would also require an 802.11a USB adapter for the Fujitsu.

1.2 Video

Position cameras at desired positions for test. This will require some experimentation with camera position and varifocal lens adjustment.

At some point, we will want to do a series of tests where the cameras are all simultaneously recording the running scoreboard; this will let us see accurately what sort of timing/synchronization errors we may get from simultaneous capture from six cameras.

Connect cameras and server to PoE switch. CAT5 cable runs will be too long for pre-built cable for all stations. We'll have a spool of CAT-5 cable and necessary connectors with us. Time permitting, we will pre-build some 200' runs; that should suffice. It's possible we'll overload the switch with a bunch of long cable runs. Moving the WAP over to its own AC power adapter should take care of that.

Use the Axis built-in viewer to verify that each camera is properly focused and is transmitting data over the network. Do this with the Fujitsu notebook, using the wireless link. Move the Fujitsu around the pool area to see if we have any bandwidth or reliability issues with the 802.11g link.

Begin video capture on each camera in succession. Verify that video is being captured to disk. After a short run, view video as a sanity check. If video is not smooth and uninterrupted, try capture on  Powerbook.

Video will be captured to <http://sigtyr.p/video/> on the server. These are playable directly from the web server. However, without streaming service, the files will rapidly become unusable directly, because they'll simply be too large.

We will require a streaming video server for the final product in order to deliver on-demand video. We are currently investigating several commonly used open-source streaming video servers (primarily Darwin Streaming Server and ffmpeg.) There are also proprietary streaming video servers available, such as Flash Media Server, but that's both expensive (\$4500) and doesn't give us source code we can analyze and modify. As time permits during the testing,  will continue to pursue this, and hopefully provide a demonstration with some of the captured video.

An appealing option, which we believe is doable (but are still researching,) is to encode the telemetry as metadata in the video stream, thus assuring that if the UI receives the video, it'll also receive the telemetry simultaneously. At this writing, we don't expect to have anything ready to test or demonstrate during the May 7-11 testing. However, we should be able to synthesize this at a later date from the captured video and telemetry from this testing.

We have captured and analyzed video of swimmers  on several occasions, but this is our first opportunity to have complete pool coverage with multiple cameras simultaneously capturing video, as well as the entire PerforMax development team available to answer important questions about optimal camera position, orientation, and depth of field. We expect to spend a lot of time moving cameras and capturing video from different positions in the natatorium. This is the single most important task to accomplish with the video subsystem during this round of testing.

Each camera position that video is captured from and the corresponding file into which the video is captured (e.g. /video/c6/test22.avi - 8' from south edge, 20' from SE corner) should be carefully logged.

1.2.1 Optional Tests

Time and progress permitting, we would also like to try these additional items:

1. Test reception of streaming video from ffserver (or another server) to QuickTime and/or Windows Media Player. First test with wired connection, then Fujitsu via wireless.
2. Deliver streaming video to the UI from a camera.
3. Deliver streaming video to the UI from all cameras, selectable by user.
4. Repositionable video to the UI; i.e.: pause, rewind, back to current time.

1.3 RF Subsystem

1.3.1 Station Receivers

Mount Station Receivers on tripods and run coax and power cables (safely tucked away or taped down) to common point for TOF measurements.

Power up system and test response from each SR. If one fails, we should have spare parts on hand. The only system dependent on all four units is the RF TOF, Data Communications Link DCL shouldn't be affected.

1.3.2 Station Transceiver

Perform baseline tests for DCL signal propagation with swimmer in pool. Evaluate number of lost packets and the RSSI variation to see how close we are to the edge of link loss. If Packet Error Rate causes accelerometers to overflow buffer storage space on SD, then we need to increase RF link margin by using higher power amplifiers, and retest system.

1.3.3 TOF Measurement

RF TOF subsystem test consists of evaluating accuracy of position data vs signal level. Position in one location should not change more than 1 or 2 feet due to large changes in signal level amplitude (due to slope of RF detector response). If value exceeds X, then we may need an additional data channel to feed RSSI information from the CC2500 located in station receiver into Master Timekeeper to compute a correction factor.

RF TOF subsystem needs to meet 2-4 feet accuracy over pool surface with a PER of 5% under normal conditions. If RF TOF does not meet accuracy and PER requirements, then we need to analyze what the nature of the variance is and devise a course of action.

If RF TOF system fails from a purely hardware perspective then we need to repair failed unit.

Post-test analysis will concentrate on evaluation of acquired accelerometer data (stored on the server) to see how well it reconstructs motion/performance of swim-

mer. [REDACTED]

1.4 Swimmer Device

Initial tests will be performed with the SD carried around various locations in open air to prove communication with the ST and SR devices.

A more advanced test will utilize a Swimmer Device (SD) board in a waterproof plastic bag strapped to the cap or wrist of a volunteer swimmer. The SD will be in two-way data communication with the ST at the edge of the pool. The data from the ST will be sent to the server for storage and later analysis. The intent is to have the swimmer swim normally and try to log the transmitted data to show acquisition of usable position and speed data.

Post-test analysis of the logged telemetry data will help us to learn as much as possible about the characteristics of the accelerometer, RF performance, cadence (time the SD is above and below water); and other measured statistics internal to the SD.

SECTION 2: USER INTERFACE PROTOTYPE

2.1 UI Overview

The User Interface (UI) will mature as both hardware functionality and data specifications are developed. The current prototype UI will be presented to elicit feedback on certain basic concepts (e.g.: navigation, sizes of screen elements and controls) and to provide a partial preview of how data may be displayed and manipulated.

Refer to Figure 2 for a flow diagram of the user interface.

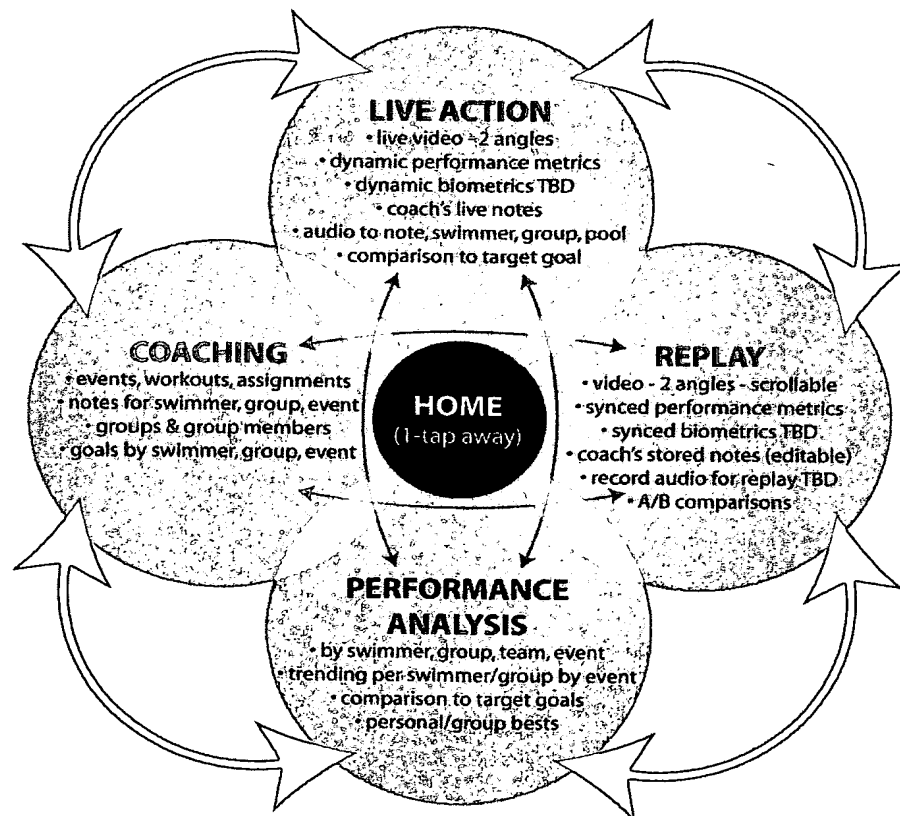


Figure 2. User Interface Flow Diagram

2.2 Functional Groupings

Conceptually, the user interface enables the user of a handheld PC to do the following

- View live action
- Replay an athlete's performance
- Analyze the collected data
- Manage the athletes and define exercises and workout routines

2.3 Data Display

Depending on the functional group being used, there may be more than one view of a swimmer's event. The following views are some of the possibilities:

- Video (live or recorded)
- Swimmer statistics (e.g.: start time, lap times, turn times, finish times) that may be displayed in various ways (graphical charts, running meters, traveling averages) to facilitate easy interpretation of the data
- Comparison of a swimmer's performance against another of his or her own, to a record or to an assigned target goal

2.4 Navigation

The UI is designed to keep the user aware of the context ("Where am I? What am I looking at?") at all times, and to make it easy and intuitive to change from one context to another. This is illustrated in the flow diagram above (see Figure 2).

Certain global buttons will keep the major functions available at all times. Where efficient and intuitive, actions taken in one function will seamlessly move the user to another appropriate function.

2.5 Direction

If preliminary results are satisfactory concerning this conceptual preview, including receiving useful feedback from all parties, the UI components will be developed, tested and refined in stages. These stages will incorporate considerations such as:

- Performance - The interface will be designed to execute efficiently.
- Intuitiveness and ease of use - The design will attempt to reduce training time to a minimum.
- Results - Provide information most useful to coaches and athletes in a way that is understandable.
- Client feedback - We plan for client feedback at several stages of progress and to

respond to that feedback.

- Visuals - Convey meaningful information in a manner that is quick to understand and easy to access.
- Analysis - Incorporate both data that are measured directly and data that can be calculated to provide information intended to assist coaches and their developing athletes and teams.

If preliminary results are unsatisfactory, then we will discuss with the users the aspects that are unsatisfactory, propose changes to make the UI more useful and appealing, and incorporate these changes into our design. Since the UI is web-based, we can quickly and easily deliver incremental improvements via the Internet for users to evaluate and comment on.

APPENDIX A: SWIMMER DEVICE ERROR BUDGET ANALYSIS

This appendix details the theoretical error budget of the Performax system based on datasheet values and basic statistical analysis.

A.1 SOURCES OF ERROR

There are three primary components to the Performax system which are subject to errors in some degree

The first is the analog accelerometer measuring system in both the analog response domain and the digital conversion state. The ADXL330 iMEMS accelerometer is inherently a mechanical device that produces an output voltage based on the stress induced on a mechanical moment arm. The obvious errors sources are ones of sensitivity, drift due to power supply, time and temperature changes, non-linearity in response to acceleration changes, lag in response to acceleration, and hysteresis due to acceleration polarity reversal.

The microcontroller converts the analog signal into a digital representation, which has a quantization error, as well as the possibility of drift, nonlinearity, and addition of noise voltage from other parts of the system such as the processor clock, etc.

Finally there are errors associated with the physical mount of the accelerometer on the body. If the Swimmer Device (SD) is loose, then additional accelerations will be recorded due to the wristband (as an example) getting rotated around the wrist as the arm impacts the water surface and drags the band around. To test for this a suitably rigid arm (mannequin) can be used to explore this potential error source. A more difficult scenario would be where the swimmer's skin and flesh actually rotate due to the torque put on the arm by the SD, as opposed to a natural torque.

The second error group is the swimmer location system, currently being implemented as a Radio Frequency Time of Flight (RF TOF) design. Here the errors can be again grouped into several categories based on the concept that distance equals time for radio frequency waves. The basic design has the signal from the SD received by a power detector that then trips a comparator when the RF packet has stopped coming from the SD. Multiple receivers each send a Change of State (CoS) pulse to a Master Timekeeper (MT) that has a running counter for each Station Receiver (SR). The differences in the counts as the receivers send in their pulses correspond to differences in the arrival times at each receiver and hence a location can be calculated. The error categories are as follows:

Biased tracking errors are errors that presumably affect each of the station receivers with the same bias, for example a temperature change may increase the power detector response time by several nanoseconds or may change the CoS travel time down the RF cable to the MT. Another bias error is the clock oscillator that increments the counters, if not exactly at 1GHz, then the distance measurements will be distorted by some equal amount. Given modern frequency control devices, this is

unlikely to be an issue.

Differential tracking errors affect each SR in a different fashion. The most complicated example would be where the RF power detector response time was dependent on the RF power level it was actually seeing. As an example a SD close to one receiver causes a high signal level and a comparatively slow response due to saturation effects, thus shifting the response by several nanoseconds, whereas a more distant receiver did not have a saturation delay, causing a positional shift in the final calculation between the two receivers; of note is that to date this effect has not been seen for the signal levels what we have been working with, but this will be quantified as part of this paper.

Random tracking errors are primarily due to indecision by the CoS detection circuit as to when the signal stop threshold has been reached. Primarily this will be at low signal levels where the noise floor will start to add an increasing amount in the instantaneous voltage presented to the comparator. As a result the comparator may fire within an increasingly wider time band, leading to a progressively larger circle of uncertainty not unlike the Global Positioning System (GPS) scenario. An additional random tracking error is where an interfering transmitter causes a shift in the comparator response time. Although not completely eliminable, these errors can be suppressed by incorporating a CC2500 into the SR to validate the incoming signal with a SYNC word strobe. The strobe itself has too much jitter to be useful as a positioning method, but is quite usable as a gate for the CoS state that is sent down to the MT.

A.2 ACCELEROMETER ERRORS:

Due to process variation possibilities, the full temperature range data are used. This is mainly due to the fact that even though each individual device has a relatively small change, it appears from the datasheet that the device-to-device variability is considerably larger. This implies somewhat difficult process control issues in manufacture, most likely the polySi spring characteristics. In any event, a worst case and realistic case column will resolve any lingering questions (caveat emptor).

The first errors are cross-axis coupling and dynamic range non-linearity, the first ostensibly due to mechanical die misalignment, the second presumably because of Hooke's Law deviations. Given a 1% typical axis cross coupling value it is imperative that some kind of easy calibration routine be developed, especially as we will be integrating to get velocity and position data. Note that the accelerometer is a static device, if the unit orientation changes and stops, the readings will not subside to a zero state but will reflect the new orientation in the gravity field (as they should). This brings up some interesting frame-of-reference issues as the bracelet attachment will have a particular orientation that will cross-couple into all three axes during motion.

With no Low Pass Filter (LPF) capacitors on the output of the accelerometer, the X, Y, and Z axes have bandwidths of 1600 Hz, 1600 Hz, and 550 Hz respectively. The sensor resonant frequency is 5.5 kHz, and the internal clock frequency is 50 kHz.

The output stage of the accelerometer has a 32K 15% resistor which will result in

conservative high frequency cutoff bandwidth design, the input impedance of the Analog to Digital Converter (ADC) must also be taken into consideration with this level of source impedance, as the Sample and Hold (S/H) acquisition time may increase. The formula given in the MSP Processor Users Guide is:

$$t_{\text{sample}} > (R_{\text{ADXL}} + R_{\text{ADC}}) \times \ln(2^{13}) \times C_{\text{ADC}} + 800\text{ns}$$

Assuming we have no LPF capacitor on the output and the worst case $R_{\text{ADXL}}=36.8\text{K}$ ohms, the formula gives a minimum sample time of 15.5 μs for a maximum sampling throughput of about 19 $\mu\text{s}/\text{sample}$ (using internal oscillator at slowest guaranteed speed), which leads to a 52 kHz sample rate, thus a 17.5 kHz sample rate per axis. The 17.5 kHz sampling rate is 10 times the maximum bandwidth of the accelerometer so no concerns there, however we will have to examine the 50 kHz internal clock frequency to make sure that it isn't aliased into the ADC reading.

In order to make sure that the switching noise is below an effective threshold for the 12 bit ADC, the filter has to reduce the voltage level to about 610 μV (assuming a 2.5 VDC full range input if using the internal reference). The datasheet is coy about the switching level noise on the outputs, but assuming 50 mV unfiltered gives us a filter capacitor of 0.008 μF to reduce the voltage to below 1 Least Significant Bit (LSb) on the ADC. This value is pretty close to the 500 Hz upper limit on the Z axis, and is in the 1600 Hz neighborhood of the X and Y axes.

The next question to answer is the inevitable noise level versus bandwidth issue. The ADC is capable of resolving down to 610 $\mu\text{V}/\text{bit}$ assuming a 2.5 VDC input swing, and the worst case sensitivity of the accelerometer is 270 mV/g yielding an overall system sensitivity of 2.26 mg/bit. The noise density of the accelerometer is 280 $\text{g}/\sqrt{\text{Hz}}$ for the X and Y axes and 350 $\text{g}/\sqrt{\text{Hz}}$ for the Z axis. For an root-mean-square (rms) value the formula for a single pole filter is:

$$V_{\text{rms}} = \mu\text{g}/\sqrt{\text{Hz}} * \sqrt{1.6 \times \text{BW}}$$

For a bandwidth of 500 Hz this yields 7.92 mg of rms noise on the X and Y axes and 9.90 mg rms on the Z axis. For a 99% confidence reading this level goes up by a factor of about 5, thus over-sampling is useful to eliminate peak-peak variations in the accelerometer readings¹. Since the sensitivity of the accelerometer is 3.70 mg/mV and our ADC LSB is 732 μV , these levels compromise the low level sensitivity of the system so we must optimize the response time of the accelerometer versus the sensitivity. To do this we need to see what the acceleration levels are in the motions we are looking at primarily at the air/water interface. We could do some basic Fourier Transform analysis to see what some postulated acceleration profiles have in terms of frequency components, but this is beyond the scope of this document².

1. The factor of five is gathered from a table given originally in Analog Devices AN-358. No references are given for the figures, which are not a simple standard deviation calculation. Further enquiry may be required.

A.3 ADC AND SAMPLING ERRORS:

Assuming we have cyclic limb motion, we are estimating that the swimmer can complete 2.5 cycles per second as a maximum rate. With 360 deg/cycle, this implies 900° per second of motion. With a sample rate of 30 Samples Per Second (SPS), we have a sample every 30 degrees, which doesn't appear to give us very good resolution if we want to do a detailed "slow motion" analysis of the limb acceleration as well as velocity and position integration operations. Perhaps we will need to look at the equivalent video frame rate to make the call. Given the maximum sampling speed of 17.5 KSPS and our accelerometer bandwidth of some 1600/500 Hz, yielding a resolution of 0.051 degrees if absolutely necessary, though a 1 degree sample interval is probably more than adequate (again depending on the integration and noise tradeoffs); post-processing may improve this value even more. This would also mean drastically wider bandwidth on the RF link unless a large memory store and forward technique is used (which eliminates near-realtime data updates). An interesting calculation on the derivative of the acceleration that the limb can undergo would be interesting because it would give us the most appropriate sampling range. There are several journal articles that have reported the results of wrist-mounted accelerometers that may be of use to us in this respect.

Given the data sheet values, it is difficult to say that a standard device will come close to any of the maxima given below, except for input offset drift and the like, which seem to be at a 1% level from the statistical curves given in other device data sheets. To be safe, we should conduct some tests with auto-calibration or settle for possibly degraded performance from one device to the next.

Using the internal reference on the ADC limits us to a maximum 2.5VDC input voltage, which means that our maximum acceleration is going to be just under 5g (due to the mid-voltage 0g bias point).

The ADC section on the MSP430 has an input impedance of $2K\parallel 40pf$ maximum, which will have to be factored into the frequency response of the accelerometers as they have a 32 K ohm output resistor (assuming there is a LPF capacitor). This is the primary reason for the 19 us sampling time calculated in the section above.

The ADC internal reference has a 17 ms startup time, a necessary but not sufficient condition to meet a 12bit accurate conversion. The internal reference also has a maximum 100 ppm/°C temperature coefficient which gives us a drift of 2/5 LSB/°C for a 2.5 VDC full scale input. The total unadjusted error for the ADC is 2 to 5 LSB, equivalent to 1.22 to 3.05 mV across the full 2.5 VDC voltage range, or about a 4.44 to 11.3mg offset which is above the rms and is about the same as a 99% confidence level for peak to peak noise. It can be expected that ADC calibration routines will null out the static errors. The reference drift can also be taken out with a temperature sensor³.

2.The primary issue here is that we don't have a good idea of what sort of levels need to be measured to be useful, it may be that the values that prove to be useful are considerably higher than the noise floor.

3.A reasonable way to calibrate the SD would be to put it on a circular table rotating at various speeds. Depending on the SD orientation wrt the center, each axis could be normalized. This may be necessary due to the variance in the sensitivity and offset of the production lots.

On the position location front, since the system can use one or more stationary calibration CC2500s as markers, the only real source of uncertainty is the decision circuitry that measures the output voltage from the RF power detector and any non-monotonic variances in the output of the power detector as the signal level drops.

Examining the behavior of power detectors points out two facts:

1. They have a finite response time mainly due to the diode detector capacitance, and that as they respond to any RF energy signal
2. They are sensitive to the broadband noise as well as the desired RF packet signal. If the RF packet level is low enough, then the background noise will start to obscure the signal, and we may start to get excessive jitter in the comparator.

