



Accelerometer

An **accelerometer** is a tool that measures proper acceleration.^[1] Proper acceleration is the acceleration (the rate of change of velocity) of a body in its own instantaneous rest frame;^[2] this is different from coordinate acceleration, which is acceleration in a fixed coordinate system. For example, an accelerometer at rest on the surface of the Earth will measure an acceleration due to Earth's gravity, straight upwards^[3] (by definition) of $g \approx 9.81 \text{ m/s}^2$. By contrast, accelerometers in free fall (falling toward the center of the Earth at a rate of about 9.81 m/s^2) will measure zero.

Accelerometers have many uses in industry and science. Highly sensitive accelerometers are used in inertial navigation systems for aircraft and missiles. Vibration in rotating machines is monitored by accelerometers. They are used in tablet computers and digital cameras so that images on screens are always displayed upright. In unmanned aerial vehicles, accelerometers help to stabilise flight.

When two or more accelerometers are coordinated with one another, they can measure differences in proper acceleration, particularly gravity, over their separation in space—that is, the gradient of the gravitational field. Gravity gradiometry is useful because absolute gravity is a weak effect and depends on the local density of the Earth, which is quite variable.

Single- and multi-axis accelerometers can detect both the magnitude and the direction of the proper acceleration, as a vector quantity, and can be used to sense orientation (because the direction of weight changes), coordinate acceleration, vibration, shock, and falling in a resistive medium (a case in which the proper acceleration changes, increasing from zero). Micromachined microelectromechanical systems (MEMS) accelerometers are increasingly present in portable electronic devices and video-game controllers, to detect changes in the positions of these devices.



An accelerometer

Physical principles

An accelerometer measures proper acceleration, which is the acceleration it experiences relative to freefall and is the acceleration felt by people and objects.^[2] Put another way, at any point in spacetime the equivalence principle guarantees the existence of a local inertial frame, and an accelerometer measures the acceleration relative to that frame.^[4] Such accelerations are popularly denoted g-force; i.e., in comparison to standard gravity.

An accelerometer at rest relative to the Earth's surface will indicate approximately 1 *g upwards* because the Earth's surface exerts a normal force upwards relative to the local inertial frame (the frame of a freely falling object near the surface). To obtain the acceleration due to motion with respect to the Earth, this "gravity offset" must be subtracted and corrections made for effects caused by the Earth's rotation relative to the inertial frame.

The reason for the appearance of a gravitational offset is Einstein's equivalence principle,^[5] which states that the effects of gravity on an object are indistinguishable from acceleration. When held fixed in a gravitational field by, for example, applying a ground reaction force or an equivalent upward thrust, the reference frame for an accelerometer (its own casing) accelerates upwards with respect to a free-falling reference frame. The effects of this acceleration are indistinguishable from any other acceleration experienced by the instrument so that an accelerometer cannot detect the difference between sitting in a rocket on the launch pad, and being in the same rocket in deep space while it uses its engines to accelerate at 1 g. For similar reasons, an accelerometer will read *zero* during any type of free fall. This includes use in a coasting spaceship in deep space far from any mass, a spaceship orbiting the Earth, an airplane in a parabolic "zero-g" arc, or any free-fall in a vacuum. Another example is free-fall at a sufficiently high altitude that atmospheric effects can be neglected.

However, this does not include a (non-free) fall in which air resistance produces drag forces that reduce the acceleration until constant terminal velocity is reached. At terminal velocity, the accelerometer will indicate 1 g acceleration upwards. For the same reason a skydiver, upon reaching terminal velocity, does not feel as though he or she were in "free-fall", but rather experiences a feeling similar to being supported (at 1 g) on a "bed" of uprushing air.

Acceleration is quantified in the SI unit metres per second per second (m/s^2), in the cgs unit gal (Gal), or popularly in terms of standard gravity (*g*).

For the practical purpose of finding the acceleration of objects with respect to the Earth, such as for use in an inertial navigation system, a knowledge of local gravity is required. This can be obtained either by calibrating the device at rest,^[6] or from a known model of gravity at the approximate current position.

Structure

A basic mechanical accelerometer is a damped proof mass on a spring. When the accelerometer experiences an acceleration, Newton's third law causes the spring's compression to adjust to exert an equivalent force on the mass to counteract the acceleration. Since the spring's force scales linearly with amount of compression (according to Hooke's law) and because the spring constant and mass are known constants, a measurement of the spring's compression is also a measurement of acceleration. The system is damped to prevent oscillations of the mass and spring interfering with measurements. However, the damping causes accelerometers to have a frequency response.

Many animals have sensory organs to detect acceleration, especially gravity. In these, the proof mass is usually one or more crystals of calcium carbonate otoliths (Latin for "ear stone") or statoconia, acting against a bed of hairs connected to neurons. The hairs form the springs, with the neurons as sensors. The damping is usually by a fluid. Many vertebrates, including humans, have these structures in their inner ears. Most invertebrates have similar organs, but not as part of their hearing organs. These are called statocysts.

Mechanical accelerometers are often designed so that an electronic circuit senses a small amount of motion, then pushes on the proof mass with some type of linear motor to keep the proof mass from moving far. The motor might be an electromagnet or in very small accelerometers, electrostatic. Since the circuit's electronic behavior can be carefully designed, and the proof mass does not move far, these designs can be very stable (i.e. they do not oscillate), very linear with a controlled frequency response. (This is called servo mode design.)

In mechanical accelerometers, measurement is often electrical, piezoelectric, piezoresistive or capacitive. Piezoelectric accelerometers use piezoceramic sensors (e.g. lead zirconate titanate) or single crystals (e.g. quartz, tourmaline). They are unmatched in high frequency measurements, low packaged weight, and resistance to high temperatures. Piezoresistive accelerometers resist shock (very high accelerations) better. Capacitive accelerometers typically use a silicon micro-machined sensing element. They measure low frequencies well.

Modern mechanical accelerometers are often small *micro-electro-mechanical systems* (MEMS), and are often very simple MEMS devices, consisting of little more than a cantilever beam with a proof mass (also known as *seismic mass*). Damping results from the residual gas sealed in the device. As long as the Q-factor is not too low, damping does not result in a lower sensitivity.

Under the influence of external accelerations, the proof mass deflects from its neutral position. This deflection is measured in an analog or digital manner. Most commonly, the capacitance between a set of fixed beams and a set of beams attached to the proof mass is measured. This method is simple, reliable, and inexpensive. Integrating piezoresistors in the springs to detect spring deformation, and thus deflection, is a good alternative, although a few more process steps are needed during the fabrication sequence. For very high sensitivities quantum tunnelling is also used; this requires a dedicated process making it very expensive. Optical measurement has been demonstrated in laboratory devices.

Another MEMS-based accelerometer is a thermal (or convective) accelerometer.^[7] It contains a small heater in a very small dome. This heats the air or other fluid inside the dome. The thermal bubble acts as the proof mass. An accompanying temperature sensor (like a thermistor; or thermopile) in the dome measures the temperature in one location of the dome. This measures the location of the heated bubble within the dome. When the dome is accelerated, the colder, higher density fluid pushes the heated bubble. The measured temperature changes. The temperature measurement is interpreted as acceleration. The fluid provides the damping. Gravity acting on the fluid provides the spring. Since the proof mass is very lightweight gas, and not held by a beam or lever, thermal accelerometers can survive high shocks. Another variation uses a wire to both heat the gas and detect the change in temperature. The change of temperature changes the resistance of the wire. A two dimensional accelerometer can be economically constructed with one dome, one bubble and two measurement devices.

Most micromechanical accelerometers operate *in-plane*, that is, they are designed to be sensitive only to a direction in the plane of the die. By integrating two devices perpendicularly on a single die a two-axis accelerometer can be made. By adding another *out-of-plane* device, three axes can be measured. Such a combination may have much lower misalignment error than three discrete models combined after packaging.

Micromechanical accelerometers are available in a wide variety of measuring ranges, reaching up to thousands of *g*'s. The designer must compromise between sensitivity and the maximum acceleration that can be measured.

Applications

Engineering

Accelerometers can be used to measure vehicle acceleration. Accelerometers can be used to measure vibration on cars, machines, buildings, process control systems and safety installations. They can also be used to measure seismic activity, inclination, machine vibration, dynamic distance and speed with or without the influence of gravity. Applications for accelerometers that measure gravity, wherein an accelerometer is specifically configured for use in gravimetry, are called gravimeters.

Notebook computers equipped with accelerometers can contribute to the Quake-Catcher Network (QCN), a BOINC project aimed at scientific research of earthquakes.^[8]

Biology

Accelerometers are also increasingly used in the biological sciences. High frequency recordings of bi-axial^[9] or tri-axial acceleration^[10] allows the discrimination of behavioral patterns while animals are out of sight. Furthermore, recordings of acceleration allow researchers to quantify the rate at which an animal is expending energy in the wild, by either determination of limb-stroke frequency^[11] or measures such as overall dynamic body acceleration^[12] Such approaches have mostly been adopted by marine scientists due to an inability to study animals in the wild using visual observations, however an increasing number of terrestrial biologists are adopting similar approaches. For example, accelerometers have been used to study flight energy expenditure of Harris's Hawk (*Parabuteo unicinctus*).^[13] Researchers are also using smartphone accelerometers to collect and extract mechano-biological descriptors of resistance exercise.^[14] Increasingly, researchers are deploying accelerometers with additional technology, such as cameras or microphones, to better understand animal behaviour in the wild (for example, hunting behaviour of Canada lynx^[15]).