A.4 SUMMARY

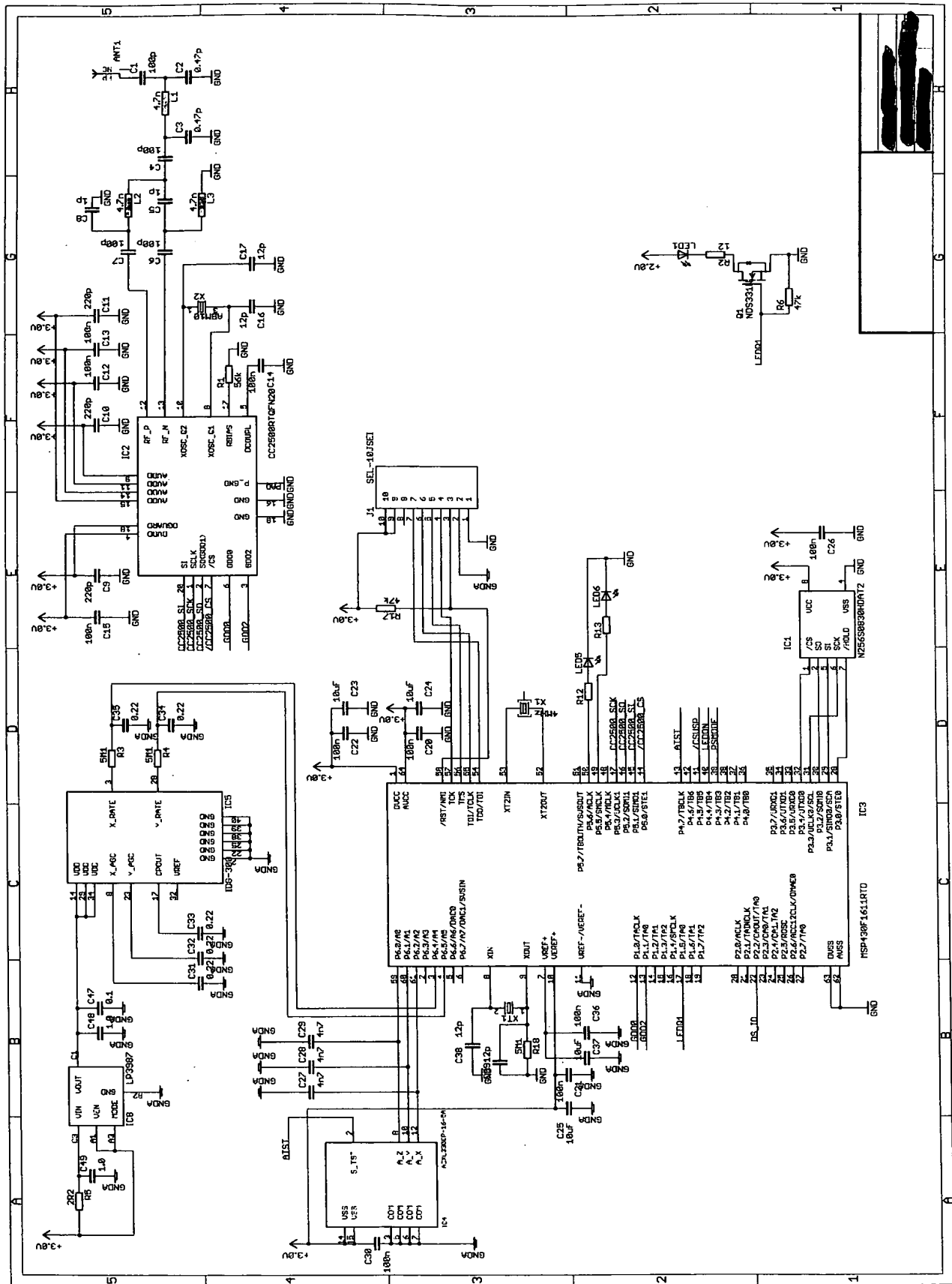
For the preliminary tests we don't expect any error compensation schemes to be implemented so the raw data error budget is given in the table below:

Package Alignment Error	$\pm 1^\circ$	Static Error
Inter-axis Alignment Error	$\pm 0.1^\circ$	Static Error
ADC resolution in volts	610 μ V/bit	With 2.5VDC internal reference
ADC resolution in g	2.26/1.85 mg/bit	With 270/330 mV/g sensitivity
Inter-axis cross-coupling	$\pm 1\%$	Proportional Error
Bandwidth Noise XY/Z in terms of acceleration	280/350 μ g/? Hz XY/Z format	BW=10Hz $\Rightarrow$ 1.12/1.40 mg rms BW=50Hz $\Rightarrow$ 2.50/3.13 mg rms BW=100Hz $\Rightarrow$ 3.54/4.43 mg rms BW=2KHz $\Rightarrow$ 15.8/19.8 mg rms
Bandwidth Noise XY/Z in terms of voltage at 0.270/0.330 V/g sensitivity	75.6/94.5 μ V/? Hz XY/Z format	BW=10Hz $\Rightarrow$ 302/378 μ V rms BW=50Hz $\Rightarrow$ 676/845 μ V rms BW=100Hz $\Rightarrow$ 956/1195 μ V rms BW=2KHz $\Rightarrow$ 4.28/5.34mV rms
Bandwidth Noise XY/Z in terms of bit count	Vref=2.5VDC 610 μ V/bit XY/Z format	BW=10Hz $\Rightarrow$ 0.495/0.620 bits rms BW=50Hz $\Rightarrow$ 1.11/1.38 bits rms BW=100Hz $\Rightarrow$ 1.57/1.96 bits rms BW=2KHz $\Rightarrow$ 7.02/8.75 bits rms
Accelerometer sensitivity change with temperature	± 150 ppm/ $^\circ$ C	Even a 10 degree change would only change the sensitivity slope by 405 μ g, not significant error yet.
Accelerometer zero-point offset drift with temperature	± 1 mg/ $^\circ$ C	This is the dominant temperature dependent parameter.
ADC temperature drift in terms of acceleration data	± 100 ppm/ $^\circ$ C 2/5 LSB/ $^\circ$ C	904/740 μ g / $^\circ$ C
ADC temperature drift in terms of voltage	± 244 μ V / $^\circ$ C	244 μ V / $^\circ$ C based on internal 2.5VDC reference

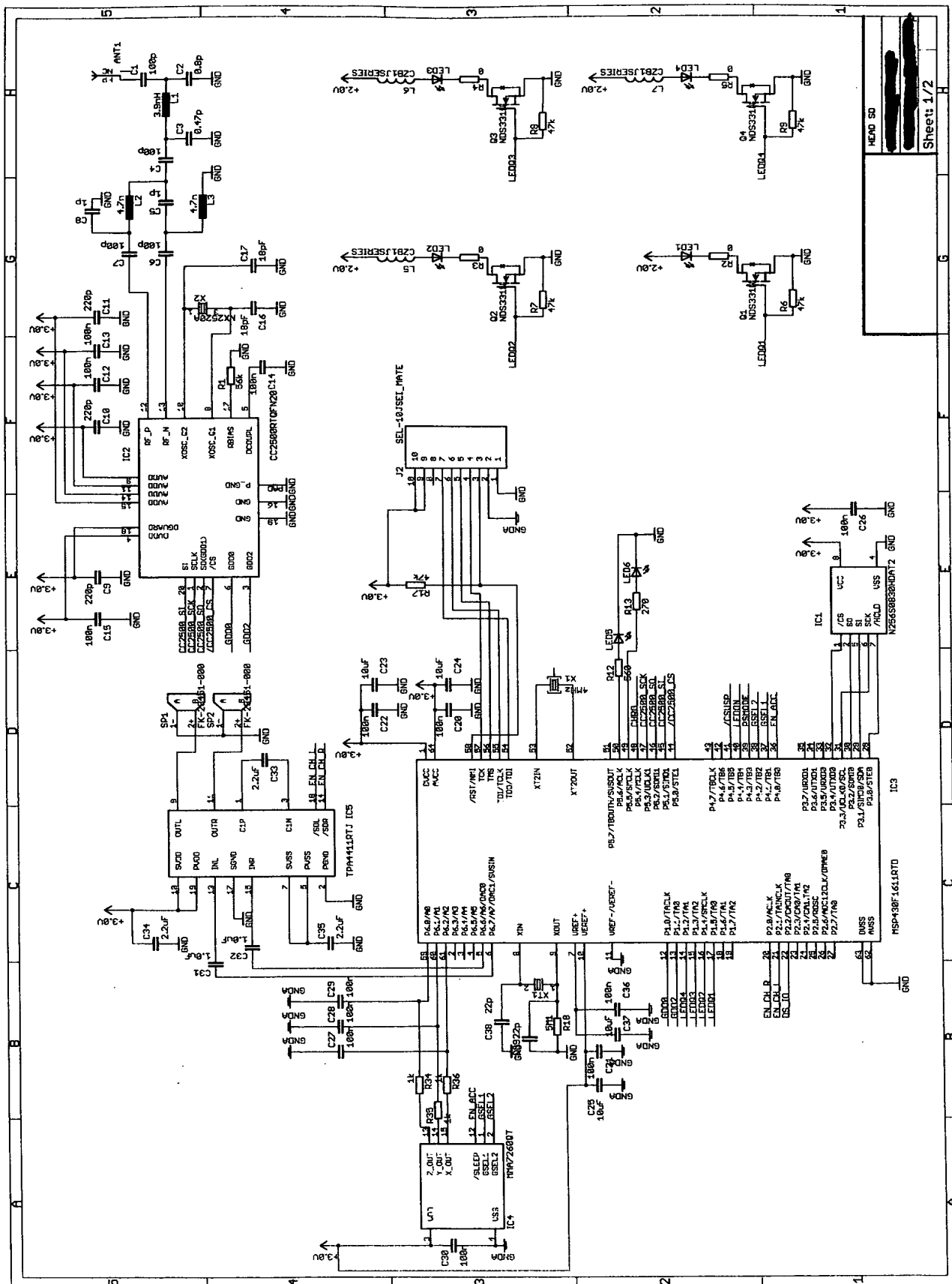
APPENDIX B: GLOSSARY

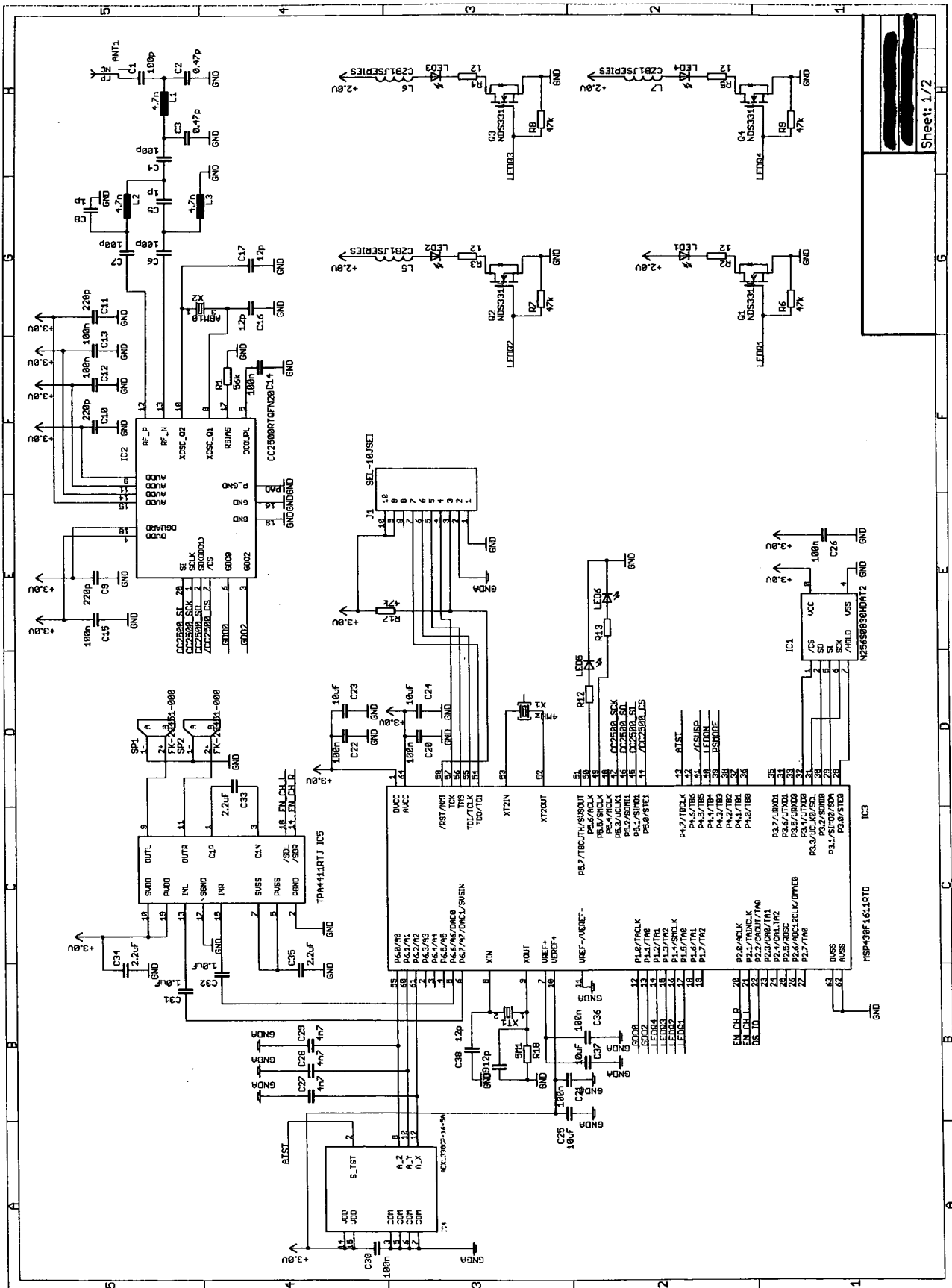
Table 2: List of Acronyms

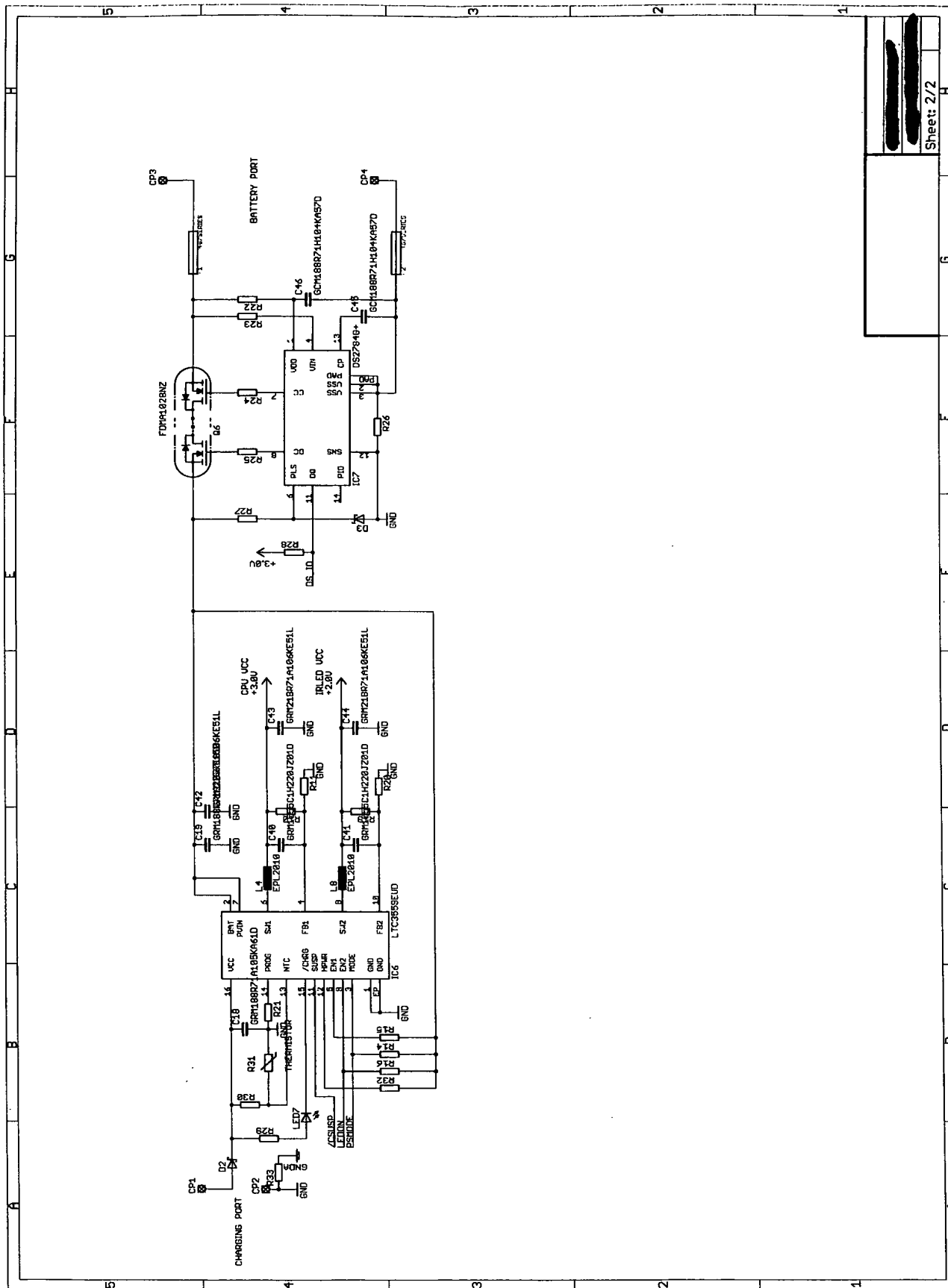
Acronym	Definition
DCL	Data Communication Link
MS	Master Station
MT	Master Timekeeper
PER	Packet Error Rate
PoE	Power over Ethernet
RF TOF	Radio Frequency Time of Flight
RSSI	Received Signal Strength Indication
SD	Swimmer Device
SR	Station Receiver
ST	Station Transceiver
SYNC	Strobe generated by CC2500 transceiver
WAP	Wireless Access Point

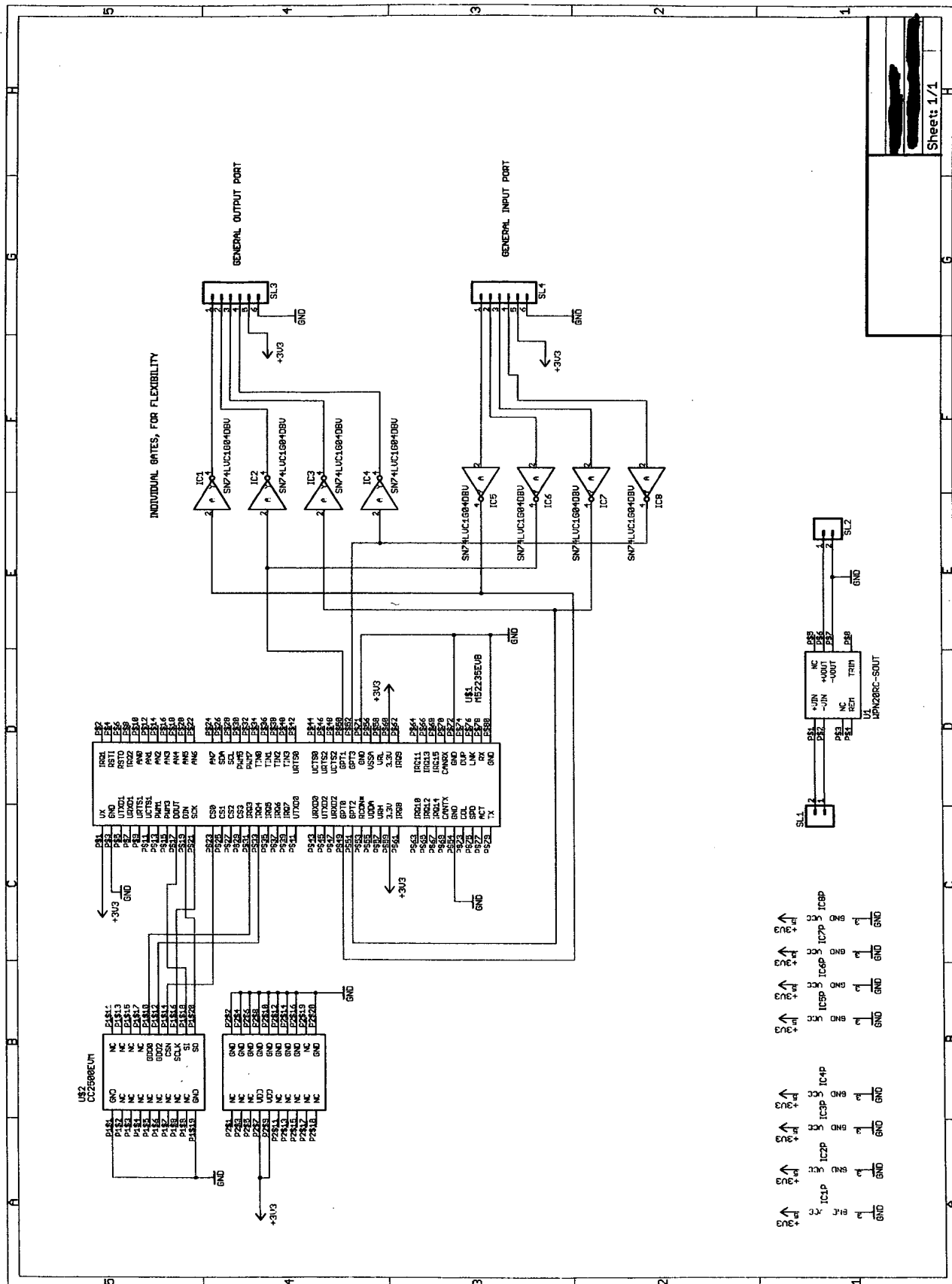












PerforMax Home Page

Breadcrumbs: Main/UserInterface > Main/UIMeetingAtFORTHOctober142008 > UserInterface/WorkoutManager > Main/SwimmerDevices > Main/HomePage

Task-related topics

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- Main.HandheldUnits
- UserInterface.Live-RecordedEvents
- Main.MasterStation
- UserInterface.DataDisplays
- Main.UserInterface
- UserInterface.UsageNotes
- Main.MiddlewareService
- Main.AlphaSystemStatus
- UserInterface.RestrictedContent
- Main.PerforMaxEventsAndMeetings
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Swimming & pools

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About PmWiki

PmWiki is a wiki-based system for collaborative creation and maintenance of websites.

Online help

PmWiki pages look and act like normal web pages, except they have an "Edit" link that makes it easy to modify existing pages and add new pages using basic editing rules. You do not need to know or use any HTML or CSS.

- The basic editing page describes how to **create pages** in PmWiki.
- You can **practice editing** in the wiki sandbox.

Swimmer Devices

Breadcrumbs: Main/UserInterface > Main/UiMeetingAtFORTHOctober142008 > UserInterface/WorkoutManager > Main/HomePage > Main/SwimmerDevices

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Background

The swimmer device (SD) is a portable data collection module with local memory storage and an RF transceiver for command/data downloads/uploads. There are two versions of the device; the one used for head mounting has connections for audio transducers for an earpiece and multiple infrared light emitting diodes (IRLEDs.) Power is provided by a single-cell Lithium-Ion Polymer battery.

Module details

Head-mounted device

Referring to the head-mounted SD schematic, we see several operational blocks.

IC3 is the MCU that has both a low power 32KHz clock XT1 and a high speed active clock X1. LED5 and LED6 are activity indicators for diagnostic purposes. IC1 provides additional SRAM storage capacity.

IC4 is the 3-axis accelerometer whose analog outputs are filtered through C27-C29 and are digitized by the ADC module on the MCU.

IC5 is the audio amplifier that takes the DAC outputs from the MCU and delivers a split rail voltage to the audio transducers SP1 and SP2 (the standard option is to have only one audio transducer in the head mounted SD).

IC2 is the 2.4GHz ISM transceiver that is used to generate the link to the Master Station. ANT1 is a dielectrically loaded antenna that is matched to the CC2500 by a bandpass filter comprised of L1-L3 and C1-C7.

Q1-Q4 are the IRLED driver switches that control the IRLEDs LED1-LED4 and generate position information for the IR CCD camera in sync with commands from the Master Station. L5-L7 are optional EMI filters for FCC compliance due to the extended reach to LED5-LED7. There are 4 IRLEDs for each side of the swimmer's head to compensate for head turns and orientation during different swim strokes.

IC6 is both a LiPo charger and a dual voltage regulator, supplying both 3.3VDC and the 2.0VDC for the IRLED circuits as necessary.

IC7 is a LiPo battery protection device that prevents excessive discharge and charge operations, as well as activating cutoffs in case of overcurrent. As a final stop, the system has a non-resettable fuse pair in case the regular protection circuitry is either damaged or a current path forms that bypasses the circuit.

Schematics

- Wrist/ankle SD
- Head SD

Data sheets

- MSP430 microcontroller
- ADXL330 3-axis accelerometer
- IDG-300 dual-axis gyro
- CC2500 2.4 GHz RF transceiver

Wearable devices include:

- a head-mounted device integrated into a custom swimming cap
- a limb-mounted device worn on wrist or ankle

Future developments/considerations

- means of acquiring accurate *heart rate*, *respirations*, *pulseOx*

Limb-mounted devices

For the arm and leg mounted SDs we can refer to limb-mounted SD schematic, and note that for the most part it is the same; however we get rid of the additional IRLEDs as well as the audio transducer. In their place, we have a gyroscope IC the gives us a 2D rotation. Given the current consumption, the placement of this device is experimental, and we may find that the accelerometer will give us enough information, thereby extending the battery life. A gyroscope for a 3rd rotation axis would deplete the battery at too high a rate given current technology.