Industry

Accelerometers are also used for machinery health monitoring to report the vibration and its changes in time of shafts at the bearings of rotating equipment such as turbines, pumps,^[16] fans,^[17] rollers,^[18] compressors,^{[19][20]} or bearing fault^[21] which, if not attended to promptly, can lead to costly repairs. Accelerometer vibration data allows the user to monitor machines and detect these faults before the rotating equipment fails completely.

Building and structural monitoring

Accelerometers are used to measure the motion and vibration of a structure that is exposed to dynamic loads. Dynamic loads originate from a variety of sources including:

- Human activities – walking, running, dancing or skipping
- Working machines – inside a building or in the surrounding area
- Construction work – driving piles, demolition, drilling and excavating
- Moving loads on bridges
- Vehicle collisions
- Impact loads – falling debris
- Concussion loads – internal and external explosions
- Collapse of structural elements
- Wind loads and wind gusts

- Air blast pressure
- Loss of support because of ground failure
- Earthquakes and aftershocks

Under structural applications, measuring and recording how a structure dynamically responds to these inputs is critical for assessing the safety and viability of a structure. This type of monitoring is called Health Monitoring, which usually involves other types of instruments, such as displacement sensors -Potentiometers, LVDTs, etc.- deformation sensors -Strain Gauges, Extensometers-, load sensors -Load Cells, Piezo-Electric Sensors- among others.

Medical applications

Zoll's AED Plus uses CPR-D•padz which contain an accelerometer to measure the depth of CPR chest compressions.

Within the last several years, several companies have produced and marketed sports watches for runners that include footpods, containing accelerometers to help determine the speed and distance for the runner wearing the unit.

In Belgium, accelerometer-based step counters are promoted by the government to encourage people to walk a few thousand steps each day.

Herman Digital Trainer uses accelerometers to measure strike force in physical training.^{[22][23]}

It has been suggested to build football helmets with accelerometers in order to measure the impact of head collisions.^[24]

Accelerometers have been used to calculate gait parameters, such as stance and swing phase. This kind of sensor can be used to measure or monitor people.^{[25][26]}

Navigation

An inertial navigation system is a navigation aid that uses a computer and motion sensors (accelerometers) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. Other terms used to refer to inertial navigation systems or closely related devices include inertial guidance system, inertial reference platform, and many other variations.

An accelerometer alone is unsuitable to determine changes in altitude over distances where the vertical decrease of gravity is significant, such as for aircraft and rockets. In the presence of a gravitational gradient, the calibration and data reduction process is numerically unstable.^{[27][28]}

Transport

Accelerometers are used to detect apogee in both professional^[29] and in amateur^[30] rocketry.

Accelerometers are also being used in Intelligent Compaction rollers. Accelerometers are used alongside gyroscopes in inertial navigation systems.^[31]

One of the most common uses for MEMS accelerometers is in airbag deployment systems for modern automobiles. In this case, the accelerometers are used to detect the rapid negative acceleration of the vehicle to determine when a collision has occurred and the severity of the collision. Another common automotive use is in electronic stability control systems, which use a lateral accelerometer to measure cornering forces. The widespread use of accelerometers in the automotive industry has pushed their cost down dramatically.^[32] Another automotive application is the monitoring of noise, vibration, and harshness (NVH), conditions that cause discomfort for drivers and passengers and may also be indicators of mechanical faults.

Tilting trains use accelerometers and gyroscopes to calculate the required tilt.^[33]

Volcanology

Modern electronic accelerometers are used in remote sensing devices intended for the monitoring of active volcanoes to detect the motion of magma.^[34]

Consumer electronics

Accelerometers are increasingly being incorporated into personal electronic devices to detect the orientation of the device, for example, a display screen.

A *free-fall sensor* (FFS) is an accelerometer used to detect if a system has been dropped and is falling. It can then apply safety measures such as parking the head of a hard disk to prevent a head crash and resulting data loss upon impact. This device is included in the many common computer and consumer electronic products that are produced by a variety of manufacturers. It is also used in some data loggers to monitor handling operations for shipping containers. The length of time in free fall is used to calculate the height of drop and to estimate the shock to the package.

Motion input

Some smartphones, digital audio players and personal digital assistants contain accelerometers for user interface control; often the accelerometer is used to present landscape or portrait views of the device's screen, based on the way the device is being held. Apple has included an accelerometer in every generation of iPhone, iPad, and iPod touch, as well as in every iPod nano since the 4th generation. Along with orientation view adjustment, accelerometers in mobile devices can also be used as pedometers, in conjunction with specialized applications.^[35]

Automatic Collision Notification (ACN) systems also use accelerometers in a system to call for help in event of a vehicle crash. Prominent ACN systems include OnStar AACN service, Ford Link's 911 Assist, Toyota's Safety Connect, Lexus Link, or BMW Assist. Many accelerometer-equipped smartphones also have ACN software available for download. ACN systems are activated by detecting crash-strength accelerations.



Tri-axis Digital Accelerometer by
Kionix, inside Motorola Xoom

Accelerometers are used in vehicle Electronic stability control systems to measure the vehicle's actual movement. A computer compares the vehicle's actual movement to the driver's steering and throttle input. The stability control computer can selectively brake individual wheels and/or reduce engine power to minimize the difference between driver input and the vehicle's actual movement. This can help prevent the vehicle from spinning or rolling over.

Some pedometers use an accelerometer to more accurately measure the number of steps taken and distance traveled than a mechanical sensor can provide.

Nintendo's Wii video game console uses a controller called a Wii Remote that contains a three-axis accelerometer and was designed primarily for motion input. Users also have the option of buying an additional motion-sensitive attachment, the Nunchuk, so that motion input could be recorded from both of the user's hands independently. Is also used on the Nintendo 3DS system.

The Sony PlayStation 3 uses the DualShock 3 remote which uses a three axis accelerometer that can be used to make steering more realistic in racing games, such as MotorStorm and Burnout Paradise.

The Nokia 5500 sport features a 3D accelerometer that can be accessed from software. It is used for step recognition (counting) in a sport application, and for tap gesture recognition in the user interface. Tap gestures can be used for controlling the music player and the sport application, for example to change to next song by tapping through clothing when the device is in a pocket. Other uses for accelerometer in Nokia phones include Pedometer functionality in Nokia Sports Tracker. Some other devices provide the tilt sensing feature with a cheaper component, which is not a true accelerometer.

Sleep phase alarm clocks use accelerometric sensors to detect movement of a sleeper, so that it can wake the person when he/she is not in REM phase, in order to awaken the person more easily.^[36]

Sound recording

A microphone or eardrum is a membrane that responds to oscillations in air pressure. These oscillations cause acceleration, so accelerometers can be used to record sound.^[37] A 2012 study found that voices can be detected by smartphone accelerometers in 93% of typical daily situations.^[38]

Conversely, carefully designed sounds can cause accelerometers to report false data. One study tested 20 models of (MEMS) smartphone accelerometers and found that a majority were susceptible to this attack.^[39]

Orientation sensing

A number of 21st-century devices use accelerometers to align the screen depending on the direction the device is held (e.g., switching between portrait and landscape modes). Such devices include many tablet PCs and some smartphones and digital cameras. The Amida Simputer, a handheld Linux device launched in 2004, was the first commercial handheld to have a built-in accelerometer. It incorporated many gesture-based interactions using this accelerometer, including page-turning, zoom-in and zoom-out of images, change of portrait to landscape mode, and many simple gesture-based games.

As of January 2009, almost all new mobile phones and digital cameras contain at least a tilt sensor and sometimes an accelerometer for the purpose of auto image rotation, motion-sensitive mini-games, and correcting shake when taking photographs.

Image stabilization

Camcorders use accelerometers for image stabilization, either by moving optical elements to adjust the light path to the sensor to cancel out unintended motions or digitally shifting the image to smooth out detected motion. Some stills cameras use accelerometers for anti-blur capturing. The camera holds off capturing the image when the camera is moving. When the camera is still (if only for a millisecond, as could be the case for vibration), the image is captured. An example of the application of this technology is the Glogger VS2,^[40] a phone application which runs on Symbian based phones with accelerometers such as the Nokia N96. Some digital cameras contain accelerometers to determine the orientation of the photo being taken and also for rotating the current picture when viewing.

Device integrity

Many laptops feature an accelerometer which is used to detect drops. If a drop is detected, the heads of the hard disk are parked to avoid data loss and possible head or disk damage by the ensuing shock.