Programming SDs from SwiftX

Launch %Projects/Performax/SD/Project.swx

F8 (INCLUDE build)

F9 (INCLUDE debug)

You should see flash erase, program, then GREET message and node #.

<node#> !ME .ME (program, verify)

DIE (force SD watchdog timeout)

Disconnect SD from programmer; you should immediately get

Can't read CPU state

Then, do

DISCONNECT TARGET

Repeat for each SD to program.

Audio support

The SDs support audio output. For the final product, this is to be used to deliver audio instructions from the coach to a swimmer. Currently, the SD's audio support is limited to playing three distinct tones:

1. "go": available to signal the start an event.
2. "yes": used to indicate successful execution or completion of an exercise.
3. "no": used to indicate unsuccessful execution of an exercise.

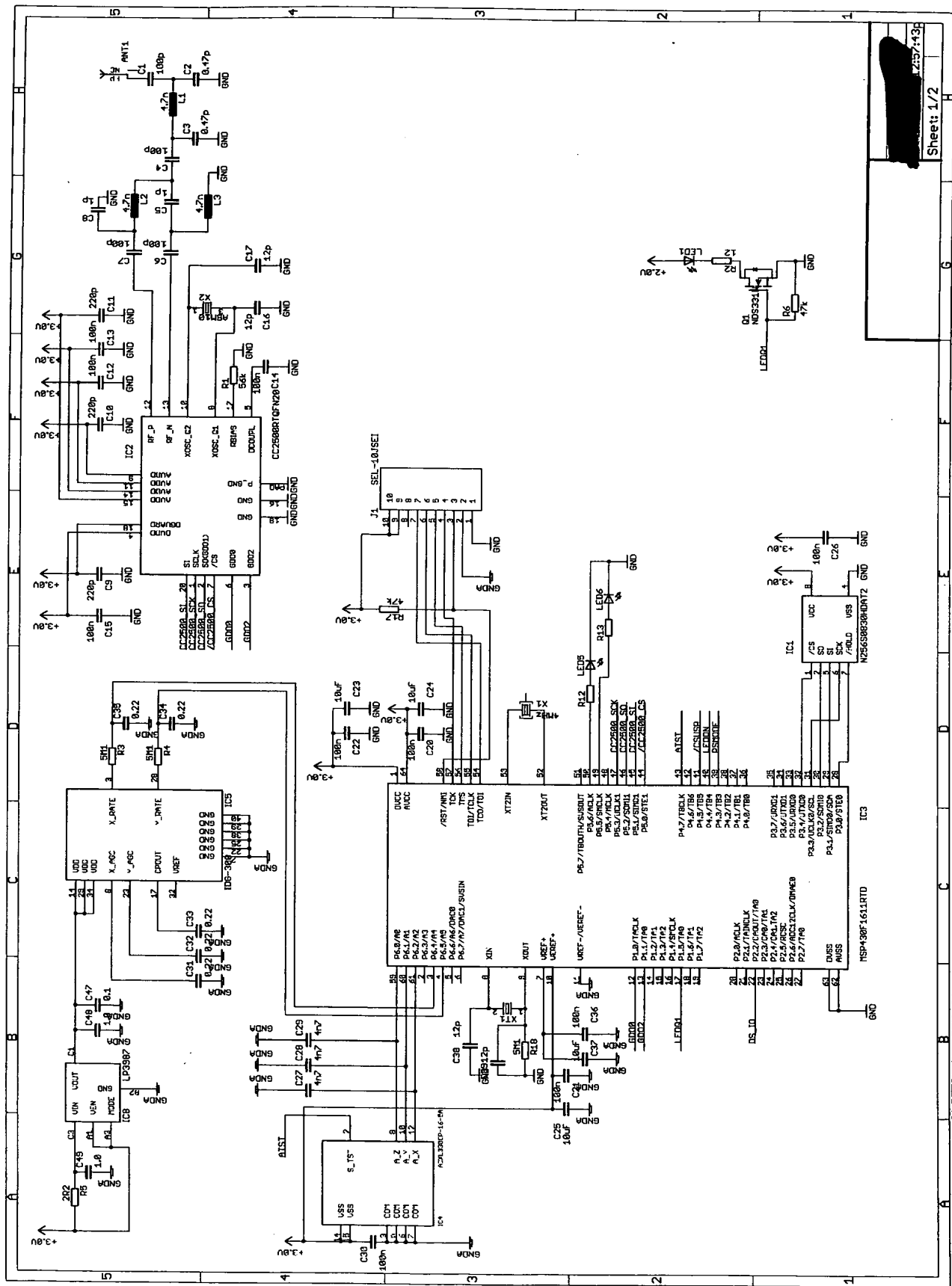
sfnet supports interactive triggering of these for testing purposes; see Manually send a tone to an SD for details.

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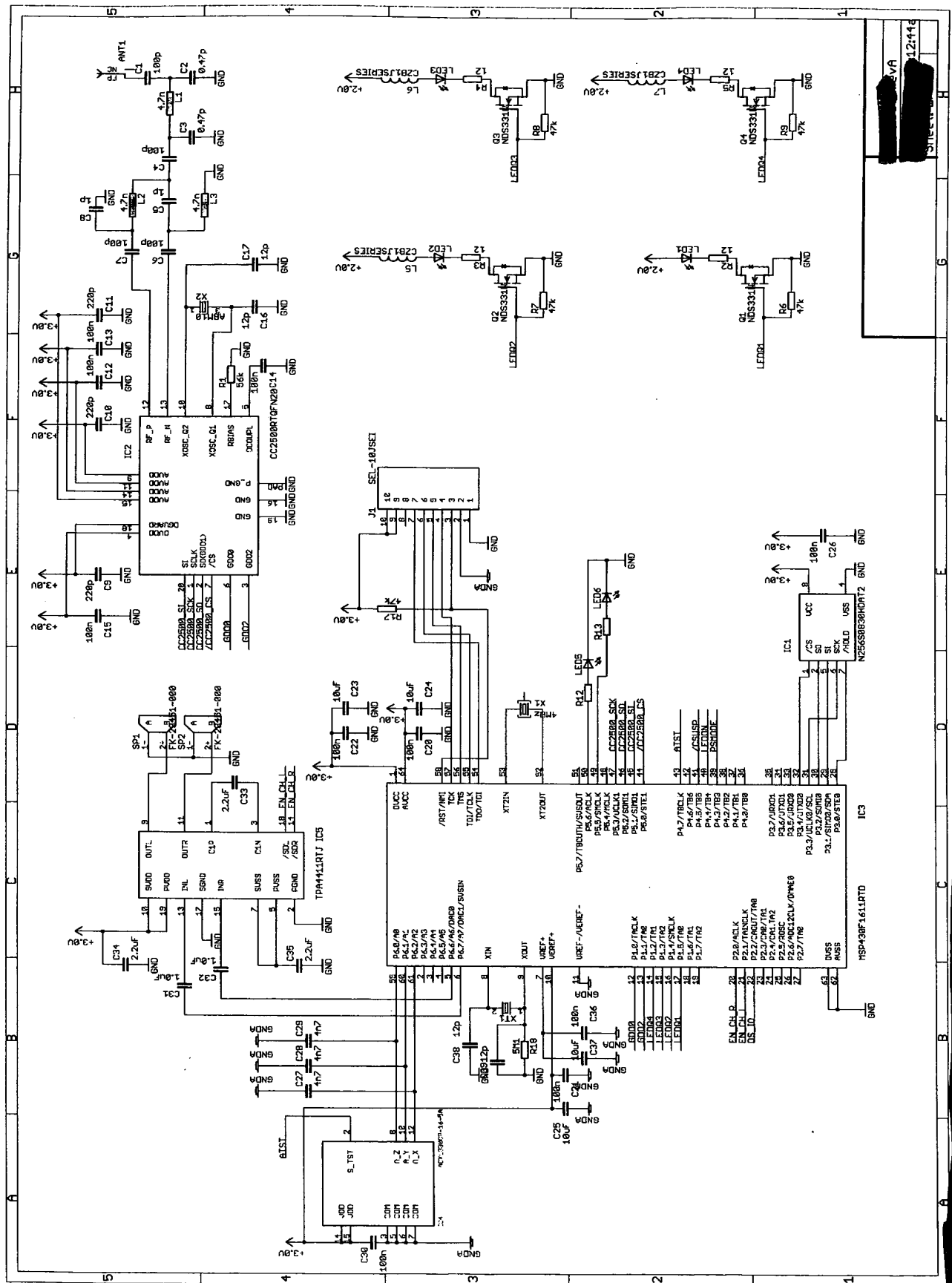
Recent Changes

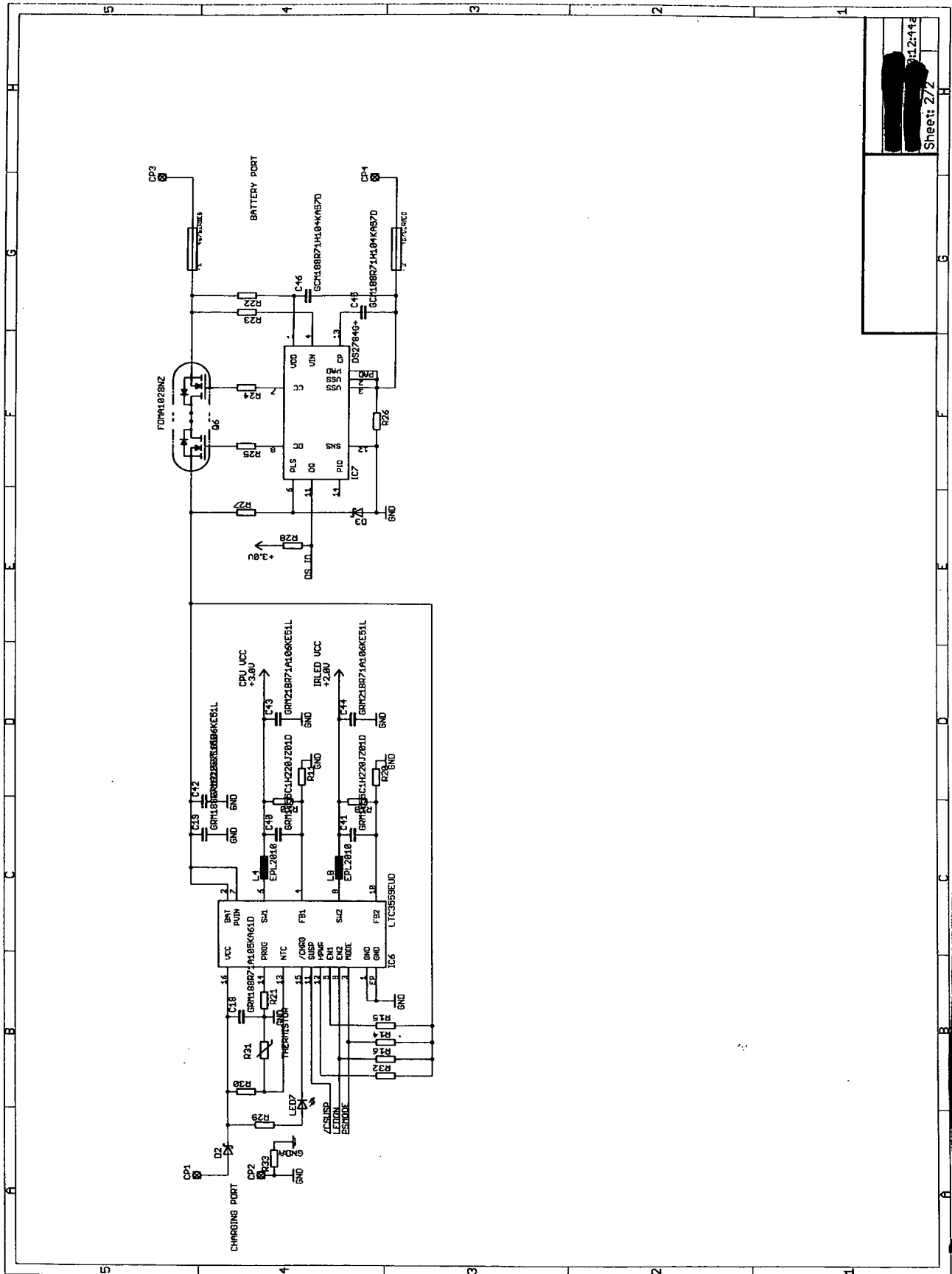
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2557435





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System Design

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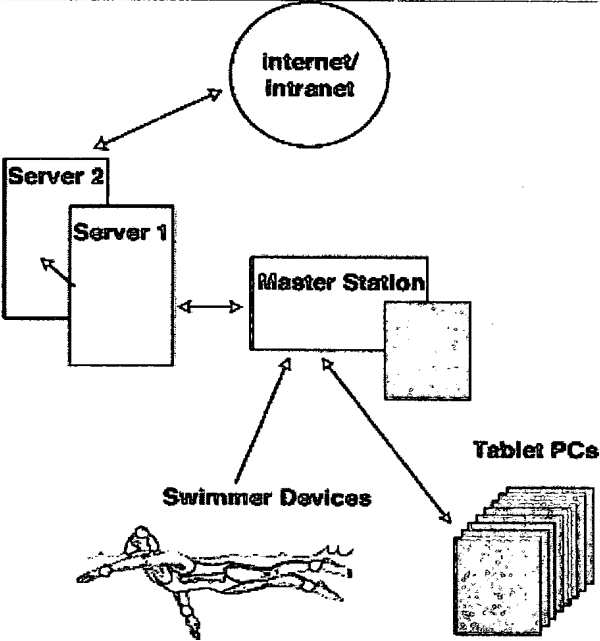
Go

Hardware

- Data Storage
 - Online storage for video, audio and data up to one year (one month for the alpha release)
 - Online storage of current athlete population's demographics
 - Offline storage/archive of all or selected (TBD) video, audio and data
- Master Station (1+)
 - High-performance PC (TBD)
 - Wide-aspect-ratio display
 - Full-functioned keyboard and mouse for data entry and maintenance tasks
 - Connection to server
 - A coach's tablet for use at this station and as a spare
- Coaches' tablets
 - Wireless connection to server #1
 - Removable or optional keyboard
 - Touchscreen display
 - Windows Tablet Edition
- Server 1 (AKA "Coach's Console," serving poolside))

This server does not accept external requests. It pushes to Server #2 the data required to serve external users.

- Hardware
 -
- Services
 -



- Server 2 (partial mirror serving internet/intranet requests)

This server never contains the primary data sources, adding a middle layer of security and off-loading from Server #1 the external requests for downloads and video file streams.

- Hardware
 -
- Services
 - secure connection (e.g., https) for entry and retrieval of a user's demographics, AKA "profile", and for password-username maintenance
- Swimmer Device
 - Swim cap
 - LED(s) -- multiple needed to capture head during all stroke types
 - on-board processors, etc.
 - integrated audio earpiece
 - accelerometer
 - power supply
 - Wrist & ankle devices
 - LED(s)
 - accelerometer
 - power source
- Cameras and mounting system
 - cameras (4)
 - lenses
 - mounting support system

Software

- Master Console(s)

The MC will be used for tasks that are, generally, more administrative than those performed on the poolside tablets. It may be stationed in a protected area of the pool deck but system design should allow it to be used from a separate office away from the pool area.

 - Web browser compliant with web standards to-be-specified.
 - Administrative functions presented in the form of a web application using the following technologies:
 - HTML
 - Javascript
- Server #1 (poss. incl. the MC, TBD) and Server #2
 - PHP 5.0+ (TBD)
 - Data files (e.g., CSV and XML files), video and system databases

- Streaming-video capable
- Coaches' tablets
 - Web browser that complies with the following:
 - HTML 4.0+
 - CSS 2.0+
 - Javascript enabled
 - Quicktime (TBD)
 - Flash Player v. 9.0+ browser plug-in
 - Windows Tablet Edition (including handwriting recognition)
 - Local data and initialization files (e.g., identifying the unit and its logged-in user, user preferences, etc.)
 - Audio encoding (via Flash TBD)
- Swimmer devices

Software approach

- Server #1
 - Serve requests to the tablet PCs and the Master Console, including multiple simultaneous video-audio-data streams.
 - Perform swimmer location, statistical analyses, etc, for as many as 100 SDs.
 - Accept multiple camera inputs and perform various transformations to the pool-wide video, with ability to correlate sync information for x cameras.
 - Provide access to all saved data for requests from poolside, performing video transforms as required to zoom in to any single swimmer or arbitrary, rectangular pool area.
 - Push content to Server #2 to service requests for downloads, etc.
- Server #2
 - This is a normal web server using open-source operating system software.
 - It should be able to serve multiple streaming video files and/or file downloads to support password-enforced requests.
 - It should have a robust method of supporting multi-user passwords, automated password recovery, etc., to minimize technical support requests to the coaching staff.
- Master Console
 - A browser-based interface will be presented using PHP on the server to access data files used to generate pages containing HTML and Javascript to be executed by the browser.
 - Client requests via form action to PHP provide data validation on both client and server sides before modifying data files on the server.
 - Ability to present a tablet view in the browser, with full tablet functions except those related to the touchscreen.
- Coaches' tablets
 - Flash applications will be used to perform many tablet tasks.

- Flash and any other content will be embedded in an HTML page for interaction using a standard web browser (Firefox 2.0 currently is our reference browser) or deployed via a standalone Flash Player.
- The Flash interface (or another method TBD) will provide a way to add audio notes to a recorded performance.
- Audible tones are generated (or replayed/assembled from stored recordings of such tones) and sent to the SDs in a way TBD.
- User requests via Flash an/or HTML forms will permit retrieval, entry and editing of certain data stored on Server #1.
- These units might not provide certain administrative and maintenance functions deemed easier to perform at the Master Console or requiring special admin login permissions.
- Swimmer Devices (SDs)
 -


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Master Station

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Background

The Master Station (MS) acts as the radio frequency (RF) link between the Ethernet based server network and the individual

Swimmer Devices (SDs). Powered by an 802.3af Power over Ethernet (PoE) capable switch or router, the device includes an embedded computer board, 2.4GHz industrial scientific medical (ISM) transceiver board, low noise amplifier/power amplifier (LNA/PA), RF filters, antenna, and the necessary RF switches and control circuitry to implement an effective 2.4GHz ISM band frequency agile transceiver.

Currently the MS is in a prototype stage, where many functions are performed by individual modules purchased through various vendors and integrated in one case with the antenna on the outside.

Schematics:

- Main board
- CPU board

Module Details

The embedded computer board (ECB) is a Freescale 52235EVB that has a PoE power option, MFC52235 Coldfire microcontroller (MCU), as well as various I/O and SPI ports. The MCU communicates with the server over the 802.3af connection, receiving commands and transmitting back the data received from the various SDs as well as other housekeeping data. The MCU communicates with the 2.4GHz ISM transceiver board using a standard Serial Peripheral Interface (SPI). The MCU also controls the RF switch configuration via general-purpose I/O (GPIO) pins so the RF transceiver is able to transmit and receive RF packets.

It is anticipated that in the final product these various modules will be merged into a single board.

The CC2500EVK board contains the CC2500 2.4GHz ISM RF transceiver that generates the 2.4GHz RF signals necessary to communicate with the SDs. The CC2500EVK receives its instructions from the MCU via the SPI bus pins, sending RF packets out through the RF switching, amplifier, and filter network to the antenna and on to the SD.

The output of the CC2500EVK goes into an RF switch network that is configured to allow either reception or transmission of RF through an RF amplifier that thus functions as either an LNA or a PA.

The RF amplifier is a low noise unit providing a gain of about 25dB, with a maximum output level of about 100mW for the transmit function.

The 100MHz filter prevents the LNA from being overloaded on receive by extraneous signals as its bandwidth is considerably greater than the 83.5MHz of the ISM band, and also attenuates out-of-band transmission harmonics of the CC2500.

The antenna is a circular polarization patch antenna, yielding a low profile, as well as a polarization diversity function to enable reception of SDs that are at various angles with respect to the MS.

Network interface

The MS provides a Forth interpreter via UDP port 5050. This is used by sfnet for all transactions. If sfnet is shut down, the MS may be connected to directly for interactive debugging. The netcat (nc) utility is useful for this. At Cranbrook, the master station is named ms0, so we can connect from the server (sigtyr) by

```
user@sigtyr:$ nc -u ms0 5050
```

Ctrl-C terminates nc.

In particular, ROLLCALL is useful during debugging. ROLLCALL queries all possible SDs and reports in the following format, one line per detected SD:

SD# firmware-signature charging (1|0)

Sample:

ROLLCALL

```
6 A116699B 1
10 9C14699B 1
12 9C14699B 1
14 7C136A9B 1
16 9C14699B 1
21 9C14699B 1
25 9C14699B 1
Ok
```

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Portable devices for on-deck use

Configuration

Portable devices for on-deck use

Configuration

http://www.forth.com/special/performax/wiki/index.php?n=Main.HandheldUnits

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- set the default font to Calibri. Under Preferences then Appearance then set standard font and set to Calibri.
- disable Java. Under Preferences then Security then Web content make sure Enable Java box is unchecked and that Enable JavaScript box is checked.
- accept cookies from sites you navigate to. Under Preferences then Security then Accept cookies check the box. Only from sites you navigate to.
- allow pop-up windows (we may test a dual-window UI option). Under Preferences then Security then Web content make sure Block pop-up windows box is unchecked.
- turn off anything related to RSS feeds, social networking sites, podcasts, etc. Under Preferences then RSS Automatically update articles in: make sure both Bookmarks bar and Bookmarks menu are unchecked. Check for updates- NEVER, Mark articles as read- after viewing the RSS page, Remove articles - NEVER
- do not store passwords or auto-fill forms.
- clear the browsing history regularly (e.g., Safari's "turn on private browsing"). Click Edit then Private browsing then turn on Private Browsing.
- Windows:
 - Vista, turn off horsepower-stealing transparency effects:
 1. Open Personalization by clicking the Start button, clicking Control Panel, clicking Appearance and Personalization, and then clicking Personalization.
 2. Click Window Color and Appearance
 3. deselect the "Enable transparency" box
 - set the desktop background to a solid color (med. pool-blue works well)
 - remove icons from the Start Menu except Firefox and the "Welcome Center" (how to operate a slate PC)
 - remove unneeded desktop shortcut icons, especially Internet Explorer -- the only shortcut strictly useful at this time is Firefox
 - run Windows update
- register one or more of the device's staff with user names (that are not required to be the same as their PerforMax username), passwords and fingerprint scans

Choices of hand-held PCs

Typically, the per-unit cost rises significantly if ruggedized units are desired or required. Ruggedized units could be part of an upgrade path. Listed here are some options and key considerations.

Slates - short list

"Slate" PCs do not have an integral keyboard. They might have on-screen keyboards and support external wireless or USB keyboards. Most, but not all, come with Windows Tablet Edition (Vista is said to incorporate Tablet Edition functions). One shown is a *wireless display only* perhaps better suited for end-of-lane displays with their own server.

Requirements:

- touchscreen ≥ 10" diagonal
- rated to withstand humidity of 90% or greater
- rated to withstand temperatures of 90 degrees or greater
- processing power to support multi-media-intensive scenarios
- wireless broadband

Desirable:

- ruggedized
- detachable/separate keyboard
- able to support multiple simultaneous video streams
- digitizing display for, e.g., handwriting recognition

Economical: If the users do not require these devices to be ruggedized for humidity, temperature and shocks, more models can be considered that are less costly, and may offer larger screens, less weight and more.

Feature comparison (including models not mentioned here)

- tablet-PC-specs.xls

Data sheets are linked next to item/images

Total cost of ownership

From the "Rugged PC Review" site :

TCO studies show that the failure rate of non-rugged devices is three to five times higher than that of rugged devices, and sometimes much worse. No equipment is ever totally immune to failure and warranty often covers the costs, but as anyone who has had to deal with warranty issues knows, the real cost of failure is downtime, possible loss of data, possible loss of business, impact on customer service, and so on. A \$500 repair may result in \$5,000 or \$50,000 in lost business. Add to that the fact that many vertical and industrial market companies do not have the large IT staffs large corporations have and there may be no one to handle smaller problems or quickly get things back to normal. So the seemingly lower price tag for deploying non-rugged computers can quickly look like a costly mistake after a Total Cost of Ownership analysis that takes failure rates and the cost of failures rates into account. And that's also before taking into consideration the usually substantially better and more personalized service that dedicated vertical market vendors provide compared to mass merchandisers.

Grouped By Ruggedness

Poolside units are in danger of sustaining *occasional* drops onto concrete, splashing, and *sustained* levels of relatively high humidity and ambient temperature. The test facility is fortunate to have no reported problems with condensation.

Off-the-shelf handheld devices can be obtained that withstand repeated drops of several feet onto steel or concrete, and that can be immersed in up to 3' of water. However, the cost of handheld devices rises with the degree of ruggedness designed into them.

Therefore, the choice of which handheld device to adopt may be facility dependent, based on the environment, users' preferences and the facility's budget. It will be good to inform customers of the total-cost-of-ownership issues (see inset) and allow them to choose from fully ruggedized, semi-rugged and standard/durable options.

Rugged and Semi-rugged

Constraints: If we reduce the list of candidate machines in the attached Excel spreadsheet to those that...

- a. have *displays 10" diagonal or larger*, and
- b. are *ruggedized, and to 90% or greater humidity*

...the initial starting list in the attached spreadsheet is reduced to these:

■ EXPLORE IX104 C4

~~*Xplore - iX104 C3 Rugged iX104C3DV~~
data sheet: ~~Xplore-ix104c3-specs.pdf~~

price: \$3845.00

review: Xplore - iX104 C4 Rugged iX104C3DV (data about this new model is not in the attached spreadsheet)

maker's product page: <http://www.xploretech.com/index.pl?id=3466&isa=Category&op=show>

specs: Xplore-iX104_C4.pdf



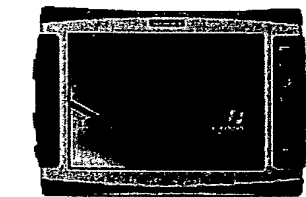
■ MARS 3100R

price: \$3350.00

review: http://www.ruggedpcpreview.com/3_slates_advantech_3100r.html

maker's product page: Advantech - MARS 3100R

data sheet: Advantech_MARS-3100R_DS.pdf

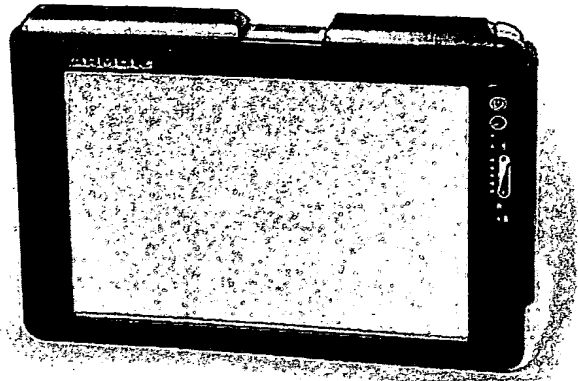


■ DRS ARMOR X10

price: \$Unknown

review: http://www.ruggedpcpreview.com/3_slates_drs_armor_x10.html

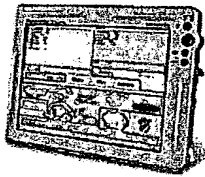
maker's product page: DRS ARMOR X10
data sheet: DRS_ARMOR_X10



End-of-Lane Devices (not for alpha)

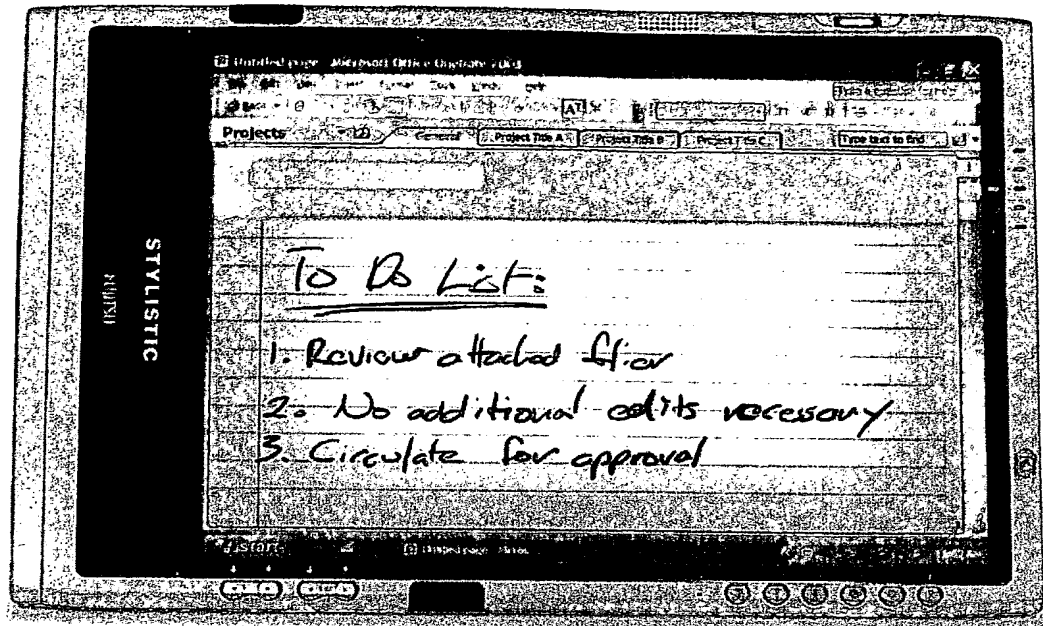
The exact requirements of these devices are yet to be determined. They must be able to withstand splashing on their own or within some enclosure that leaves their controls/touchscreen accessible. They will be placed on deck within easy sight of a near-end-of-lane swimmer and possibly within reach of a swimmer at the wall.

- **Panasonic (CF08)** (requires a server that can support multiple displays)
Panasonic (CF08) Toughbook **Wireless Display** data sheet: Toughbook-WD.pdf
This "wireless display" approach requires either a PC for each handheld unit, or a server capable of supporting up to ~9 of these units at once.
But very light weight.



"Durable" and "Standard"

- **Fujitsu Stylistic ST5111 and ST5112 Tablet PC**
requires active pen, no passive touchscreen
price: \$2,719
review of 5100 series: http://www.ruggedpcreview.com/3_slates_fujitsu_st5100.html
maker's product page: <http://store.shopfujitsu.com/fpc/Ecommerce/buildseriesbean.do?series=ST5100&ptype=TB>
data sheet: Fujitsu-ST-5111.pdf (combined specs for 5111 and 5112)



▣ **Electrovaya Scribbler SG-4000**

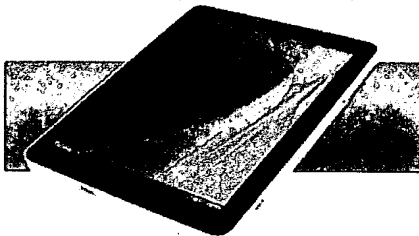
requires active pen, no passive touchscreen

price: from \$2,049

review: http://www.ruggedpcreview.com/3_slates_electrovaya_sc4000.html

maker's product page: <http://www.electrovaya.com/products/scribbler/models/Scribbler4000.aspx>

data sheet: [Electrovaya_Scribbler_4000.pdf](#)

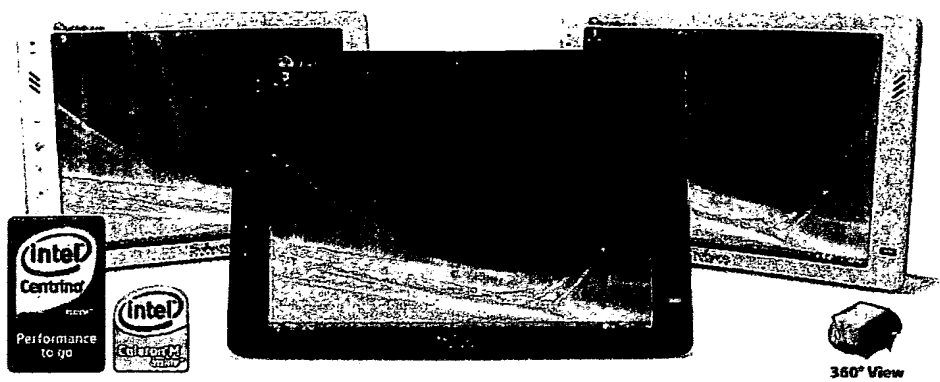


▣ **TabletKiosk's Sahara Slate i440D**

price: \$2,099

review (of earlier model): http://www.ruggedpcreview.com/3_slates_sahara_tuftab_i310xt.html

maker's product page: http://www.tabletkiosk.com/products/sahara/i440s_pp.asp



360° View

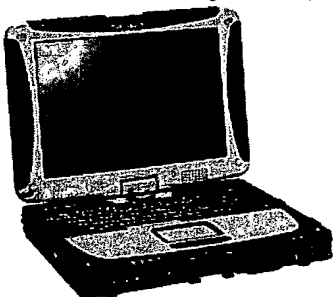
▪ **Motion Computing**
Some promising models, but all require pen-based input, no passive touchscreen.

maker's site: <http://www.motioncomputing.com/products/index.asp>

Convertibles

"Convertibles" have an integral keyboard that pivots out of the way to allow tablet-style operation via touchscreen and/or digitizer. At this time, we are not specifying one of these for this project, in favor of the lighter weight, smaller size and less fumbling anticipate with slate models. Following is an example of a "convertible" model for reference:

▪ **Panasonic - Toughbook 19 Tablet**
data sheet: [Panasonic-Toughbook-19.pdf](#)



**Panasonic recommends
Windows Vista™ Business**

See also: Former candidates

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System Databases

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Database Structures

Databases are created in MySQL to support fundamental PerforMax operations. This section describes the database structures that have been defined.

The monolithic database is named for the facility where the system is installed; in this case, it is named "cranbrook". It contains a number of individual tables:

mysql> show tables;

Tables_in_cranbrook
SDassignments
countries
users
usersArchived
usersOnDeck

5 rows in set (0.00 sec)

"SDassignments" is used by lower-level system functions to know which user is associated with up to five swimmer devices.

The "countries" table may be used for localization purposes.

"users" is the repository of users' log-in and demographic information (aka "user profile"), and is where the current user's unique user ID is correlated to their identity and other personal information (see below for the table's structure).

The "usersArchived" table has the same structure as the "users" table, shown below:

System Users (registrants)

mysql> describe users;

Field	Type	Null	Key	Default	Extra
id	int(11)	NO	UNI	NULL	auto_increment
uuid	varchar(8)	NO	PRI	00000000	
login	varchar(25)	NO	UNI		
pw	varchar(32)	NO			
lastname	varchar(32)	NO			
firstname	varchar(32)	NO			
middlename	varchar(32)	NO			
birthyear	int(4)	NO		0	
birthmonth	tinyint(2)	NO		0	
birthday	tinyint(2)	NO		0	
gender	enum('male','female','NA')	NO		NA	
height	decimal(5,2)	NO		0.00	
weight	decimal(5,2)	NO		0.00	
athleteClass	varchar(30)	NO			

http://www.forth.com/special/performax/wiki/index.php?n=Main.SystemDatabases

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Installation

The following steps are for setting up the Performax MySql database on a clean system. This assumes the middleware is installed on the same machine as the database.

Install MySql - this requires the root password for the machine

```
sudo apt-get install mysql-server
```

Check out the file db.sql from cvs. The location is: Projects/Performax/middleware/db/db.sql. Execute the script in in mysql to generate the database.

```
mysql -uroot -p mysql < db.sql
```

Remote Access

If the middleware is installed on a separate machine, the configuration must be changed as follows to enable remote access.

Edit the config file...

```
sudo vi /etc/mysql/my.cnf
```

...and comment out the bind-address line like so...

```
# bind-address = 127.0.0.1
```

...then restart the server.

```
/etc/init.d/mysql restart
```

Follow the same steps above for creating the user, tables and indexes; except use the middleware hostname in place of localhost for the GRANT command.

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Swimmer Devices

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Background

The swimmer device (SD) is a portable data collection module with local memory storage and an RF transceiver for command/data downloads/uploads. There are two versions of the device; the one used for head mounting has connections for audio transducers for an earpiece and multiple infrared light emitting diodes (IRLEDs.) Power is provided by a single-cell Lithium-Ion Polymer battery.

Module details

Head-mounted device

Referring to the head-mounted SD schematic, we see several operational blocks.

IC3 is the MCU that has both a low power 32KHz clock XT1 and a high speed active clock X1. LED5 and LED6 are activity indicators for diagnostic purposes. IC1 provides additional SRAM storage capacity.

IC4 is the 3-axis accelerometer whose analog outputs are filtered through C27-C29 and are digitized by the ADC module on the MCU.

IC5 is the audio amplifier that takes the DAC outputs from the MCU and delivers a split rail voltage to the audio transducers SP1 and SP2 (the standard option is to have only one audio transducer in the head mounted SD.

IC2 is the 2.4GHz ISM transceiver that is used to generate the link to the Master Station. ANT1 is a dielectrically loaded antenna that is matched to the CC2500 by a bandpass filter comprised of L1-L3 and C1-C7.

Q1-Q4 are the IRLED driver switches that control the IRLEDs LED1-LED4 and generate position information for the IR CCD camera in sync with commands from the Master Station. L5-L7 are optional EMI filters for FCC compliance due to the extended reach to LED5-LED7. There are 4 IRLEDs for each side of the swimmer's head to compensate for head turns and orientation during different swim strokes.

Schematics

- Wrist/ankle SD
- Head SD

Data sheets

- MSP430 microcontroller
- ADXL330 3-axis accelerometer
- IDG-300 dual-axis gyro
- CC2500 2.4 GHz RF transceiver

Wearable devices include:

- a head-mounted device integrated into a custom swimming cap
- a limb-mounted device worn on wrist or ankle

Future developments/considerations

- means of acquiring accurate *heart rate*, *respirations*, *pulseOx*

IC6 is both a LiPo charger and a dual voltage regulator, supplying both 3.3VDC and the 2.0VDC for the IRLED circuits as necessary.

IC7 is a LiPo battery protection device that prevents excessive discharge and charge operations, as well as activating cutoffs in case of overcurrent. As a final stop, the system has a non-resettable fuse pair in case the regular protection circuitry is either damaged or a current path forms that bypasses the circuit.

Limb-mounted devices

For the arm and leg mounted SDs we can refer to limb-mounted SD schematic, and note that for the most part it is the same; however we get rid of the additional IRLEDs as well as the audio transducer. In their place, we have a gyroscope IC that gives us a 2D rotation. Given the current consumption, the placement of this device is experimental, and we may find that the accelerometer will give us enough information, thereby extending the battery life. A gyroscope for a 3rd rotation axis would deplete the battery at too high a rate given current technology.

Programming SDs from SwiftX

Launch %Projects/Performax/SD/Project.swx

F8 (INCLUDE build)

F9 (INCLUDE debug)

You should see flash erase, program, then GREET message and node #.

```
<node#> !ME .ME ( program, verify)
```

DIE (force SD watchdog timeout)

Disconnect SD from programmer; you should immediately get

Can't read CPU state

Then, do

DISCONNECT TARGET

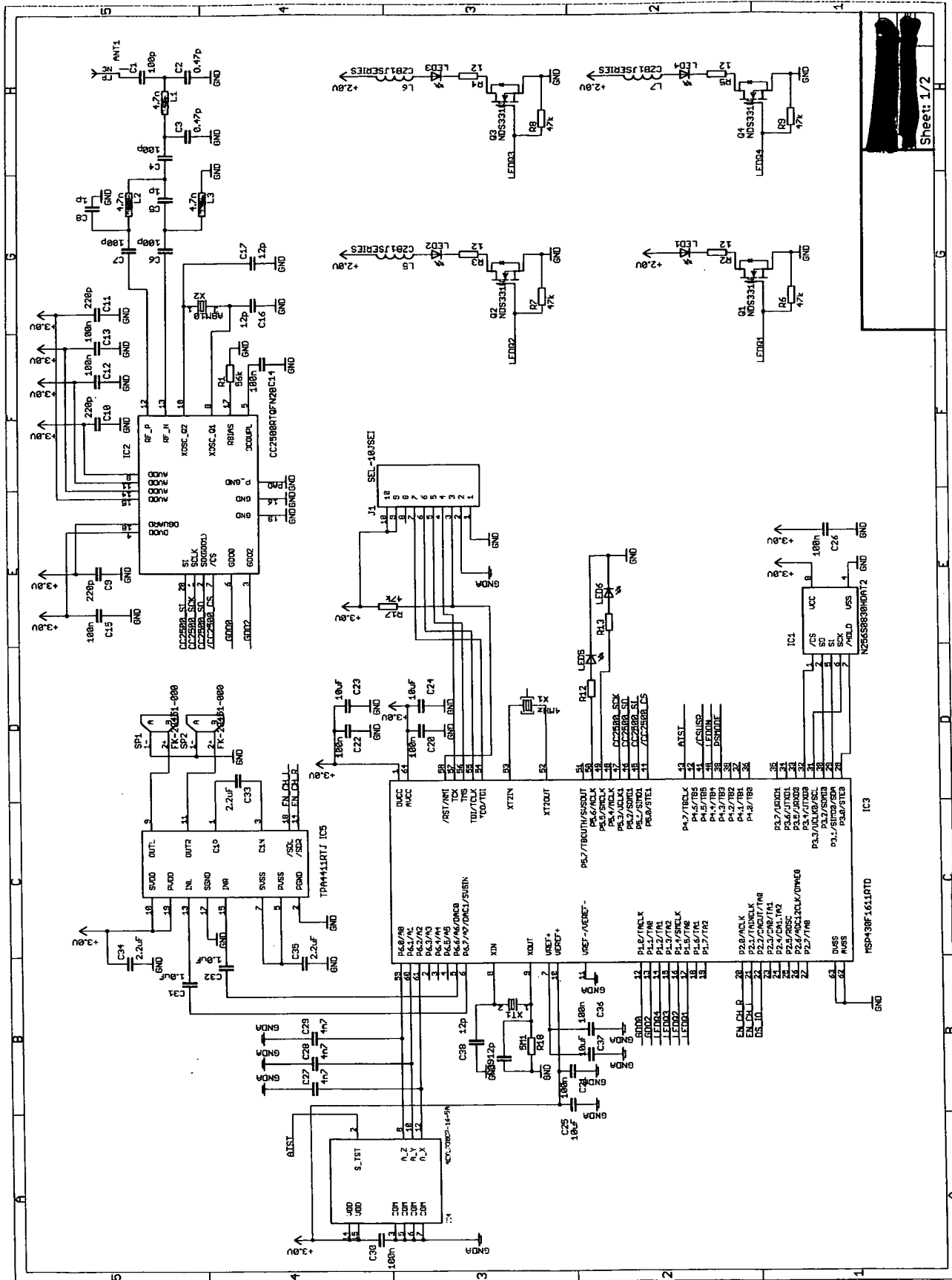
Repeat for each SD to program.