Gravimetry

A **gravimeter** or gravitometer, is an instrument used in gravimetry for measuring the local gravitational field. A gravimeter is a type of accelerometer, except that accelerometers are susceptible to all vibrations including noise, that cause oscillatory accelerations. This is counteracted in the gravimeter by integral vibration isolation and signal processing. Though the essential principle of design is the same as in accelerometers, gravimeters are typically designed to be much more sensitive than accelerometers in order to measure very tiny changes within the Earth's gravity, of 1 *g*. In contrast, other accelerometers are often designed to measure 1000 *g* or more, and many perform multi-axial measurements. The constraints on temporal resolution are usually less for gravimeters, so that resolution can be increased by processing the output with a longer "time constant".

Types of accelerometer

- Bulk micromachined capacitive
- Bulk micromachined piezoelectric resistive
- Capacitive spring mass system base
- DC response
- Electromechanical servo (servo force balance)
- High gravity
- High temperature
- Laser accelerometer
- Low frequency
- Magnetic induction
- Modally tuned impact hammers
- Null-balance

- Optical
- Pendulous integrating gyroscopic accelerometer (PIGA)
- Piezoelectric accelerometer
- Quantum (rubidium atom cloud, laser cooled)
- Resonance
- Seat pad accelerometers
- Shear mode accelerometer
- Strain gauge
- Surface acoustic wave (SAW)
- Surface micromachined capacitive (MEMS)
- Thermal (submicrometre CMOS process)
- Triaxial
- Vacuum diode with flexible anode^[41]
- potentiometric type
- LVDT type accelerometer

Exploits and privacy concerns

Accelerometer data, which can be accessed by third-party apps without user permission in many mobile devices,^[42] has been used to infer rich information about users based on the recorded motion patterns (e.g., driving behavior, level of intoxication, age, gender, touchscreen inputs, geographic location).^[43] If done without a user's knowledge or consent, this is referred to as an inference attack. Additionally, millions of smartphones could be vulnerable to software cracking via accelerometers.^{[44][45]}

See also

- Accelerograph
- Degrees of freedom
- g-force
- Geophone
- Gyroscope
- Inclinometer
- Inertial measurement unit
- Inertial navigation system
- Magnetometer
- Seismometer
- Vibration calibrator

References

1. Tinder, Richard F. (2007). *Relativistic Flight Mechanics and Space Travel: A Primer for Students, Engineers and Scientists*. Morgan & Claypool Publishers. p. 33. ISBN 978-1-59829-130-8. Extract of page 33 (<https://books.google.com/books?id=-uMRwLaNbC8C&pg=PA33>)