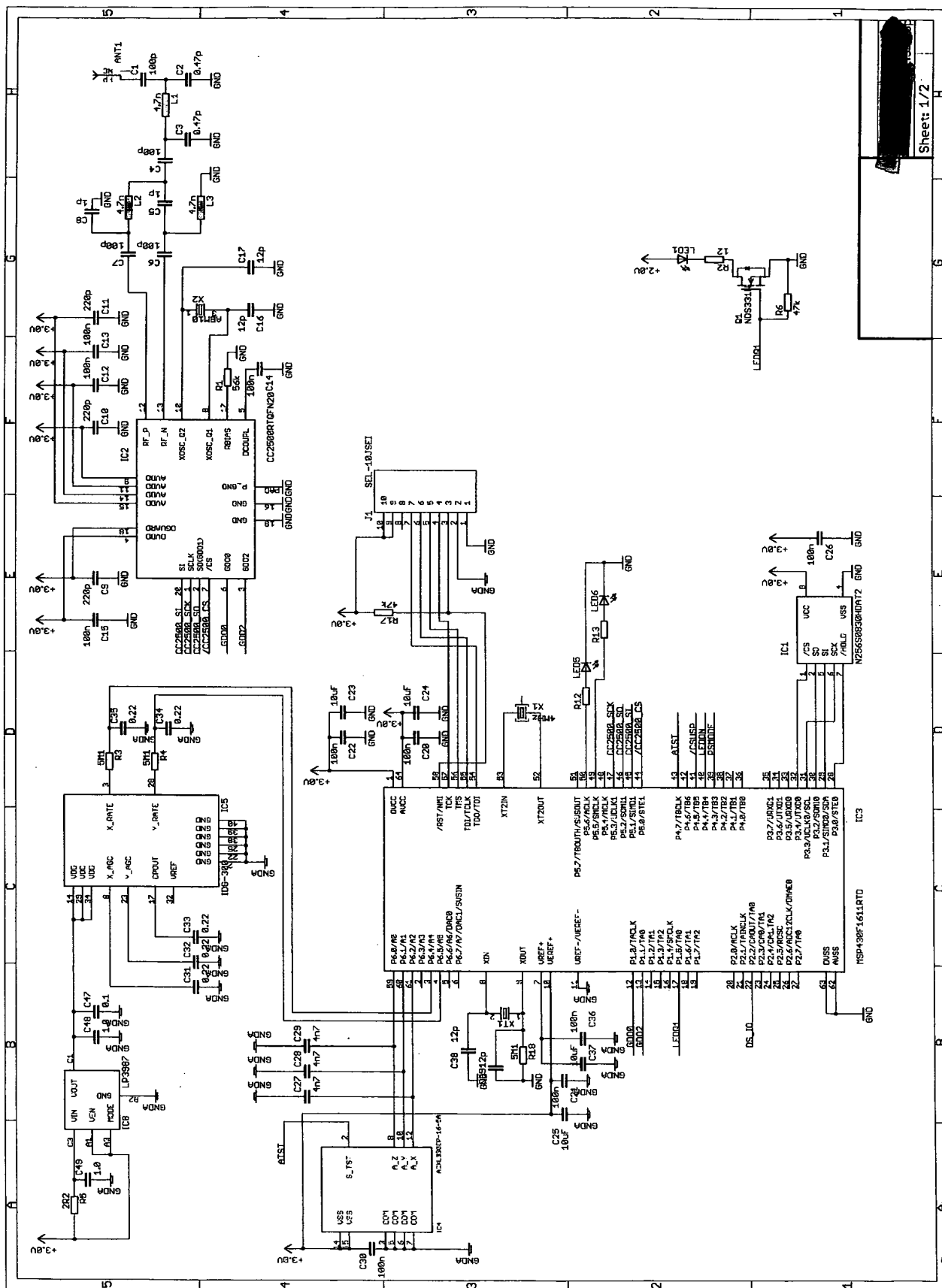
Audio support

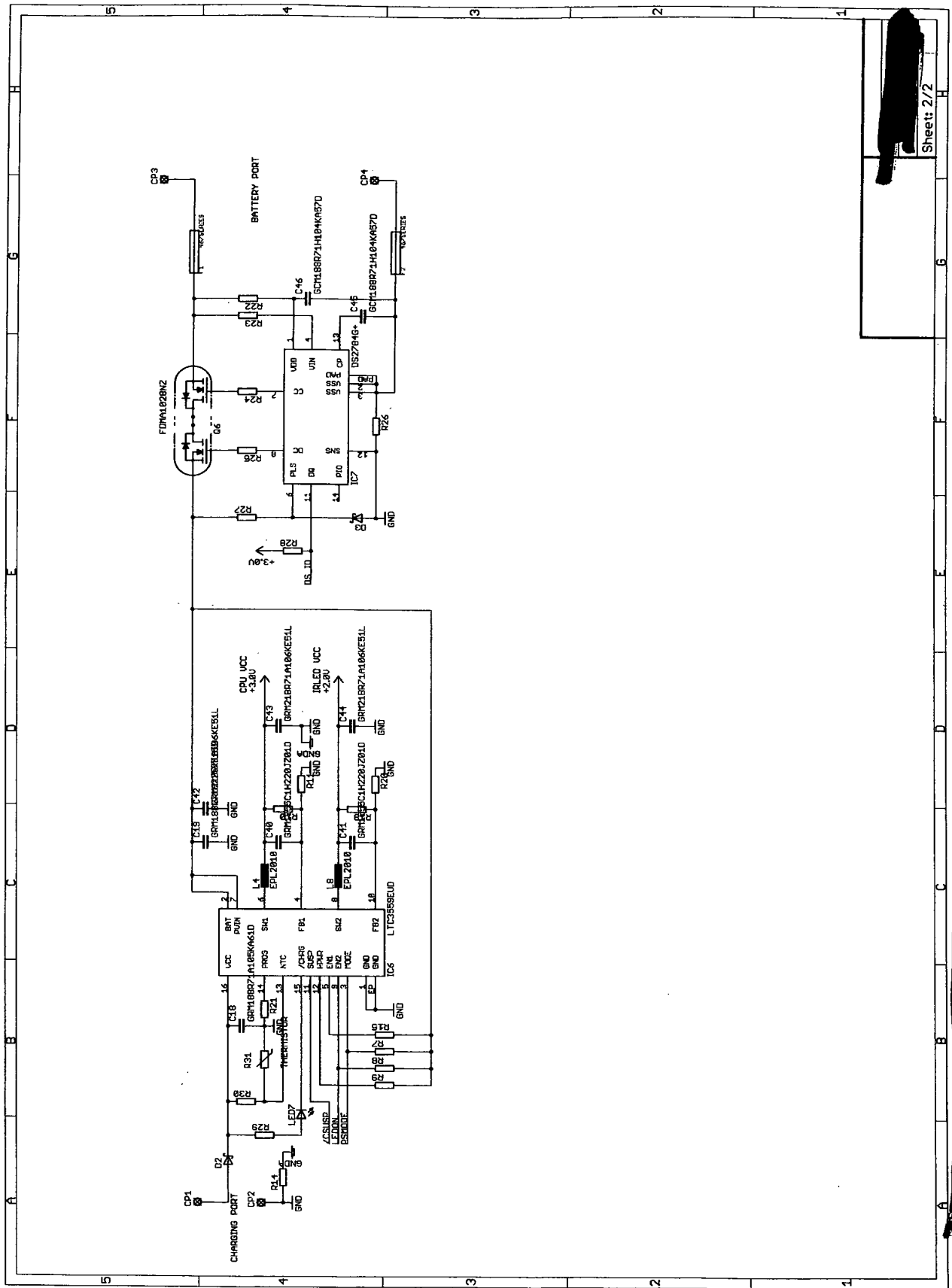
The SDs support audio output. For the final product, this is to be used to deliver audio instructions from the coach to a swimmer. Currently, the SD's audio support is limited to playing three distinct tones:

1. "go": available to signal the start an event.
2. "yes": used to indicate successful execution or completion of an exercise.
3. "no": used to indicate unsuccessful execution of an exercise.

sfnet supports interactive triggering of these for testing purposes; see Manually send a tone to an SD







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Sfnet

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sfnet

Overview

"sfnet" (name subject to change as we think of a better one) is the SwiftForth application that runs on the server. Currently, it is responsible for all interaction with the Master Station (MS) and and the locator. It polls the MS and receives telemetry from it, and also receives locator information from the locator.

Building the sfnet application

Currently, turnkey generation isn't working properly. When fixed, this is how it's done:

From directory %Projects/Performax/sfnet:

```
user@sigtyr:~$ sf
SwiftForth i386-Linux 3.1.9f 03-Dec-2008
INCLUDE build ok ( F8 also does this)
STARTER GO ok
PROGRAM sfnet ok
BYE
```

This builds the sfnet executable in the current directory.

Interactive work with sfnet application

It's sometimes useful during development to start up pieces of the sfnet application, instead of the entire application. The examples below all start in the same fashion:

```
user@sigtyr:~$ sf
SwiftForth i386-Linux 3.1.9f 03-Dec-2008
INCLUDE build ok ( F8 also does this)
INIT ( This is normally done by GO)
```

Poll a single SD manually

```
<SD#> FLAM
```

Manually send a tone to an SD

```
<tone#> <SD#> BEEP where <tone#> is
```

1. "go" tone
2. "yes" tone
3. "no" tone

Telemetry/locator record format

For ease of parsing and insertion into the database, a unified record format is used to encode SD telemetry and locator information. A record will either have telemetry or location, but not both.

Sample:

```
6,12/10/2008,22:09:58,1228946998905,FALSE,,,,TRUE,21,827,1001,,,,,,,,
```

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Unique User ID

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Permanent, unique user ID (UUID) for each registrant

Design of certain aspects of the user interface is simplified, certain tasks may be more efficient, and the possibility of negative-impact name collisions is greatly reduced, by assigning a permanent "unique ID" to each person (athlete and staff) registered in the system.

Qualities of this unique ID *as it is being used in the prototype UI* are:

▣ It is an 8-character ASCII string.

▣ It begins with a three-letter alphabetical prefix unique to the facility in which the system is installed. For our prototyping, the facility code is CBK (for "Cranbrook"). This code is helpful for future systems that will be able to compare stats between systems installed in different facilities.

▣ Assigning a unique facility code will be a configuration task when installing new systems.

▣ The remaining 5 digits are a simple numeric counter (starting at 00000).

▣ The numeric portion is always incremented, so retired IDs are *not* reassigned; and it is padded with leading zeroes to provide a full-length unique ID. (By not re-using IDs, we are facilitating future ability to view/replay/compare performances of matriculated athletes without ID collision.)

▣ This ID will likely never be seen by the end user, probably not even by coaching staff.

▣ The ID shall remain free of characters that would prevent its use in directory and file names, in PHP variables, Javascript and as an ID for XHTML 1.0 elements.

Elements rejected from use in the unique ID include:

▣ year of birth (may be edited by user, e.g., to repair bad data entry)

▣ last name (although human-readable, it's verbose and can change due to family changes, marital status, editing, etc.)

▣ year of registration into the system (no correlation to other useful data)

▣ projected year of graduation (can change)

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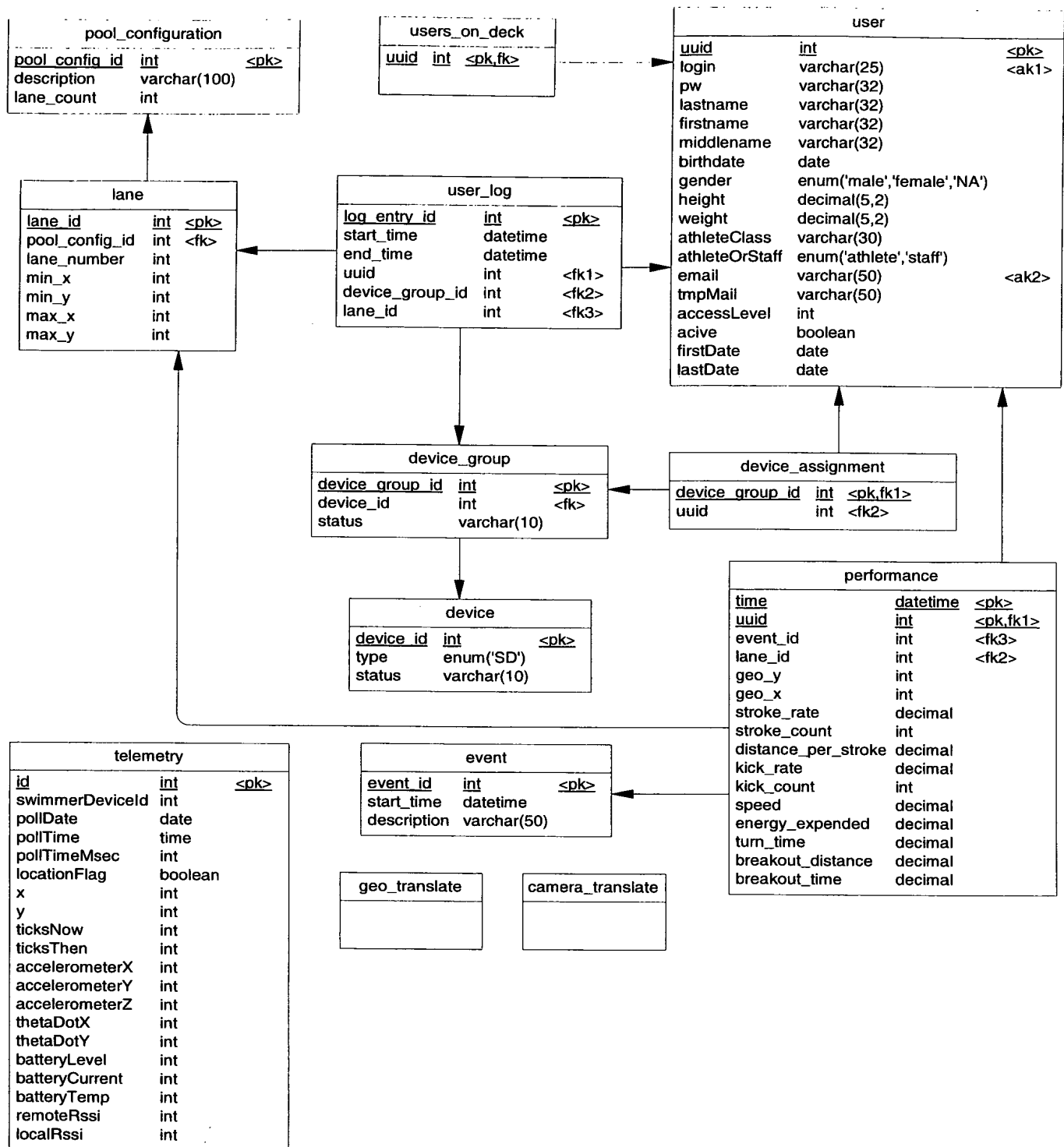
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- Overview of swimmer locator system
- Locator sequence of events

Overview of swimmer locator system

The swimmer locator system uses cameras and image analysis software to detect the infrared light emitting diodes (IRLEDs) that are part of the head-mounted Swimmer Device (SD). The IRLEDs are illuminated on a per-swimmer basis by commands from the Master Station (MS). When the MS receives a reply from the SD (coincident with the SD turning on its IRLED), the cameras are triggered by the MS. Each camera snaps an image of its respective pool region. The Location Computer (LC) acquires the images from the cameras and determines the location of the illuminated IRLED by analyzing the images.

IRLEDs were chosen because they produce light that is visible by the cameras, yet is generally not visible to the naked eye. IR bandpass filters are used in front of the camera lenses to eliminate most other light.

turbulence in the water actually helps us detect the SDs by diffusing other light sources (sunlight in particular).

The cameras currently used for the locator are monochrome JAI CM-140GE . The CM-140GE is a monochrome progressive scan camera with 1.4 million pixels resolution and GigE Vision interface.

Locator sequence of events

1. Server commands MS to poll a particular head-mounted SD and activate its IRLED.
2. SD replies to MS with currently available telemetry data.
3. On completion of transmission of telemetry data, SD turns on IRLED.
4. On completion of reception of SD reply (coincident with IRLED on), MS sends trigger pulse to cameras.
5. LC acquires images from cameras and determines SD location
6. LC reports location to server via TCP connection.

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Master Station

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- ☐ Background
- ☐ Module Details
- ☐ Network interface

Background

The Master Station (MS) acts as the radio frequency (RF) link between the Ethernet based server network and the individual

Swimmer Devices (SDs). Powered by an 802.3af Power over Ethernet (PoE) capable switch or router, the device includes an embedded computer board, 2.4GHz industrial scientific medical (ISM) transceiver board, low noise amplifier/power amplifier (LNA/PA), RF filters, antenna, and the necessary RF switches and control circuitry to implement an effective 2.4GHz ISM band frequency agile transceiver.

Schematics:

- ☐ Main board
- ☐ CPU board

Currently the MS is in a prototype stage, where many functions are performed by individual modules purchased through various vendors and integrated in one case with the antenna on the outside.

Module Details

The embedded computer board (ECB) is a Freescale 52235EVB that has a PoE power option, MFC52235 Coldfire microcontroller (MCU), as well as various I/O and SPI ports. The MCU communicates with the server over the 802.3af connection, receiving commands and transmitting back the data received from the various SDs as well as other housekeeping data. The MCU communicates with the 2.4GHz ISM transceiver board using a standard Serial Peripheral Interface (SPI). The MCU also controls the RF switch configuration via general-purpose I/O(GPIO) pins so the RF transceiver is able to transmit and receive RF packets.

It is anticipated that in the final product these various modules will be merged into a single board.

The CC2500EVK board contains the CC2500 2.4GHz ISM RF transceiver that generates the 2.4GHz RF signals necessary to communicate with the SDs. The CC2500EVK receives its instructions from the MCU via the SPI bus pins, sending RF packets out through the RF switching, amplifier, and filter network to the antenna and on to the SD

The output of the CC2500EVK goes into an RF switch network that is configured to allow either reception or transmission of RF through an RF amplifier that thus functions as either an LNA or a PA.

The RF amplifier is a low noise unit providing a gain of about 25dB, with a maximum output level of about 100mW for the transmit function.

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The 100MHz filter prevents the LNA from being overloaded on receive by extraneous signals as its bandwidth is considerably greater than the 83.5MHz of the ISM band, and also attenuates out-of-band transmission harmonics of the CC2500.

The antenna is a circular polarization patch antenna, yielding a low profile, as well as a polarization diversity function to enable reception of SDs that are at various angles with respect to the MS.

Network interface

The MS provides a Forth interpreter via UDP port 5050. This is used by sfnet for all transactions. If sfnet is shut down, the MS may be connected to directly for interactive debugging. The netcat (`nc`) utility is useful for this. At Cranbrook, the master station is named `ms0`, so we can connect from the server (`sigtyr`) by

```
user@sigtyr:~$ nc -u ms0 5050
```

Ctrl-C terminates `nc`.

In particular, `ROLLCALL` is useful during debugging. `ROLLCALL` queries all possible SDs and reports in the following format, one line per detected SD:

SD# firmware-signature charging (1|0)

Sample:

```
ROLLCALL
```

```
6 A116699B 1
10 9C14699B 1
12 9C14699B 1
14 7C136A9B 1
16 9C14699B 1
21 9C14699B 1
25 9C14699B 1
ok
```

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Biomechanics & forces measurement

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Also see: performance metrics

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Information on axis definitions for the SDs as mounted on the swimmer for the September 2008 in-pool tests. For the following description, picture the swimmer as standing with arms at their side, palms facing inward, feet parallel.

Each accelerometer has three axes, each of which has a bias voltage of approximately 1.65VDC (Vdd/2) in this design. The voltage changes from this bias point depending on the acceleration vector; increasing the voltage by approximately 300mV/g along the pointing direction, decreasing if the vector is in the opposite direction.

Each gyroscopic sensor has orthogonal axes or rotation through the body of the sensor, there is no 'Z-axis' from the top of the sensor. The output voltage is not ratiometric, unlike the accelerometer data, but has a nominal bias of 1.5VDC with a sensitivity of about 2mV/degree/sec.

Head SDs were mounted at the crown of the head with no particular angle requirements aside from IRLED visibility (bilateral symmetry was not measured, but was close). The orientation is such that the accelerometer is "upside down" with respect to the earth, so that A(z) is pointing nominally "down" through the face, A(x) is pointing "back" along (but at an angle) the body axis, and A(y) is pointing to the "left". Head SDs do not have gyroscopic sensors.

Arm (limb) SDs were mounted on the inside of the wrist, with the Z-axis pointing through the arm (normal to the arm surface), A(x) pointing down to the fingertips, and A(y) pointing to back on the left arm and the front on right arm mounting point. The gyroscope sensor is mounted such that the dotX axis is along the length of the arm, and positive with a clockwise rotation when looking down at the arm. The dotY axis is orthogonal to the dotX axis and biomechanically may not be very active due to the positioning of the sensor, with a positive offset for a clockwise spin from the swimmers' perspective.

Leg (limb) SDs were mounted on the inside of the legs, above the ankle in the same orientation as the arm SDs; with the Z-axis pointing through the leg (normal to the leg surface), A(x) pointing down to the foot, and A(y) pointing to back on the left leg and the front on right leg mounting point. The gyroscope sensor is mounted such that the dotX axis is along the length of the leg, and positive with a clockwise rotation when looking down at the leg. The dotY axis is orthogonal to the dotX axis, with a positive offset for a clockwise spin from the swimmers' perspective.

Whereas the behavior of the accelerometer is relatively well known, the gyroscopic sensor data may be affected by the fact that the chip is not necessarily moving through it's center of mass, and they are considered experimental at this point.

One of the goals of these tests is to determine if we need additional information by adding 'redundant'

http://www.forth.com/special/performax/wiki/index.php?n=Main.Biomechanics

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axes to the SDs. The physical design would lend itself relatively well to this, but at an added equipment expense. The gyrosopic sensor in particular may benefit from a repositioning to be placed directly at the wrist and ankle joint, but swimmer comfort must be taken into account.

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Performance Metrics

Breadcrumbs: Main/MasterStation > Main/HomePage > Main/Biomechanics > Main/OtherSystems > Main/PerformanceMetrics

On this page... (hide)

Mechanical technique

Performance

Swimmer physiology

Also see: other systems, especially detailed information from the Estonia web site.

Mechanical technique

Consistent *rate and force of stroke cycle and kicks* for each event type.

Comparison of force exerted by right-left arms and legs.

Full range of stroke motion — fully extend arm forward, also involving shoulder reach; pull until arm is fully extended back towards hips, involving shoulder in the same direction.

Nearness of hip to wall during turns -- i.e., too close means legs flex at knees too much (e.g., femur-tibia angle less than 90 degrees) and thereby lose power on the push, or they flex too little (hips too far away) to achieve good thrust. We can use swimmer height and a forensic table of average proportions (or detailed swimmer measurements) to derive the length of femur and tibia. The ratios may vary for men/women, race and approx. age (pre-pubescent, peri-pubescent and post-pubescent). Without a hip-to-wall measure or knee-flexion angle, how can the coach know whether turn-time is influenced more by (a) overall swimmer strength, (b) streamlining, (c) stroke power or (d) leg thrust?

Performance

Finish time (without a touchpad in pool) = last touch of wall or next-to-last touch (i.e., when the leading arm stops even though the trailing arm is still in motion).

Finish strokes (also pre-turn strokes) — the number of strokes taken after crossing the 5-yard line before touching the wall.

Stroke count (per lap and avg. per lap for an event/exercise)

current & avg. speed, and target speed

lap/yards counter

Turn times are measured differently depending on the type of stroke used. Butterfly: from first finger touch to last foot push-off. Freestyle & Backstroke: from first crossing of the 5-yard marker toward

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wall to next crossing away from wall (of what body part?). Therefore, turn times should be associated with the type of stroke/stroke transition. Also accommodate medley events, wherein one stroke is employed moving toward the wall and a different stroke after the turn.

Swimmer physiology

- *Heart rate is highly desirable*; Scott's research suggests the only reasonably accurate place to measure is over the heart. His sources say other places on the body are too subject to distortion (although I'd suggest the femoral artery would be a candidate, strap on high inner thigh).
- *Respirations might be obtainable* via a chest strap, but will need to distinguish respirations from rib cage expansion due to stroking-involved muscles (e.g., lats expand outward, chest and back may expand).
- *Lactate levels* — (see link below) assumed not directly measurable non-invasively; but see web link below and also check for other ways to infer/deduce this. It's generally considered an important factor for which specific exercises are used to reduce muscle-recovery times. An indirect measure (probably also invasive) would be the lactase levels (the enzyme lactate dehydrogenase) or cellular pH (which decreases with lactic acid build-up).

For web info related to non-invasive measurement of lactate, including one specific to young swimmers and at least one that discussed such measurement via transdermal means, try this Google search

For a minority, alternative view of lactate (e.g., "it's not the enemy"), see this trainer's perspective

- *PulseOx* — it's reported that most non-invasive methods of measuring pulse oximetry are affected by body temperature and especially motion. SPO Medical offers a \$169 (non-submersible) off-the-shelf product unaffected by body motion; they might be interested in expanding their market beyond the purely medical arena as a strategic partner in the PerforMax project. SPO products page

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Statement Of Work

Breadcrumbs: Main/PerformanceMetrics > Main/Biomechanics > Main/HomePage > Main/AlphaSystemStatus > Main/StatementOfWork

For Phase II

[REDACTED]

[REDACTED]

Confidential and Proprietary Information

Red/Blocked Comments – components of the Alpha (80%) System to be built, installed, and in operation at the [REDACTED]

The PerforMax system will be a training optimizer for competitive swimmers or any athlete wanting to maximize his/her aquatic conditioning. The system components to include a swimmer locator, RF interface, swimmer device, host computer, and video capture system. The system will provide to coach, swimmer, and parent the following capabilities:

- Ability to track 100 swimmers in a pool, a pool as large as 50 meters long by 25 meters wide – 64 swimmers total or 16 per quadrant – [REDACTED] to have Alpha system cover two quadrants on south side of pool.
- Archive video and data for at least one year per swimmer – 1 month
- Provide the coach a software system that's easy to use and navigate – fully functional with 80% system, but in need of refinement
- Provide the following data for each swimmer:
 - Stroke rate (tempo) – time for each stroke cycle
 - Stroke count - # of strokes per pool length
 - Distance per actual stroke and stroke cycle
 - Kick rate – time for each kick cycle
 - Kick count - # of kicks per pool length
 - Speed at any point in a given length or other specified distances (50 yard or meter, 100)
 - Energy expenditure at any given point
 - Turn times – Free/Back-when head crosses under flags (5 yards from wall) and then again crosses under it again after the turn. Breast/Fly-time from when hands simultaneously touch wall until the feet leave the wall after the turn
 - Breakout time and distance – when the feet leave the wall/starting block until the head breaks the surface or the hands begin the first stroke
- Provide zoomed-in above water video footage of each swimmer synchronized with the above mentioned data and coaches voice comments
- Allow each swimmer to “chime in” to host computer
- Allow coach to voice communicate to a swimmer, small group, or entire pool of swimmers – [REDACTED] swimmer rather the ability for the swimmer to hear a variety of tones
- Allow coach to send voice comments to host computer for future review, these are not heard by

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swimmer during training

- Allow host computer to speak to each swimmer individually during practice providing selected data mentioned above – no actual voice communication to swimmer rather the ability for the swimmer to hear a variety of tones
- Locate and track each swimmer to a maximum of a 5" accuracy – the video locator will be able to track swimmers within 5 feet and use the accelerometer data to interpolate the swimmers' location between
- Send coaches/host computer's voice comments to swimmer within 4 seconds – tone only, no voice
- Collect, process and send to coach above mentioned data within 10 seconds
- Collect and process zoomed-in video in near-real time (? within 10 seconds ?) – [REDACTED]
- Recognize each swimmer at each practice and associate his/her swimmer devices – [REDACTED]
- Upload all video, data, and voice comments to a PerforMax website or team/school website – [REDACTED]
- Allow swimmers and parents to download and view all video, data, and voice comments from home – [REDACTED]
- Offer stylish swimmer devices for the head, wrists, and ankles for under \$150 each retail
- Offer an aesthetically acceptable truss frame for locating the optical locator, RF transmitter & receiver, and cameras.
- Offer a host computer with all necessary drivers and hardware to operate all the above
- Offer portable coaches tablets for each coach on deck – up to at least 8 coaches – provide up to at least 8 coaches a portable tablet. [REDACTED]

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Networking

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PerforMax system components are currently networked exclusively using IP over Ethernet. Both TCP and UDP are used for various interconnects.