2. Rindler, W. (2013). *Essential Relativity: Special, General, and Cosmological* (<https://books.google.com/books?id=WTfnBwAAQBAJ>) (illustrated ed.). Springer. p. 61. ISBN 978-1-4757-1135-6. Extract of page 61 (<https://books.google.com/books?id=WTfnBwAAQBAJ&pg=PA61>)
3. Corke, Peter (2017). *Robotics, Vision and Control: Fundamental Algorithms In MATLAB* (<https://books.google.com/books?id=d4EkDwAAQBAJ>) (second, completely revised, extended and updated ed.). Springer. p. 83. ISBN 978-3-319-54413-7. Extract of page 83 (<https://books.google.com/books?id=d4EkDwAAQBAJ&pg=PA83>)
4. Einstein, Albert (1920). "20" (<http://www.bartleby.com/173/20.html>). *Relativity: The Special and General Theory*. New York: Henry Holt. p. 168. ISBN 978-1-58734-092-5.
5. Penrose, Roger (2005) [2004]. "17.4 The Principle of Equivalence". *The Road to Reality* (https://archive.org/details/roadtorealitycom00penr_0). New York: Knopf. pp. 393–394 (https://archive.org/details/roadtorealitycom00penr_0/page/393). ISBN 978-0-470-08578-3.
6. Doscher, James. "Accelerometer Design and Applications" (https://web.archive.org/web/20081213001559/http://www.analog.com/en/technical-library/faqs/design-center/faqs/CU_faq_MEMs/resources/fca.html). Analog Devices. Archived from the original (http://www.analog.com/en/technical-library/faqs/design-center/faqs/CU_faq_MEMs/resources/fca.html) on 13 December 2008. Retrieved 23 December 2008.
7. Mukherjee, Rahul; Basu, Joydeep; Mandal, Pradip; Guha, Prasanta Kumar (2017). "A review of micromachined thermal accelerometers" (<http://stacks.iop.org/0960-1317/27/i=12/a=123002?key=crossref.1e9a8280a933644098e54f005bcc2082>). *Journal of Micromechanics and Microengineering*. **27** (12): 123002. arXiv:1801.07297 (<https://arxiv.org/abs/1801.07297>). Bibcode:2017JMiMi..27I3002M (<https://ui.adsabs.harvard.edu/abs/2017JMiMi..27I3002M>). doi:10.1088/1361-6439/aa964d (<https://doi.org/10.1088%2F1361-6439%2Faa964d>). S2CID 116232359 (<https://api.semanticscholar.org/CorpusID:116232359>).
8. "Quake-Catcher Network – Downloads" (<https://web.archive.org/web/20100621235440/http://qcn.stanford.edu/downloads/index.php>). Quake-Catcher Network. Archived from the original (<http://qcn.stanford.edu/downloads/index.php>) on 21 June 2010. Retrieved 15 July 2009. "If you have a Mac laptop , a Thinkpad (2003 or later), or a desktop with a USB sensor, you can download software to turn your computer into a Quake-Catcher Sensor"
9. Yoda et al. (2001) *Journal of Experimental Biology* 204(4): 685–690
10. Shepard, Emily L. C.; Wilson, Rory P.; Quintana, Flavio; Laich, Agustina Gómez; Liebsch, Nikolai; Albaredas, Diego A.; Halsey, Lewis G.; Gleiss, Adrian; Morgan, David T.; Myers, Andrew E.; Newman, Chris; Macdonald, David W. "Identification of animal movement patterns using tri-axial accelerometry" (<https://www.int-res.com/articles/esr2008/theme/Tracking/TMVpp1.pdf>) (PDF). *int-res.com*. Archived (<https://web.archive.org/web/20121107053420/http://www.int-res.com/articles/esr2008/theme/Tracking/TMVpp1.pdf>) (PDF) from the original on 7 November 2012. Retrieved 11 September 2014.
11. Kawabe et al. (2003) *Fisheries Science* 69 (5):959 – 965
12. Wilson et al. (2006) *Journal of Animal Ecology*:75 (5):1081 – 1090
13. Walsum, Tessa A. Van; Perna, Andrea; Bishop, Charles M.; Murn, Campbell P.; Collins, Philip M.; Wilson, Rory P.; Halsey, Lewis G. (2020). "Exploring the relationship between flapping behaviour and accelerometer signal during ascending flight, and a new approach to calibration" (http://centaur.reading.ac.uk/82069/1/Walsum_et_al-2019-Ibis.pdf) (PDF). *Ibis*. **162** (1): 13–26. doi:10.1111/ibi.12710 (<https://doi.org/10.1111%2Fibi.12710>). ISSN 1474-919X (<https://www.worldcat.org/issn/1474-919X>). S2CID 92209276 (<https://api.semanticscholar.org/CorpusID:92209276>).