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Master Station

The Master Station is accessed exclusively via UDP. UDP was chosen because a simple and compact UDP implementation was readily available. Also, UDP suffices for the simple, short transactions between the Master Station and the locator system.

Cameras

The cameras, currently Mobotix network cameras, use TCP exclusively. They are powered using Power over Ethernet (PoE), which simplifies installation.

Poolside tablet PCs

A secure, wireless protocol needs to be specified that provides enough bandwidth to handle streaming video and enough security -- possibly including encryption of transmissions -- to prevent data theft or tampering by malicious parties.

External requests (e.g., internet, intranet)

Common web-serving protocols will be used to service internet-based requests, including the facility's intranet. Connection shall be robust enough to meet the anticipated demand of multiple, simultaneous multimedia downloads and/or streams.

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Sfnet

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sfnet

Overview

"sfnet" (name subject to change as we think of a better one) is the SwiftForth application that runs on the server. Currently, it is responsible for all interaction with the Master Station (MS) and the locator. It polls the MS and receives telemetry from it, and also receives locator information from the locator.

Building the sfnet application

Currently, turnkey generation isn't working properly. When fixed, this is how it's done:

From directory `%Projects/Performax/sfnet`:

```
user@sigtyr:~$ sf
SwiftForth i386-Linux 3.1.9f 03-Dec-2008
INCLUDE build ok ( F8 also does this)
STARTER GO ok
PROGRAM sfnet ok
BYE
```

This builds the `sfnet` executable in the current directory.

Interactive work with sfnet application

It's sometimes useful during development to start up pieces of the `sfnet` application, instead of the entire application. The examples below all start in the same fashion:

```
user@sigtyr:~$ sf
SwiftForth i386-Linux 3.1.9f 03-Dec-2008
INCLUDE build ok ( F8 also does this)
INIT ( This is normally done by GO)
```

Poll a single SD manually

```
<SD#> FLAM
```

Manually send a tone to an SD

```
<tone#> <SD#> BEEP where <tone#> is
```

1. "go" tone
2. "yes" tone
3. "no" tone

Telemetry/locator record format

For ease of parsing and insertion into the database, a unified record format is used to encode SD telemetry and locator information. A record will either have telemetry or location, but not both.

Sample:

```
6,12/10/2008,22:09:58,1228946998905,FALSE,,,TRUE,21,827,1001,,,,,,,,,
```

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User Interface

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On this page... (hide)

- Previews of UI Developments
- User Instructions
- Overview
 - Elements of the PerforMax *user interface* include:
- User Functions
 - Detailed description of user functions
 - Web-based prototype

Previews of UI Developments

For details about online previews of certain system functions and interface elements, see [Previews](#).

User Instructions

Information about the use of the certain features will be collected in the [Usage Notes](#) section.

Overview

The user interface (UI) conveys information between the user and the system. It is actually a set of interfaces for each of the following devices:

- athlete kiosk/tablet
 - check into system while on deck
 - associate the swimmer with that swimmer's SDs after/while retrieving them from the re-charging station
- Coaches' Console
 - enter & edit swimmer demographics
 - define & edit swim exercises
 - define & assign workout regimens
 - system maintenance tasks (e.g., archiving, deleting)
 - retrieve, analyze and display captured data & video
- Poolside Tablet PCs
 - select & display video and data for arbitrary swimmer in pool

Elements of the PerforMax *user interface* include:

- workout manager (also see the broader discussion of the workout manager)
- handheld PCs (hardware, poolside)
- Coaches' Console (AKA "Server 1")
- home PCs and other delivery devices
- data files
- user management
- user authentication
- data displays

Server-side processes that might improve performance include:

- server "push" or e.g., XMLHttpRequest, of new information needed by tablet users (e.g., a new swimmer comes on deck, the start of a timed event)
- SSL for external login.
- use of PHP shared memory allocation to store sessions in locked files

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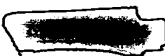
Go

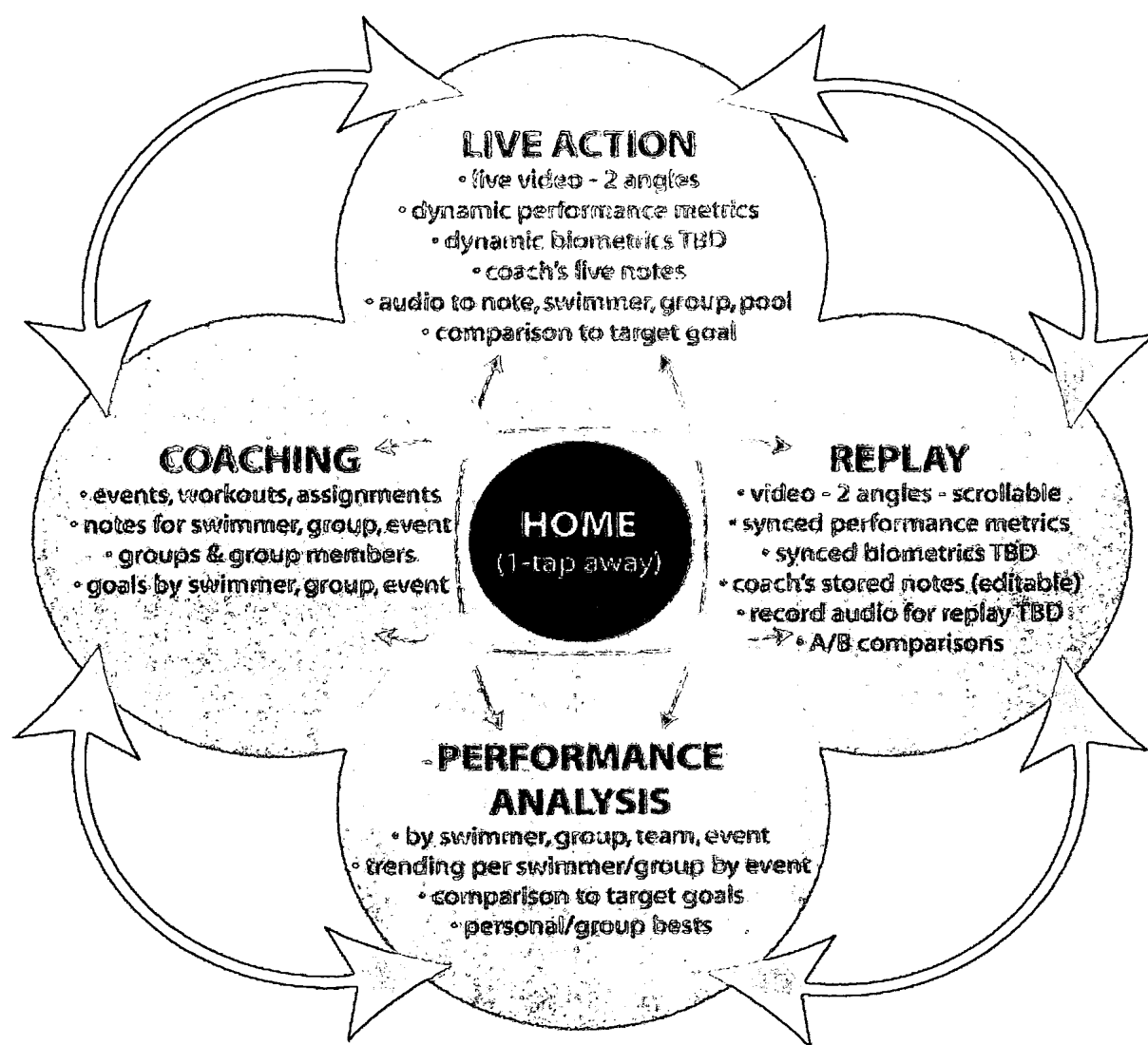
- assign exercises
 - playback recorded video & data
 - provide audio (voice and/or tone) to swimmer or as voice-over on the video recording
 - note-taking feature and ability to associate with a swimmer/event/date
 - Take-home playback devices and home PCs
 - select & play video and data of the user's recorded performances
 - provide trends analysis showing the user's progress-over-time for common events and exercises
 - permit a degree of comparison to teammates, school records (if in system), personal bests, records at sanctioned event, et al.
- Data sources (e.g., persistent arrays, etc.):
 - MySQL database
 - ID of all swimmers now on deck
 - ID of all staff now using handheld units

User Functions

The UI presents user-level functions to users. Those functions can be thought of as belonging to one of four general categories.

Not all users have access to the same content and features; see Restricted Content.





Detailed description of user functions

Web-based prototype

We are prototyping the user interface as a web application. This permits us to build on existing, open source tools and technologies that are well tested and supported. Some performance overhead should be expected, but this approach speeds prototyping and testing. If the system's user-perceived performance is good, we expect to deliver the entire final product as a web application.

If the media-heavy, real-time aspects of the UI are slowed too much by presenting them in a web browser, we can (a) first test those using a standalone Flash player (the simplest course correction, because these parts of the UI will already be running in a Flash player embedded in the browser's window, but we are

unsure of the performance improvement to expect) and then (b) consider a dedicated application. Certain components of the UI, such as those used for registering a new athlete and editing their demographic info, lend themselves well to the web-app approach for final delivery.


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Usage Notes

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[UserInterface/UsageNotes](#) Information can be collected here about details of the use of certain system features.

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Microphone

Flash client security settings

Flash requires the user of a handheld unit to give permission to Flash to access the user's microphone. Flash presents a dialog box for this purpose, asking the user to allow or deny access to the mic.

The Flash player's security settings related to use of the local system's microphone and/or camera can be managed to a certain extent via that dialog. But because the Flash player's local security-settings panel can be difficult to use with a tablet interface, the following procedure can be used to enable Flash to use the microphone to record staff's audio notes via a web interface provided by Adobe.

1. Using the primary browser used for the PerforMax system, navigate to a Flash application that requests access to the local microphone. For example:
<http://sigtyr.forth.com/poolTest.html>
2. When the Flash file loads, it will present a dialog box requesting permission to use the mic. If the tablet interface does not allow clicking either "Allow" or "Deny," instead click the small "?" info icon to navigate to the Adobe site. This of course requires access to the internet.
3. On the resulting web page, choose the "Website Privacy Settings Panel." The panel listing "Visited Websites" should contain the web domain name of the PerforMax application (e.g., sigtyr.forth.com).
4. Select that domain by tapping or clicking, and from the available options, select "Always allow."
5. Refresh the browser page. Return to the PerforMax pool-view Flash page and the dialog box should no longer appear.
6. Untested: some performance improvement might be achievable by allowing the Flash player to store more information on the PC. To do so using the same Adobe web application as above, click on the folder icon for "Website Storage Settings" and increase the amount allowed for the PerforMax web domain to 1MB or more.

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Restricted Content

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The phrase "restricted content" refers to static or dynamic content and to system applications that are not available to all users of the system.

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feature	staff	athletes
lane picker	yes	no
video on/off	yes	no
microphone	yes	no
menu: global nav	yes	no ¹
menu: athletes	yes	no ²
menu: events	yes	yes ³
data displays	yes	yes
audio-notes control	yes	yes

1. For non-staff users, this button is a link to their home/welcome page (instead of invoking the drop-down navigation controls staff users see).

2. Because non-staff users are only allowed to view their own recorded performances, instead of an athletes drop-down list, the logged-on user's name is displayed.

3. Non-staff users' events menu will only be populated with events they have permission to view (e.g., their own).

SD-assignment and report tool

This tool is available to *all staff users only*.

feature	staff	athletes
list & assign SDs	yes	no

journal/notes tool

This tool is available to *all staff users only*.

feature	staff	athletes
enter, edit & delete notes	yes	no

welcome/home page

At this time, content on this page is identical for staff and non-staff users, except staff users have *additional navigation controls* (i.e., to pages for which others users do not have sufficient access

http://www.forth.com/special/performax/wiki/index.php?n=UserInterface.RestrictedContent

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UI

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User "Views" and Flow-of-Use

We discussed, e.g.:

1. Staff user with poolside handheld or full console
global controls to invoke the main VIEWS:
Staff Journal
Workout Manager
Users, Groups and Profiles and
Live-Recorded Events
Pool view (select lanes, identify swimmers in lanes, sort and filter results)
Staff Users' Welcome-Home page (post log-in)
2. Staff member/coach using remote PC
Staff Users' Welcome-Home page (post log-in)
TBD: other staff features might be made available via internet, e.g., the Workout Manager and Journal.
TBD: possible use of remote PC to monitor live events, perform administrative tasks, etc.
3. Athletes at poolside
Poolside check-in
Charging Station
4. Athletes and parents using remote PC
Athletes' Welcome-Home page (post log-in)
log in, edit personal profile, recover lost password, upload personal photo, view messages from staff users, record personal goals (TBD), review personal performance data (not in alpha)
5. Administrator
Admin Welcome-Home page (post log-in)

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Staff Journal

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Staff Journal

Staff users may:

▫ save, review, edit and delete personal notes

▫ send a note to an athlete, staff member or group (post-alpha)

▫ attach a note to a swim-event (post-alpha; prob. denoted by a system-generated timecode)

▫ search their own notes for content (post-alpha; simple, literal string searches)

Admin users may:

▫ un-publish or delete notes from users with lesser access level (TBD)

▫ publish a special notice that has priority visual treatment on the welcome page *of all users or of a specified user or group* until its creator deletes it

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Workout Manager

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On this page... (hide)

- ▣ Workout Manager tasks include:
 - ▣ Managing workouts
 - ▣ Managing exercises
 - ▣ Existing exercises
 - ▣ Defining new exercises

The overview is available at Main.Workout Manager. This list is intended to be comprehensive given the current development plans.

Workout Manager tasks include:

- ▣ select from pre-defined exercises and workouts
- ▣ create new, or edit existing, exercises
- ▣ select several exercises to create a workout
- ▣ name and save workouts and individual exercises
- ▣ assign exercises and workouts to individuals and groups
- ▣ correlate assignments to recorded results (i.e., on completion, record all data and provide link to user)
- ▣ exercises & workouts go into a DB that contains a timestamp of every time each was-performed.

Managing workouts

A workout may consist of several exercises performed sequentially.

- ▣ The UI should provide a way to group exercises into a "workout," and to name, edit and save workouts.
- ▣ The UI should allow the poolside user to assign single exercises or workouts to swimmers.
- ▣ A staff user should also be able to *post-name* an event (e.g., "that was a Texas 25") for purposes or re-use and comparison, or just annotation.

Managing exercises

"Exercises," in the PerforMax system, are definitions consisting of prescribed, athlete movements and actions. Multiple repetitions of a single exercise is an *exercise set*. A *workout* is one or a series of exercises/sets.

Existing exercises

The UI must provide a way for the user to access and manage existing exercises. Some of these tasks may be relegated to the Master Station, if it is simpler to do them there than on the handheld units.

- ▣ Display predefined exercises in a way that makes them easy to find. To this end, we propose the UI presents filtered lists, such as:
 - ▣ facility-wide exercises
 - ▣ common strokes
 - ▣ exercises defined by the current user

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- ▣ exercises marked as "favorites" by the current user
- ▣ exercises defined by other users
- ▣ The logged-in user's exercises
 - Ability to display, delete, edit and rename exercises the user has entered into the system.
- ▣ All other exercises
 - Cannot rename system-wide or other users' exercises, but can copy them to rename, edit, etc. as their own exercise.
- ▣ Admin users
 - Ability to rename, edit and delete all exercises.
 - Ability to promote (and demote) any exercises into more-persistent status (i.e., so it appears with facility-wide exercises and cannot be deleted by non-admin, poolside users)

Defining new exercises

The system must provide a way to define new exercises. The mechanism must be as flexible as possible, to accommodate different coaches' techniques.

- ▣ As a conceptual framework both to help *classify exercises* and to *design an interface for defining them*, we currently are using the system described in Exercise Categories. We believe most imaginable swimming exercises can fit comfortably into one of those general categories.
- ▣ The above classification system pertains to timing, distances, intervals and repeats; it is also necessary to provide an interface for specifying the fundamental motions that comprise an exercise.

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Users Groups And Profiles

Breadcrumbs: Main/UserInterface > UserInterface/StaffJournal > UserInterface/WorkoutManager > Main/UIMeetingAtFORTHOctober142008 > UserInterface/UsersGroupsAndProfiles

Users Tool

Only staff users have access to this tool. It enables them to:

- view and edit other user's profiles (depending on their access level, TBD)
- delete photos uploaded by users
- display filtered lists of users
- archive/un-archive users
- switch athlete users from inactive to active
- create named groups of users (e.g., a relay team or a certain day's 10:00 am class)
- assign messages/assignments to users and groups (see Staff Journal and Workout Manager)

Admin-level users can also:

- switch staff-level users from inactive to active
- delete users permanently from the system, along with all their associated data
- create, publish and delete pre-defined groups available to staff users

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Live-Recorded Events

Breadcrumbs: [UserInterface/StaffJournal](#) > [UserInterface/WorkoutManager](#) >

[UserInterface/UsersGroupsAndProfiles](#) > [Main/UiMeetingAtFORTHOctober142008](#) > [UserInterface/Live-RecordedEvents](#)

View Event (live or recorded)

Only staff users have access to this tool. The views of live and recorded events will have few differences and are discussed together here. We will determine during development if some of these will not appear in the alpha version.

- display list of athlete and staff users on deck (see [Users, Groups and Profiles](#))
- select an athlete or group
- locate athletes and display info in non-video pool view
- select area by lane to focus on swimmers in that lane
- send audible tones to selected swimmer(s)
- ability to adjust volume of audio output (e.g., low-med-high will suffice)
- pre-event: ability of staff, and possibly athlete, to tell system which elements of the event to send tones about¹
- chime-in event from swimmers (TBD, double-flick wrist)
- view/review video and performance data for selected athlete(s), with pause, fast-forward, rewind, et al.
- video zoom (post-alpha; TBD)
- clock showing actual local time
- stopwatch (post-alpha; TBD)
- side-by-side video (post-alpha; TBD)

The following data are desired for display when an athlete's video performance is being viewed:

- elapsed (total) time
- stroke rate (tempo)
- stroke count
 - the stroke begins at the fullest extension of the limb(s) in the direction of movement (in breaststroke and butterfly, both hands extend at the same time)
- distance per stroke
- kick rate (tempo)
- kick count
- speed
- energy expended
- turn times
 - In butterfly and breaststroke, the interval between the first hand touching wall to last foot leaving wall.
 - In freestyle and backstroke, the interval between the body first touching the 5 yard/meter line

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towards the wall and first breaking the same line moving away from the wall (the hands don't touch the wall in these strokes' turns)

- *TBD configuration option:* some coaches measure the freestyle and backstroke turn times from first crossing the 5-yard line toward the wall until the last toe leaves the wall.
- breakout distances
 - The distance from the surface the athlete is leaving (wall or platform) to the point where the head first breaks the surface.
- breakout times
 - The interval required to cover the breakout distance.
 - It is *illegal to stroke before the breakout* except the breaststroke is allowed one underwater pull before surfacing.

other:

- breath count and rate
- easy access to other recent/similar swim events by selected athlete & by timestamp
- choose event by chime-in mark, by date/time, by attached coach's note
- audio (or written) note from coach to one or more athletes
- navigate to desired video in these ways, e.g.:
 - swimmer (or coach) chime at start-stop of an event (like a timestamped bookmark)
 - by attached staff note
 - by user-specified time (I was swimming yesterday at 4:00 p.m.)
 - TBD: by system detecting when the assigned SD was doing something that seems significant

1. Current tone set consists of Go (steady tone), Yes (low-high sequence), and No (high-low sequence).

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Pool View

Breadcrumbs: [UserInterface/WorkoutManager](#) > [UserInterface/UsersGroupsAndProfiles](#) >

[Main/UIMeetingAtFORTHOctober142008](#) > [UserInterface/Live-RecordedEvents](#) > [UserInterface/PoolView](#)

Pool view

This is a staff-only representation of live pool activity. It may provide a simple list of all on-deck swimmers, or a list of post-event swimmers sorted in various ways by available performance data. It's attributes include:

- It is not constrained to an animated graphical representation, the intent is to provide useful data.
- Start and stop controls to signal the beginning and end of an event of interest.
- Controls to compare performances in an event to another performance in the same event (e.g., to a school record or average).

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Staff Users Welcome-Home Page

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Staff Welcome-Home Page

See also: [Athletes Welcome-Home Page](#)

This is the page to which the staff user is directed after successful log-in. Elements it contains include:

- personalized greeting
- ability (not *required* or staff) to upload a photo of themselves
- random motivational quote (list of quotes may be different for staff than for athletes)
- global buttons and other controls to provide features available to normal staff users (admin-level users will have additional tools)
 - filter & sort report of user log-ins (date-timestamp) with (TBD) amount of time spent online (can be circumvented if used as a measure of real system usage)

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Athletes Welcome-Home Page

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Athlete's Welcome-Home Page

See also: [Staff Users Welcome-Home Page](#)

This is the page to which athlete-users (and parents, etc.) are directed after successful log-in from an internet connection. Its elements include:

- personalized greeting
- motivational quote (quotes may vary from those used for staff home pages)
- ability to upload a personal photo
- edit the user's profile
- ability to enter personal goals
- training planning reminder, e.g., "When is your next taper meet?" -- might work similar to a staff note that is assigned to an athlete, or standard prompts can be used to elicit user participation and buy-in.
- recent events - a reverse-chronological list of events in which the user appears
 - if staff notes are attached to a listed event, signify or display the note

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Coaching And Management

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- [Registration and User Management](#)
- [Coach's Journal](#)
- [Workout Manager](#)

Individual functions in this category are described below.

Registration and User Management

See [User Management](#).

Coach's Journal

This is a note-taking function. User's notes are stored as text files, and are parsed as UTF-8 encoded to allow for tildes, accented character and other common Western characters. Each staff user can:

- *read and write only notes in their own user's "Journal"*
- enter a new note
- list notes by date
- display a note
- edit a displayed note
- delete a displayed note

Future features:

- Allow staff user to e-mail their notes to the e-mail address they used to register with the system.
- Add text-search function.
- Send their notes to archive, individually, by date, or by "season," and allow for retrieval and search.

Workout Manager

At this time, athletic exercises are either:

- standard exercises common to sanctioned events
- custom exercises common to the facility
- custom exercises defined by staff users

Exercises that can be defined in standard terms and in a standard format can provide many more opportunities for statistical analysis than exercises defined in more-or-less freeform manner. But entering them freeform allows for more personalization, on-the-fly exercise definition, and doesn't constrain the staff user in any way.

The product should provide ways to:

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- choose a standard, sanctioned exercise
- enter freeform exercise definitions
- enter exercises in a structured way (this is the most challenging, and several approaches are under consideration)
- share facility-wide exercises
- allow a staff user to share some or all of their custom exercises with other staff and/or athletes
- group exercises into workouts, which can be edited and shared as for individual exercises


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User Management

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Athlete and Staff Registration

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Here, "registration" means entering personal data (the user's "profile") into the PerforMax system for an athlete or staff user. Unless the scope of the project grows to include team management functions, "registration" is not related to registering for participation in the athletic program, only with the PerforMax system.

- first-time registration for athlete and staff users
- authentication utilities, including:
 - user-selected password and e-mail address
 - auto-recover password
 - change password, e-mail address
- create (and edit later) a user "profile" (see Data Files for descriptions and example files)

athlete profile

- name (last, first, middle)
- birthdate
- gender
- height
- weight
- status (active/inactive)
- standing at facility:
 - enrolled: freshman, sophomore, junior, senior; *or*
 - visitor: swim camp, alumnus, college athlete, other program, other

staff user's profile

- name (last, first, middle)
- status (active/inactive)
- standing at facility:
 - coach, assistant coach, other assistant, manager

System considerations:

- There will be a directory for each athlete and staff user in the system, and a central file — e.g., `/data-files/staff/system-registrations.csv` — containing their profiles and an unknown-to-users unique user ID.
- an archive file correlates all unique IDs ever assigned to key demographic data for that individual (e.g., name); this might help with maintenance tasks like locating orphaned athlete directories and finding who they belong to, or in other unforeseen ways.
- if the system allows entry of any personal information that is particularly private or sensitive, discuss any best-practice ways to safeguard that from accidental disclosure.
- file formats -- plaintext and CSV are convenient for some purposes, but XML could excel for some Flash-based or other parts of this application.

Future features:

- correlate with customization file(s) containing, e.g.:
 - each coach's system-specific preferences
 - students/classes for which they are the primary coach
- TBD in consultation with coaching staff and field testing

Managing Athlete and Staff Users

The system shall accommodate editing and management of **basic athlete or staff user profiles**, defined above).

- athlete and staff users log in to edit/maintain their profile and login
- staff ability to toggle athlete status active/inactive
- staff ability to archive any user's data

Future features:

- ability to block user log in, without necessarily removing them from the system
- burn all or selected media files and data files to CD/DVD/et al. for purposes like:
 - offline storage
 - delivery to athlete
 - delivery for import into another PerforMax facility's system
- permanently delete selected users from the system, including all their data and media files (does not affect records that have been copied into other data files or directories outside the user's personal directory structure)

Current status

The prototype user interface currently provides ways to:

- register new athletes
- list current and archived swimmers
- locate and edit an existing athlete's current profile
- mark a registered athlete as "inactive" or "active"
- move an athlete's records to a common archive
- resurrect an athlete's records from the archive
- perform client-side (Javascript) and server-side (PHP) validation on form fields, with user prompts

Details

- Athlete and staff users may enter and maintain their own data via internet connection to Server 2 and coaching staff may do so via the same interface from the Coach's Console.
 - Requires a unique log-in name and e-mail address.
 - May check on registration for existing users with same first, middle (if any) and last name.
 - An unchanging unique user ID is assigned by the system when a new athlete is registered.
- *Data format:* User registration "profiles" are stored in MySQL.
- **Pending issues:**

- Planning to install a widget ("enter the text you see here") to help ensure no non-humans submit the form.
- Athletes can maintain their own profiles (e.g., changes to height, weight, even name), reset their passwords and change their e-mail contact address without assistance from coaching staff.
- HTTPS should be used during the registration process.
- On installation, a software switch will be set to require new registrations be approved by a staff-level user before the new account becomes active.

Features remaining/under consideration:

- review and compare past/present data (e.g., changes in height, weight) -- requires adding a data file to hold history for each athlete
- delete athlete (e.g., for athletes who graduate or transfer out), *but see below from SH*
 - TBD: auto-moves their data files to a deeper archive, or offline, or just deletes
 - ability to retain certain data files for future inter-swimmer-comparison functions, most notably the record-holders' performances
- provide a way to store and retrieve selected videos, even of athletes who have been removed from the system.
 - SH - very good and important


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Authentication

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Various authentication measures will be employed to help protect the system from unauthorized access.

Types of Users

There are four types of users, each of which has distinct privileges and permissions that may require more or less stringent authentication measures.

Which content is filtered based on user privileges (a.k.a., "access level") is discussed in Restricted Content.

- ▣ athletes
- ▣ coaching staff
- ▣ head coach or facility operator
- ▣ technical

The Authentication System

The authentication utility should minimize the need for staff administration. To that end, it should allow users to recover lost passwords themselves. It probably is also desirable for them to be able to change their e-mail addresses, and to allow first-time users to register (i.e., no staff input when new users enter the system).

First-time setup for PHP and MySQL

- ▣ adjust settings in the file `/classes/access_user/db_config.php`
(extension `.php` changed to `.html` for wiki).

Hardware devices

It may be advisable to install security certificates on the handhelds and any other devices that communicate with Server 1. Facilities that wish to try their own hardware devices for interacting with the UI or server would then be required to obtain a certificate that would give those units access.

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Athlete users

Part of the PerforMax system provides a public-facing (internet) utility for athletes to enter and update their personal data. Although the functions it provides are limited, the exposure is relatively great and the system should be designed *as if* the registration and log-in pages are posted publicly. Security measures will include all the following:

- first-time registration (only):
 - Most secure would be to require athletes or staff to enter the athlete's e-mail address at poolside, and from that entry generate an e-mail containing a unique, temporary login URL and a credential they are required to change on first access.
 - If those logistics are undesirable, a generic login can be provided to gain access to the first-time registration page. In this case, (a) new-athlete registrations should be flagged for staff to approve (with a click or two) before the system accepts them, and (b) the generic login should be changed routinely (which could be enforced in software, TBD).
- username and password
- a "captcha" widget presenting graphical words the user must type; we have chosen to use reCAPTCHA:
 - it supports vision-impaired users via an audio alternative
 - users' responses are used for an academic-friendly purpose
 - see the Wikipedia entry
 - Carnegie Mellon's ReCAPTCHA site
- physical isolation of this server (server 2) from server 1 (see discussion of System Design)
- no file uploads are enabled at this time, only text fields in normal HTML forms
 - if future releases allow file uploads (e.g., head shots, records from other facilities), the client-side should impose routine checks for file size and extension, but the server should be responsible for checking actual filetype and size (not relying on the file's extension)
- HTTPS can be employed to further reduce exposure, although at this time the data intended to be transmitted is not *highly* sensitive

Coaching staff users

Coaching staff will have access to the poolside equipment, including handhelds and the Coaches' Console (aka Server 1). Because physical access to these is limited, and because users must be able to log in and out quickly, security measures are limited to:

- username-password authentication
- password recovery and management, as above
- any measures that could reduce use of the device for other internet uses unrelated to PerforMax (TBD)

Head coach or administrator

The head coach may have special privileges, such as deleting a staff member from the system and editing other staff records, that most coaching staff will not have. If we restrict these functions to machines with *no user-accessible internet connection*, authentication may consist simply of:

- username and password

- password recovery and management, as above (unless this should be restricted more, somehow, because of the special privileges of this user)

Technical

This tier of user might not be needed, but is included here to provide completeness. In theory, it could provide entry for long-distance diagnostics, backups, automatic upgrades, etc.

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Data Files

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- Athlete profile
- Coach & staff profile (CSV)
- Configuration details (PHP variables)
- Swims and exercises
- Groups and classes
- Correlation of athletes to events and media files

Data sources: The user interface is populated by, and interacts with, data from a number of sources. By convention used here, except where noted, the files kept in CSV format contain a header line documenting the meaning of each field. In some cases, XML may be used for, e.g., ease of importing into Flash as arrays.

Directory structure: The system design should facilitate archiving and un-archiving of athletes' data. To this end, a separate directory is created for each staff and athlete user.

Athlete profile

Currently stored as a CSV file, containing all the data listed for athletes at User Management, plus:

- A unique user ID (the next-available value is a candidate for including in a data file, or as a persistent PHP variable, rather than sorting an array of all active & archived athletes -- *at this time* the performance hit only occurs during the registration process).

Coach & staff profile (CSV)

Currently stored as a CSV file, containing all the data listed for staff at User Management, plus:

Example files:

user profiles:

- system-registrations.csv for athletes contains data for every registered athlete that has not been archived or deleted; archived entries have been moved to a similar file in an archive directory until an administrative user deletes them.
- system-registrations.csv for staff contains a subset of the same data stored for athletes, but maintains a structure orthogonal to that of athletes for purposes of code re-use and future feature additions.

on-deck users

- on-deck-staff.csv for logged-in, poolside staff users -- for early development, this will be a flat file containing one unique user ID (UUID) per line.
- on-deck-athletes.csv for logged-in, poolside staff users -- same format as above, with possible extra field for correlation to on-deck coach (if that is static in real use).

sessions, cookies and preferences

- Browser "cookies" may be used to store persistent session data for each handheld coach's unit, and/or locked session files on the

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- unique ID (same format and sequence used for athletes, no distinction)

Configuration details (PHP variables)

- facility and system identifiers
- pool size and units of measure
- which level staff can edit info about athletes and other staff

Swims and exercises

- definitions, in a system-specific format, of common swims (e.g., those at sanctioned meets)
- definitions of swims common to the facility
- coach-defined swims
- workouts, composed of groups of swims/exercises

Groups and classes

The purpose of having arbitrary, user-defined "groups" of athletes is to make it easier for coaches to select and manage multiple athletes at a time. These act as user-defined filters when presenting user functions and athlete data. Examples include:

- a relay team
- all swimmers on deck assigned to the user-coach
- swimmers who compete
- add swimmer(s) to a coach-named group, and add the group to *that coach's* lists

Correlation of athletes to events and media files

A mechanism needs to be defined to serve these purposes:

- Store each event type/name performed by an athlete over their entire history, with a reference to any related media file (video), and to any post-processed analysis/report, etc. that is deemed better to create once than to re-create on demand.
- prevent deletion of video while active references to it exist

server.

- layout prefs, e.g., width of buttons in athlete display

user login and unique user IDs

- usernameToUUID.csv may be used to correlate the logged-in user to their system-assigned unique user ID (UUID). If so, it is kept in the /admin/private_data directory, whose access should be restricted not just to staff but to admin-level users and scripts that manage the data needed.

notes files

- plain-text files may be used to store coaches' notes exactly as entered, with no HTML interjected (formatting will be applied on-the-fly when retrieving, more flexible during testing)
- optional subject line
- optional keywords (to support future search & filter features)
- tag a note as related to/accessible by an athlete or a group (incl. other coaches)

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Telemetry Data

Breadcrumbs: UserInterface/UserManagement > UserInterface/CoachingAndManagement > Main/UserInterface > Main/HomePage > Main/TelemetryData

Collection of data records

Data records from (and about) the Swimmer Devices are collected by a polling process on the server computer. Each SD of interest is queried by sending a UDP request to the Master Station, which polls the SD via the RF link. If it's a head-mounted SD, the polling command also includes timer values for firing the device's IR LED used by the Locator subsystem to determine the location of the swimmer's head in the pool. The Server retrieves the location via a TCP connection to the Locator.

Log file format

Each line of the file is a comma-separated-value (CSV) data record. There are two main record types:

1) The SD poll record identifies which swimmer device is being polled.

Sample head SD poll record:

SD16,09/10/2008,18:46:50,67610747,TRUE,408,694

Sample limb SD poll record:

SD64,09/10/2008,18:46:50,67610759,

The first element, SDxx identifies the polled device. Note that in the current addressing scheme, SDs 16-63 are head-mounted and 64-254 are limb devices. This is followed by the date and time of the poll transaction. After the "clock" format time is the time represented as the integer number of milliseconds since midnight. In the case of the head SD, the locator results are appended at the end of the record (location result as TRUE or FALSE, and the X,Y coordinates which may be null if the location could not be determined by the imaging subsystem).

2) One ore more SD telemetry data records can follow each SD poll record.

Sample head SD telemetry records:

38905,38427,1504,1615,1280,3821,-18,31,-62,-56
38905,38428,1482,1558,1280,3821,-18,31,-62,-56
38905,38429,1491,1515,1265,3821,-18,31,-62,-56
38905,38430,1542,1550,1283,3821,-18,31,-62,-56
38905,38431,1568,1530,1254,3821,-18,31,-62,-56
38905,38432,1558,1531,1265,3821,-18,31,-62,-56

Sample limb SD telemetry records:

37079,36600,1602,1453,1283,1628,1446,3738,-26,29,-61,-51
37079,36601,1630,1444,1285,1626,1446,3738,-26,29,-61,-51
37079,36602,1654,1468,1309,1615,1461,3738,-26,29,-61,-51
37079,36603,1687,1487,1291,1575,1489,3738,-26,29,-61,-51

The first pair of numbers establish the time at which each record was sampled. These numbers are in timer "ticks" at 125 ms per tick (8 Hz sample rate). The first number is "ticks now" (the time at which the record was transmitted) and the second is "ticks then" (when the sample record was stored). Next are the accelerometer X, Y, and Z readings (in mV). For the limb device only, these are followed by the gyro theta-dot-X and theta-dot-Y readings (also mV). The final 5 values are battery level (mV), current (mA, plus or minus for charge or discharge mode), temperature (degrees C), remote RSSI (received signal strength indicator in dBm), and local RSSI. Those battery and RSSI values are primarily for diagnostic purposes as we buzz out the hardware.

Here's one entire poll sequence as found in the telemetry data file:

Sample log files

polls2.txt

One swimmer with 5 SDs

polls3.txt

Three swimmers with head and wrist SDs

journal.txt

List of events and notes for polls2 and polls3

User name and password are the same as for this wiki.

http://www.forth.com/special/performax/wiki/index.php?n=Main.TelemetryData

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```
SD16,09/10/2008,18:46:50,67610747,TRUE,408,694
38905,38433,1572,1530,1234,3821,-18,30,-62,-56
38905,38434,1570,1580,1260,3821,-18,30,-62,-56
38905,38435,1606,1578,1242,3821,-18,30,-62,-56
38905,38436,1616,1546,1252,3821,-18,30,-62,-56
38905,38437,1611,1523,1248,3821,-18,30,-62,-56
38905,38438,1602,1507,1254,3821,-18,30,-62,-56
SD64,09/10/2008,18:46:50,67610759,
37079,36604,1659,1501,1255,1615,1493,3738,-26,30,-61,-51
37079,36605,1647,1523,1277,1609,1479,3738,-26,30,-61,-51
37079,36606,1628,1541,1284,1597,1493,3738,-26,30,-61,-51
37079,36607,1632,1594,1271,1537,1485,3738,-26,30,-61,-51
SD65,09/10/2008,18:46:50,67610770,
38906,38431,1610,1352,1374,1645,1520,3752,-26,31,-61,-51
38906,38432,1599,1328,1382,1639,1528,3752,-26,31,-61,-51
38906,38433,1579,1364,1370,1614,1531,3752,-26,31,-61,-51
38906,38434,1555,1349,1370,1685,1536,3752,-26,31,-61,-51
SD66,09/10/2008,18:46:50,67610782,
38904,38429,1289,1553,1563,1622,1379,3767,-27,31,-78,-68
38904,38430,1296,1515,1564,1630,1380,3767,-27,31,-78,-68
38904,38431,1294,1524,1567,1646,1377,3767,-27,31,-78,-68
38904,38432,1302,1525,1564,1653,1379,3767,-27,31,-78,-68
SD67,09/10/2008,18:46:50,67610793,
61609,61134,1274,1622,1583,1391,1437,3747,-26,30,-82,-70
61609,61135,1310,1747,1585,1340,1456,3747,-26,30,-82,-70
61609,61136,1230,1673,1653,1451,1467,3747,-26,30,-82,-70
61609,61137,1271,1626,1620,1471,1465,3747,-26,30,-82,-70
```

Flat Format

Here's an example of the telemetry data in the "flattened" out format for the middleware