14. Viecelli, Claudio; Graf, David; Aguayo, David; Hafen, Ernst; Fuchslin, Rudolf M. (15 July 2020). "Using smartphone accelerometer data to obtain scientific mechanical-biological descriptors of resistance exercise training" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7363108>). *PLOS ONE*. **15** (7): e0235156. Bibcode:2020PLoSO..1535156V (<https://ui.adsabs.harvard.edu/abs/2020PLoSO..1535156V>). doi:10.1371/journal.pone.0235156 (<https://doi.org/10.1371%2Fjournal.pone.0235156>). ISSN 1932-6203 (<https://www.worldcat.org/issn/1932-6203>). PMC 7363108 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7363108>). PMID 32667945 (<https://pubmed.ncbi.nlm.nih.gov/32667945>).
15. Studd, Emily K.; Derbyshire, Rachael E.; Menzies, Allyson K.; Simms, John F.; Humphries, Murray M.; Murray, Dennis M.; Boutin, Stan (2021). "The Purr-fect Catch: Using accelerometers and audio recorders to document kill rates and hunting behaviour of a small prey specialist" (<https://doi.org/10.1111%2F2041-210X.13605>). *Methods in Ecology and Evolution*. **12** (7): 1277–1287. doi:10.1111/2041-210X.13605 (<https://doi.org/10.1111%2F2041-210X.13605>). S2CID 235537052 (<https://api.semanticscholar.org/CorpusID:235537052>).
16. Klubnik, Renard; Sullivan, Ron. "Know the Age of your Pumps" (<https://web.archive.org/web/20121114125302/http://www.wilcoxon.com/knowdesk/Know%20the%20health%20of%20your%20pumps.pdf>) (PDF). Archived from the original (<http://www.wilcoxon.com/knowdesk/Know%20the%20health%20of%20your%20pumps.pdf>) (PDF) on 14 November 2012. Retrieved 9 January 2009.
17. Wilcoxon Research. "Guidance for mounting 4–20 mA vibration sensors on fans" (<https://web.archive.org/web/20160304101438/http://www.wilcoxon.com/knowdesk/Guidance%20for%20mounting%204-20mA%20sensors%20on%20fans.pdf>) (PDF). Archived from the original (<http://www.wilcoxon.com/knowdesk/Guidance%20for%20mounting%204-20mA%20sensors%20on%20fans.pdf>) (PDF) on 4 March 2016. Retrieved 11 September 2014.
18. Klubnik, Renard; Sullivan, Ron. "Know the Health of your Pumps" (<https://web.archive.org/web/20121114125302/http://www.wilcoxon.com/knowdesk/Know%20the%20health%20of%20your%20pumps.pdf>) (PDF). Archived from the original (<http://www.wilcoxon.com/knowdesk/Vibration%20monitoring%20of%20slow%20speed%20rollers.pdf>) (PDF) on 14 November 2012. Retrieved 11 September 2014.
19. "Low Frequency Vibration Measurements on a Compressor Gear Set" (<https://web.archive.org/web/20121114125343/http://www.wilcoxon.com/knowdesk/LF%20VM%20on%20compressor%20gear%20set.pdf>) (PDF). *wilcoxon research*. 14 November 2014. Archived from the original (<http://www.wilcoxon.com/knowdesk/LF%20VM%20on%20compressor%20gear%20set.pdf>) (PDF) on 14 November 2012. Retrieved 11 September 2014. "The gear set on a critical turbo-compressor was monitored with a standard industrial accelerometer at very low frequencies..."
20. "Gearbox tutorial" (<https://web.archive.org/web/20121114125238/http://www.wilcoxon.com/knowdesk/gear.pdf>) (PDF). Wilcoxon Research. 11 September 2014. Archived from the original (<http://www.wilcoxon.com/knowdesk/gear.pdf>) (PDF) on 14 November 2012. Retrieved 9 January 2009.
21. "Bearing Failure: Causes and Cures Bearing Failure: Causes and Cures" (<https://web.archive.org/web/20150922024053/http://www.wilcoxon.com/knowdesk/bearing.pdf>) (PDF). *wilcoxon.com*. Archived from the original (<http://www.wilcoxon.com/knowdesk/bearing.pdf>) (PDF) on 22 September 2015. Retrieved 11 September 2014.
22. The Contender 3 Episode 1 SPARQ testing ESPN
23. "Welcome to GoHerman.com innovator of interactive personal training for fitness, – MARTIAL ARTS & MMA" (<http://www.goherman.com/martialarts.aspx>). Retrieved 12 September 2014.
24. Nosovitz, Dan (12 January 2011). "NFL Testing Helmets With Impact-Sensing Accelerometers for Concussion Analysis" (<http://www.popsci.com/technology/article/2011-01/nfl-test-helmets-impact-sensing-accelerometers-concussion-analysis>). *Popular Science*. Archived (<https://web.archive.org/web/20140912010842/http://www.popsci.com/technology/article/2011-01/nfl-test-helmets-impact-sensing-accelerometers-concussion-analysis>) from the original on 12 September 2014.