```
81,12/01/2008,00:08:53,1412343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3452,2185,2265,1559
81,12/01/2008,00:08:53,1414343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3453,2195,2276,1569
91,12/01/2008,00:08:53,1416343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3454,2189,2271,1559
91,12/01/2008,00:08:53,1418343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3455,2189,2271,1569
94,12/01/2008,00:08:53,1420343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3456,2190,2282,1568
81,12/01/2008,00:08:53,1422343,42,0,27,-60,-59,FALSE,,,FALSE,,,3930,3457,2187,2271,1566
82,12/01/2008,00:09:00,1424343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3182,2302,1336,1466
82,12/01/2008,00:09:00,1426343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3183,2300,1344,1457
82,12/01/2008,00:09:00,1428343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3184,2288,1340,1466
83,12/01/2008,00:09:00,1430343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3185,2295,1331,1453
72,12/01/2008,00:09:00,1432343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3186,2304,1346,1477
73,12/01/2008,00:09:00,1434343,41,0,28,-64,-64,TRUE,920,584,215,FALSE,,,3660,3187,2301,1344,1456
```

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Video

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Video acquisition & processing

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4. Delete these instructions.

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2. The sidebar's link "Basic Editing" provides more details.
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Workout Manager

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Also see: [user interface -- workout manager](#)

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Support information

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The workout manager may be considered a nearly independent PerforMax sub-system. It provides a way for coaches to define, retrieve, assign and modify workout routines.

Much of its complexity lies in creating a flexible interface for rapid retrieval and on-the-fly definition of exercises.

It is convenient to consider the Workout Manager and a related Team Manager separately. *Core PerforMax features do not include comprehensive team management tools.* The Workout Manager must be implemented on the poolside tablet PCs but the Team Manager may be implemented only for use at a Master Console, or could be reserved as a value-added product option.

Functions available, or planned, for this application are discussed in [UserInterface.WorkoutManager](#).

Team Manager tasks include:

- [enter and edit / user profiles](#)
- [create, save and delete named groups of athletes](#), allowing the Workout Manager to assign workouts to groups; such as...
 - [by grade level](#)
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 - [by coach and class](#)
 - [relay team](#)
 - [arbitrary groups of two or more athletes](#)

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Workout Manager

Breadcrumbs: Main/SwimmerDevices > Main/Video > Main/HomePage > Main/WorkoutManager >

UserInterface/WorkoutManager

On this page... (hide)

- Workout Manager tasks include:
 - Managing workouts
 - Managing exercises
 - Existing exercises
 - Defining new exercises

The overview is available at Main.Workout Manager. This list is intended to be comprehensive given the current development plans.

Workout Manager tasks include:

- select from pre-defined exercises and workouts
- create new, or edit existing, exercises
- select several exercises to create a workout
- name and save workouts and individual exercises
- assign exercises and workouts to individuals and groups
- correlate assignments to recorded results (i.e., on completion, record all data and provide link to user)
- exercises & workouts go into a DB that contains a timestamp of every time each was-performed.

Managing workouts

A workout may consist of several exercises performed sequentially.

- The UI should provide a way to group exercises into a "workout," and to name, edit and save workouts.
- The UI should allow the poolside user to assign single exercises or workouts to swimmers.
- A staff user should also be able to *post-name* an event (e.g., "that was a Texas 25") for purposes of re-use and comparison, or just annotation.

Managing exercises

"Exercises," in the PerforMax system, are definitions consisting of prescribed, athlete movements and actions. Multiple repetitions of a single exercise is an *exercise set*. A *workout* is one or a series of exercises/sets.

Existing exercises

The UI must provide a way for the user to access and manage existing exercises. Some of these tasks may be relegated to the Master Station, if it is simpler to do them there than on the handheld units.

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- Display predefined exercises in a way that makes them easy to find. To this end, we propose the UI presents filtered lists, such as:
 - facility-wide exercises
 - common strokes
 - exercises defined by the current user
 - exercises marked as "favorites" by the current user
 - exercises defined by other users
- The logged-in user's exercises
 - Ability to display, delete, edit and rename exercises the user has entered into the system.
- All other exercises
 - Cannot rename system-wide or other users' exercises, but can copy them to rename, edit, etc. as their own exercise.
- Admin users
 - Ability to rename, edit and delete all exercises.
 - Ability to promote (and demote) any exercises into more-persistent status (i.e., so it appears with facility-wide exercises and cannot be deleted by non-admin, poolside users)

Defining new exercises

The system must provide a way to define new exercises. The mechanism must be as flexible as possible, to accommodate different coaches' techniques.

- As a conceptual framework both to help *classify exercises* and to *design an interface for defining them*, we currently are using the system described in Exercise Categories. We believe most imaginable swimming exercises can fit comfortably into one of those general categories.
- The above classification system pertains to timing, distances, intervals and repeats; it is also necessary to provide an interface for specifying the fundamental motions that comprise an exercise.

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Exercise Categories

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Ways to categorize exercises

See also: exercise purposes

We will explore ways to categorize exercises to assist in defining/presenting them logically and selecting/assigning them easily. One way to categorize exercises very generally includes these categories (source: <http://www.usms.org/fitness/content/usingthepaceclock>):

- **Straight Sets** — a fixed number of repetitions of one exercise of a fixed length (yards/meters), for a fixed time interval (interval = swim time + rest time between repetitions). The send-off time on the clock will be different for each repetition unless the interval is an even minute:

Example #1: 10 x 50 yards on 1:00

Explanation:

10 — number of repetitions

50 yards — distance of each repetition

1:00 — interval for each repetition (swim + rest)

Example #2: 10 x 50 yards on :55

Explanation:

10 — number of repetitions

50 yards — distance of each repetition

:55 — interval for each repetition (the send-off time will be 5 seconds earlier on the clock for each successive repetition)

(In a mixed-ability pool, this challenges the slower swimmers and they get less time to rest than faster swimmers.)

- **Fixed-Rest Sets** — less demanding for swimmers, this allows a fixed amount of rest time after each repetition regardless of swim time. The swimmer will start each repetition at a different clock time because their swim time will vary.

Example: 4 x 200 yards with :30 rest

Explanation:

4 repetitions of a 200 yard swim, with 30 seconds rest between each repetition

- **Variable-Rest Sets** — unlike Fixed-Rest Sets, the resting time varies before each repetition.

Example: 4 x 200 yards with :30, :20 and :10 rest

Explanation:

4 repetitions of a 200 yard swim, with 30 seconds rest after the first 200 yards, 20 seconds rest after the second 200 yards and 10 seconds rest after the third repetition.

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- **Timed Swims** — the swimmer swims for a fixed period of time, with or without repetitions. The clock will differ at the start of each repetition if the fixed swim time plus the fixed rest time do not equal a whole number of minutes.

Example #1: T-20

Explanation:

Swim continuously for 20 minutes

Example #2: 4 x 5:00 with 1:00 rests

Explanation:

Repeat this 4 times: swim for 5 minutes then rest one minute.

- **Broken Swims** — this is a fixed swim distance, broken into arbitrary swim lengths each followed by a fixed or variable resting time.

Example: Broken 200 as 50, 25, 50, 25, 50 with :15 rests

Explanation:

Swim 50 yards/meters, rest 15 seconds; swim 25 yards/meters, rest 15 seconds; etc. System should provide total time, total swim time and break times (the time for each of the assigned lengths).

- **Descending Interval** — a fixed-length swim with shorter rests between each repetition.

Example: 6 x 100 with a starting 2:00 interval descending by :05 for each repetition.

Explanation:

Swim 100 yards/meters and rest just enough so the next send-off is at the 2:00 mark; then swim 100 yards/meters and rest just enough so the next send-off is at 1:55; etc., until 6 repetitions have been completed.

- **Ascending Interval** — like Descending Interval but increasing the interval value at each repetition.
- **Pyramid Intervals** — Pyramid intervals are sets that combine descending and ascending intervals. For example, a pyramid set might consist of 7 x 150 on intervals of 2:20, 2:30, 2:40, 2:50, 2:40, 2:30 and 2:20.
- **Descending Interval/Descending Times** — for each repetition, the interval is decreased until the swimmer cannot complete the assigned distance in the allotted interval.

Example #1: 50s starting on 1:00, descending interval by :01 per 50 until failure.

Explanation:

Swim 50 yards on a 1 minute interval; swim 50 on a :59 second interval; swim 50 on a :58 interval; etc. until swimmer cannot swim the 50 in that repetition's interval.

Example #2: Same as above, but also descend times by :01 per 50.

Explanation:

As above, but the swimmer must complete each 50-yard/meter repetition 1 second faster than the preceding repetition, not including any rest time.

- **Ladders** — a set of various swim distances to be swum on a fixed interval per a given distance.

Example: 300, 275, 250, 225, 200...25 on :35 per 25 yards

Explanation:

Swim 300 yards at a fixed interval of 35 seconds per each 25 yards ($((300/25)*35 = 420$ seconds to complete 300 yards); swim 275 at same interval ($((275/25)*35 = 385$ seconds to complete 275 yards); swim 250 on the same interval ($((250/25)*35 = 350$ seconds to complete 250 yards); etc.

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Exercise Purposes

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Designating the purposes of an exercise

See also: exercise categories

PerforMax may provide a way to describe the focus, or purpose, of each exercise and allow users to find/select exercises by this attribute. An exercise may have one or more attributes, or none, assigned to it. Such attributes might include...

- stamina
- pulmonary
- cardio
- endurance
- strength
- speed
- stroke/kick efficiency
- turns
- one-side strength
- pull stroke
- kick/stroke strength/tempo
- aerobic
- anaerobic
- sprint
- etc.

...and new descriptives might be added/edited by coaching staff.

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Athlete and Staff Registration

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Here, "registration" means entering personal data (the user's "profile") into the PerforMax system for an athlete or staff user. Unless the scope of the project grows to include team management functions, "registration" is not related to registering for participation in the athletic program, only with the PerforMax system.

- first-time registration for athlete and staff users
- authentication utilities, including:
 - user-selected password and e-mail address
 - auto-recover password
 - change password, e-mail address
- create (and edit later) a user "profile" (see Data Files for descriptions and example files)

athlete profile

- name (last, first, middle)
- birthdate
- gender
- height
- weight
- status (active/inactive)
- standing at facility:
 - enrolled: freshman, sophomore, junior, senior; *or*
 - visitor: swim camp, alumnus, college athlete, other program, other

staff user's profile

- name (last, first, middle)
- status (active/inactive)
- standing at facility:
 - coach, assistant coach, other assistant, manager

System considerations:

- There will be a directory for each athlete and staff user in the system, and a central file — e.g., /data-files/staff/system-registrations.csv — containing their profiles and an unknown-to-users unique user ID.
- an archive file correlates all unique IDs ever assigned to key demographic data for that individual (e.g., name); this might help with maintenance tasks like locating orphaned athlete directories and finding who they belong to, or in other unforeseen ways.
- if the system allows entry of any personal information that is particularly private or sensitive, discuss any best-practice ways to safeguard that from accidental disclosure.
- file formats -- plaintext and CSV are convenient for some purposes, but XML could excel for some Flash-based or other parts of this application.

Future features:

- correlate with customization file(s) containing, e.g.:
 - each coach's system-specific preferences
 - students/classes for which they are the primary coach
- TBD in consultation with coaching staff and field testing

Managing Athlete and Staff Users

The system shall accommodate editing and management of **basic athlete or staff user profiles**, defined above).

- athlete and staff users log in to edit/maintain their profile and login
- staff ability to toggle athlete status active/inactive
- staff ability to archive any user's data

Future features:

- ability to block user log in, without necessarily removing them from the system
- burn all or selected media files and data files to CD/DVD/et al. for purposes like:
 - offline storage
 - delivery to athlete
 - delivery for import into another PerforMax facility's system
- permanently delete selected users from the system, including all their data and media files (does not affect records that have been copied into other data files or directories outside the user's personal directory structure)

Current status

The prototype user interface currently provides ways to:

- register new athletes
- list current and archived swimmers
- locate and edit an existing athlete's current profile
- mark a registered athlete as "inactive" or "active"
- move an athlete's records to a common archive
- resurrect an athlete's records from the archive
- perform client-side (Javascript) and server-side (PHP) validation on form fields, with user prompts

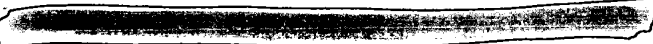
Details

- Athlete and staff users may enter and maintain their own data via internet connection to Server 2 and coaching staff may do so via the same interface from the Coach's Console.
 - Requires a unique log-in name and e-mail address.
 - May check on registration for existing users with same first, middle (if any) and last name.
 - An unchanging unique user ID is assigned by the system when a new athlete is registered.
- *Data format:* User registration "profiles" are stored in MySQL.
- **Pending issues:**

- Planning to install a widget ("enter the text you see here") to help ensure no non-humans submit the form.
- Athletes can maintain their own profiles (e.g., changes to height, weight, even name), reset their passwords and change their e-mail contact address without assistance from coaching staff.
- HTTPS should be used during the registration process.
- On installation, a software switch will be set to require new registrations be approved by a staff-level user before the new account becomes active.

Features remaining/under consideration:

- review and compare past/present data (e.g., changes in height, weight) -- requires adding a data file to hold history for each athlete
- delete athlete (e.g., for athletes who graduate or transfer out), *but see below from SH*
 - TBD: auto-moves their data files to a deeper archive, or offline, or just deletes
 - ability to retain certain data files for future inter-swimmer-comparison functions, most notably the record-holders' performances
- provide a way to store and retrieve selected videos, even of athletes who have been removed from the system.
 - SH - very good and important


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Features Under Consideration

Breadcrumbs: Main/UniqueUserID > UserInterface/UserManagement > Main/WorkoutManager >

Main/HomePage > Main/FeaturesUnderConsideration

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- Features and Upgrade/New Product Paths
- Un-categorized
 - Future Features
 - Upgrades/Product-Enhancement Paths
 - Fee-for-services
 - Supplemental Products & Options

Features and Upgrade/New Product Paths

Also see: blue sky thinking

Future Features

These are not scheduled to be part of the **beta** release, but may be incorporated into subsequent beta tests or later.

- **heart rate.**
- Side-by-side video replay of, e.g.:
 - two similar swim events by one athlete
 - two athletes in same or similar event
 - same athlete in one event from two camera angles.
- Coaches' ability to log in via internet to use, e.g., the Workout Manager.
- Coach ability to e-mail their poolside notes to themselves.
- When coach selects an event, auto-key to their notes near to that event's time.
- Ability to manually enter data for events at locations that aren't PerforMax capable; enter whatever data is available, leave other fields blank ("NA" or "ND") and don't include them in

Un-categorized

This non-canonical list is used simply to collect ideas as they arise. Please contribute freely. If a feature is adopted, add it to a new or existing wiki page, and either add a link to the relevant page or delete its entry here. If it's too fanciful to entertain, demote it to blue sky thinking and add your commentary.

- What sort of data should we be collecting? Perhaps any and all data we can.
- Within a single event/exercise, it is helpful to record time-per-length/lap/stroke/cycle to show e.g., sprint ability (e.g., attempting to overtake a swimmer) and to measure post-sprint fallback. This esp. helps swimmers who aren't good at using the clock.
- Best to measure performance by no more than a single pool length (send-off to first touch on opposite wall) because even a short sprint in a short pool can show performance drop-off on the return (after the turn), and because including the turn time would skew the sprint measurements.
- Not all swimmers in the pool may be performing the same exercise

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averages, etc.; no video.

- False start — detect and reset/clear data (option to review video might be useful for fine-tuning starts but it wouldn't be necessary to save such video if the false start forces the event for start over for all swimmers.
- split times
- stroke effectiveness, compare to rival teammate/other benchmark stats, effort level, hydration and glucose, coach's comments
- send-offs (meeting these goal times is a measure of accomplishment and an aid to setting future send-off times for any given exercise)
- breaths-per-lap and where/when in the lap each breath were taken
- compare to personal performances and personal goals
- athletes able to see/hear their exercise assignments
- ability to see, and for coaches to set, the purpose/goal of the exercise
- clock in ear
- coach-to-coach communication
- hand-off of one on-deck coach's athletes to another on-deck coach
- Custom browser chrome for application/UI functions & branding, or use of Gecko engine to create Firefox-like, fully dedicated application (e.g., via tools described at the Mozilla Developer Center as XULRunner
- video — need ability to fast-forward (the sentiment was that the time spent studying their swimming shouldn't take away from their homework time)
- total yardage and total rest time for each exercise and for an overall workout
- allow coaches to specify that one of their notes is to be shared with an athlete or group

Upgrades/Product-Enhancement Paths

These are features that could be included in future development to entice existing users to upgrade.

- *IR lane markers* are needed for the system to provide lane-oriented information to the users. This will allow poolside users to quickly select swimmers by lane and for the system to send audio to groups of swimmers by lane. Lane widths and configurations change (see Terminology), and using IR markers would eliminate the need to manually calibrate lane-marker displays at each session. The markers will need to be wireless, submersible and fixable to the ends of the lane ropes.
- *IR corner markers* placed at each corner of the pool might give the system a degree of self-calibration if the cameras or their supporting structure move.
- Coach-less operation -- athletes can sign in a record their workout without coaching staff.

- If the system can emit a starter klaxon (pool-wide or individual swimmer), we're closer to achieving a degree of coach-less operation.
- Import/export standard-format files of event results (such a standard has been established by officiating organizations for electronic filing of sanctioned meet results)
- PulseOx
- interface to facility's timing clock
- integrated team/club management tools

Fee-for-services

- long-distance diagnostics, backups, automatic upgrades, etc.
(unless Server 1 has a probably undesirable internet connection, the public-facing Server 2 can be used to mediate the process by capitalizing on the fact that Server 1 can read and write files on Server 2; see System Design)
- hosting a facility's Server 2
- subscription to electronic records (nonn-video; in electronic format used by governing bodies) of sanctioned events, for purposes of comparison, study and general interest

Supplemental Products & Options

- products
 - delivery of video and stats to, e.g., iPhones, Pocket PCs, Palms (pay-per-download and/or pay for software widget on handheld that plays these files)
 - option for above to permit poolside use by coaches *and spectators* during events, with server broadcasting wi-fi to these
 - heads-up display in goggle (e.g., lap counter, split time)
 - team management and event management suite of tools (if coupled with PerforMax video & stats, might dominate existing products in this niche)
- system options
 - fully customized handheld coaches' units
 - handheld wireless displays (for weight consideration) with supporting server(s)



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Blue Sky Thinking

Breadcrumbs: [UserInterface/UserManagement](#) > [Main/WorkoutManager](#) > [Main/HomePage](#) >

[Main/FeaturesUnderConsideration](#) > [Main/BlueSkyThinking](#) **Please help to organize or categorize these** (e.g., do-able, impossible, imponderable, later, etc.). Feel free to adopt an item by moving it into an appropriate topic, or promote it to features under consideration:

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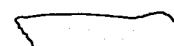
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- CFD (computational fluid dynamics) analysis of swimming, as described here
- "Force balance" for measuring swimmer's kick thrust. See this page for details. This is much simpler to implement than the CFD system described on the previous page.
- pre-set coach's comments
- live audio could be annoying if there's a delay; audio on/off switch on SD or goggle.
- depth info
- comparing stoke counts should take into account different arm lengths (there are swimmers of dramatically different sizes; also involved is how well the shoulder participates in the reach and the pull)
- comparison of streamlining distances (ed: there must be a speed drop-off beyond which greater underwater distance post-entry or post-turn is not an advantage) and distance-from-wall of initial entry (ed: angle of entry also a factor)
- measure of the force of the push-off from wall (may be calculated indirectly, but distance covered after push-off before stroking is influenced by e.g., streamlining and body shape)
- student swim journal to voluntarily record diet, last meal time, hours of rest, amount and quantity of water consumed pre-event (how each of these influences a given swimmer is highly individual and shouldn't necessarily be compared to other swimmers).
- Variable-weight medicine ball
- an underwater screen at the end of lane giving the last split time and the lap count (does Cranbrook have mirrors — if so, how are they used?)
- fog-less goggles, variable-tint goggles (for indoor/outdoor/bright/cloudy conditions)
- Allow a "nickname" that can override the actual name for certain screen displays; a user convenience that also pays off on the rare occasion two students have the "same" name when it's abbreviated/truncated in various ways.
 - **SH:** I think their proper first and last name is fine, no nickname needed. I'm thinking they will, or a parent or coach, enter themselves into the "system" from home via the internet on the PerforMax webpage.

Items moved to "Features Under Consideration":

- heads-up display in goggle (e.g., lap counter, split time)
- current/avg. speed and target speed
- breaths-per-lap and where in the lap each breath were taken
- split times
- compare to personal performances and personal goals
- see/hear their exercise assignments
- lap/yards counter



- turn times
- video — need ability to fast-forward (the sentiment was that the time spent studying their swimming shouldn't take away from their homework time)
- stats: stroke effectiveness, compare to rival teammate/other benchmark stats, effort level, hydration and glucose, coach's comments
- send-offs (meeting these goal times is a measure of accomplishment and an aid to setting future send-off times for any given exercise)
- see/set the purpose/goal of the exercise
- total yardage and total rest time for each exercise and for an overall workout
- clock in ear

Items moved to other pages (provide links):

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Coachless Operation

Breadcrumbs: Main/TeamMeeting2008July1-2 > Main/PerforMaxEventsAndMeetings > Main/OtherSystems > Main/SwimCamp2008 > UserInterface/CoachlessOperation

Coach-less operation

There will be times when it is useful to allow one or more swimmers to use the system without the presence of coaching staff. Some constraints would need to be imposed for system integrity (e.g., no defining exercises, no saving video or data permanently — although it might be kept temporarily to allow swimmer-coach review and the coach could choose to save it then). Coach-less operation may require new or modified system capabilities.

Points of discussion include:

- Can the system detect when an exercise is started and completed without hands-on assistance at the Master Station?
- Can the SD or an end-of-lane device include a button-switch to send a signal indicating swimmer readiness, or can the swimmer somehow use the LED to do so (e.g., simply covering/revealing it with hand á la simplified Morse code, with the system sending an audio response to the earpiece to acknowledge)?
- Can the system use the SD's earpiece to emit a count-down-to-send-off, interval expired, etc. tone? Could voice synthesis (e.g., provided by the Master Console's host OS) send an audio lap count to the swimmer's earpiece?
- Can the system recognize what exercise an athlete is performing? Otherwise, someone has to provide input to indicate "I'm doing this exercise now."

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<http://www.forth.com/special/performax/wiki/index.php?n=UserInterface.CoachlessOperation>

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Workout Sessions

Breadcrumbs: Main/Swimming > Main/FeaturesUnderConsideration > Swimming/Exercises > Main/SwimCamp2008 > Swimming/WorkoutSessions

Workout Sessions

General structure of most workouts

1. If new/returning/unknown-to-coach swimmers are present, an initial few lengths may be observed to group them in lanes by general ability in the exercise being performed; this is done to minimize drafting and interference.
2. **Warm-up** -- specific examples may prescribe:
 - x lengths/laps, any style ("free swimming")
 - assigned style down the length, any other stroke back
 - x lengths/laps
 - no resting, no treading water
3. **Rev-up** -- (Cranbrook-specific, this stage of the workout prepares swimmers for exertion)
 - Given an exercise assignment, the first repetition uses moderate effort, next followed by better effort, then by all-out effort (may repeat x times/y distance).
 - Some might use this to determine target times for the primary exercises.
4. **Main/primary workout**
 - Different exercises for different purposes: endurance/stamina, technique, pulmonary (via specifying how often and when to breath) and strength.
 - "Something specific" or "anything except something" (e.g., no freestyle) or "not this" (e.g., no breaths) or swimmer's choice of stroke, for a duration or distance or until an event (time of day, or the coach says to stop).
 - Commonly an exercise is given for X distance (in lengths, laps or yards/meters), but sometimes it might be a number of strokes or kicks, or a given stroke for a distance less than the full pool length. E.g., for weaker swimmers the breaststroke can be exhausting, so the coach might assign 15 breaststrokes then freestyle to complete the assigned length, or assign breaststroke for a certain distance less than a lap then freestyle, et al.
 - E.g., one set of x stroke type to judge their general ability (e.g., for new/unfamiliar students whose skill level is unknown), then repeat with the goal of e.g., technique or speed or comparison to their target/benchmark time).
 - E.g., purpose: develop pacing and skill at progressive effort; based on past/recent

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performances and on time differences between successive lengths/laps, determine when to go all out and help swimmer learn how to expend energy (i.e., can't go all out all the time) — for example, a 3 x 50m freestyle first at moderate pace, then another faster, then another sprinting.

- x lengths/laps, each under a specified time.
- Kick board, 4 lengths, showing better effort each of x laps, and a given target time
- Lactate — an intense, full-out exercise with a longer rest interval afterward; e.g., simulates event conditions, in which a swimmer must wait to get called on deck; intended, can be used, e.g., to improve recovery time for next-event readiness.

5. Warm-down (aka "cool-down"); may be same or similar to exercises used for warm-up

- E.g., 4 lengths/100 yards using any stroke

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Exercise Categories

Breadcrumbs: Swimming/Exercises > Swimming/WorkoutSessions > UserInterface/WorkoutManager >

Main/SwimCamp2008 > WorkoutManager/ExerciseCategories

Ways to categorize exercises

See also: exercise purposes

We will explore ways to categorize exercises to assist in defining/presenting them logically and selecting/assigning them easily. One way to categorize exercises very generally includes these categories (source: <http://www.usms.org/fitness/content/usingthepaceclock>):

- **Straight Sets** — a fixed number of repetitions of one exercise of a fixed length (yards/meters), for a fixed time interval (interval = swim time + rest time between repetitions). The send-off time on the clock will be different for each repetition unless the interval is an even minute:

Example #1: 10 x 50 yards on 1:00

Explanation:

10 — number of repetitions

50 yards — distance of each repetition

1:00 — interval for each repetition (swim + rest)

Example #2: 10 x 50 yards on :55

Explanation:

10 — number of repetitions

50 yards — distance of each repetition

:55 — interval for each repetition (the send-off time will be 5 seconds earlier on the clock for each successive repetition)

(In a mixed-ability pool, this challenges the slower swimmers and they get less time to rest than faster swimmers.)

- **Fixed-Rest Sets** — less demanding for swimmers, this allows a fixed amount of rest time after each repetition regardless of swim time. The swimmer will start each repetition at a different clock time because their swim time will vary.

Example: 4 x 200 yards with :30 rest

Explanation:

4 repetitions of a 200 yard swim, with 30 seconds rest between each repetition

- **Variable-Rest Sets** — unlike Fixed-Rest Sets, the resting time varies before each repetition.

Example: 4 x 200 yards with :30, :20 and :10 rest

Explanation:

4 repetitions of a 200 yard swim, with 30 seconds rest after the first 200 yards, 20 seconds rest after the second 200 yards and 10 seconds rest after the third repetition.

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- **Timed Swims** — the swimmer swims for a fixed period of time, with or without repetitions. The clock will differ at the start of each repetition if the fixed swim time plus the fixed rest time do not equal a whole number of minutes.

Example #1: T-20

Explanation:

Swim continuously for 20 minutes

Example #2: 4 x 5:00 with 1:00 rests

Explanation:

Repeat this 4 times: swim for 5 minutes then rest one minute.

- **Broken Swims** — this is a fixed swim distance, broken into arbitrary swim lengths each followed by a fixed or variable resting time.

Example: Broken 200 as 50, 25, 50, 25, 50 with :15 rests

Explanation:

Swim 50 yards/meters, rest 15 seconds; swim 25 yards/meters, rest 15 seconds; etc. System should provide total time, total swim time and break times (the time for each of the assigned lengths).

- **Descending Interval** — a fixed-length swim with shorter rests between each repetition.

Example: 6 x 100 with a starting 2:00 interval descending by :05 for each repetition.

Explanation:

Swim 100 yards/meters and rest just enough so the next send-off is at the 2:00 mark; then swim 100 yards/meters and rest just enough so the next send-off is at 1:55; etc., until 6 repetitions have been completed.

- **Ascending Interval** — like Descending Interval but increasing the interval value at each repetition.
- **Pyramid Intervals** — Pyramid intervals are sets that combine descending and ascending intervals. For example, a pyramid set might consist of 7 x 150 on intervals of 2:20, 2:30, 2:40, 2:50, 2:40, 2:30 and 2:20.
- **Descending Interval/Descending Times** — for each repetition, the interval is decreased until the swimmer cannot complete the assigned distance in the allotted interval.

Example #1: 50s starting on 1:00, descending interval by :01 per 50 until failure.

Explanation:

Swim 50 yards on a 1 minute interval; swim 50 on a :59 second interval; swim 50 on a :58 interval; etc. until swimmer cannot swim the 50 in that repetition's interval.

Example #2: Same as above, but also descend times by :01 per 50.

Explanation:

As above, but the swimmer must complete each 50-yard/meter repetition 1 second faster than the preceding repetition, not including any rest time.

- **Ladders** — a set of various swim distances to be swum on a fixed interval per a given distance.

Example: 300, 275, 250, 225, 200...25 on :35 per 25 yards

Explanation:

Swim 300 yards at a fixed interval of 35 seconds per each 25 yards $((300/25)*35 = 420$ seconds to complete 300 yards); swim 275 at same interval $((275/25)*35 = 385$ seconds to complete 275 yards); swim 250 on the same interval $((250/25)*35 = 350$ seconds to complete 250 yards); etc.

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