25. Irvin Hussein López-Nava (2010). "Towards Ubiquitous Acquisition and Processing of Gait Parameters". *Towards Ubiquitous Acquisition and Processing of Gait Parameters – Springer*. Lecture Notes in Computer Science. Vol. 6437. pp. 410–421. doi:10.1007/978-3-642-16761-4_36 (https://doi.org/10.1007%2F978-3-642-16761-4_36). ISBN 978-3-642-16760-7.
26. Lopez-Nava I. H. et Munoz-Melendez A. (2010). Towards ubiquitous acquisition and processing of gait parameters (<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.701.7421&rep=rep1&type=pdf>). In 9th Mexican International Conference on Artificial Intelligence, Hidalgo, Mexico.
27. "Vertical Speed Measurement, by Ed Hahn in sci.aeronautics.airliners, 1996-11-22" (http://yarchive.net/air/airliners/ins_novert.html). Retrieved 12 September 2014.
28. US patent 6640165 (<https://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US6640165>), Hayward, Kirk W. and Stephenson, Larry G., "Method and system of determining altitude of flying object", issued 2003-10-28
29. "Dual Deployment" (<http://westrocketry.com/articles/DualDeploy/DualDeployment.html>). Retrieved 12 September 2014.
30. "PICO altimeter" (<https://web.archive.org/web/20051219001601/http://www.picoalt.com/>). Archived from the original (<http://www.picoalt.com/>) on 19 December 2005. Retrieved 12 September 2014.
31. "Design of an integrated strapdown guidance and control system for a tactical missile" WILLIAMS, D. E. RICHMAN, J. FRIEDLAND, B. (Singer Co., Kearfott Div., Little Falls, NJ) AIAA-1983-2169 IN: Guidance and Control Conference, Gatlinburg, TN, 15–17 August 1983, Collection of Technical Papers (A83-41659 19–63). New York, American Institute of Aeronautics and Astronautics, 1983, p. 57-66.
32. Andrejašić, Matej (March 2008). *MEMS ACCELEROMETERS* (http://mafija.fmf.uni-lj.si/seminar/files/2007_2008/MEMS_accelerometers-koncna.pdf) (PDF). University of Ljubljana. Archived (https://web.archive.org/web/20140611054427/http://mafija.fmf.uni-lj.si/seminar/files/2007_2008/MEMS_accelerometers-koncna.pdf) (PDF) from the original on 11 June 2014.
33. Tilting trains shorten transit time (<http://www.memagazine.org/backissues/membersonly/june98/features/tilting/tilting.html>) Archived (<https://web.archive.org/web/20110604063917/http://www.memagazine.org/backissues/membersonly/june98/features/tilting/tilting.html>) 4 June 2011 at the Wayback Machine. Memagazine.org. Retrieved on 17 October 2011.
34. Michael Randall. "USGS – volcano monitoring" (https://vulcan.wr.usgs.gov/Glossary/Seismicity/description_seismic_monitoring.html). Retrieved 12 September 2014.
35. Eaton, Kit (18 February 2014). "These Apps Are Made For Walking - NYTimes.com" (<https://www.nytimes.com/2014/02/20/technology/personaltech/these-apps-are-made-for-walking.html>). *The New York Times*. Retrieved 12 September 2014.
36. Nam, Yunyoung; Kim, Yeesock; Lee, Jinseok (23 May 2016). "Sleep Monitoring Based on a Tri-Axial Accelerometer and a Pressure Sensor" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4883440>). *Sensors (Basel, Switzerland)*. **16** (5): 750. Bibcode:2016Senso..16..750N (<https://ui.adsabs.harvard.edu/abs/2016Senso..16..750N>). doi:10.3390/s16050750 (<https://doi.org/10.3390%2Fs16050750>). PMC 4883440 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4883440>). PMID 27223290 (<https://pubmed.ncbi.nlm.nih.gov/27223290>).
37. [1] (<https://www.analog.com/en/analog-dialogue/articles/mems-accelerometers-as-acoustic-pickups.html>) Using MEMS Accelerometers as Acoustic Pickups in Musical Instruments
38. [2] (https://venetosmani.com/publications/Speech_Activity_Detection_Using_Accelerometer_IEEE_EMBC_2012.pdf) IEEE 2012, Speech Activity Detection using Accelerometer, Aleksandar Matic, et.al.
39. [3] (<https://spectrum.ieee.org/tech-talk/telecom/security/smartphone-accelerometers-can-be-fooled-by-sound-waves>) IEEE Spectrum Smartphone Accelerometers Can Be Fooled by Sound Waves.
40. "Glogger" (<http://m.eyetap.org>). Retrieved 12 September 2014.

41. "Mullard: *DDR100 Accelerometer Double Diode* data sheet" (<http://tubedata.milbert.com/sheets/154/d/DDR100.pdf>) (PDF). Retrieved 7 May 2013.
 42. Bai, Xiaolong; Yin, Jie; Wang, Yu-Ping (2017). "Sensor Guardian: prevent privacy inference on Android sensors" (<https://doi.org/10.1186%2Fs13635-017-0061-8>). *EURASIP Journal on Information Security*. **2017** (1). doi:10.1186/s13635-017-0061-8 (<https://doi.org/10.1186%2Fs13635-017-0061-8>). ISSN 2510-523X (<https://www.worldcat.org/issn/2510-523X>).
 43. Kröger, Jacob Leon; Raschke, Philip (January 2019). "Privacy implications of accelerometer data: a review of possible inferences". *Proceedings of the International Conference on Cryptography, Security and Privacy*. ACM, New York. pp. 81–87. doi:10.1145/3309074.3309076 (<https://doi.org/10.1145%2F3309074.3309076>).
 44. Dockrill, Peter (18 March 2017). "Millions of Smartphones Could Be Vulnerable to Hacking Via Sound Waves" (<https://www.sciencealert.com/millions-of-smartphones-could-be-vulnerable-to-hacking-via-sound-waves>). *ScienceAlert*. Retrieved 13 March 2019.
 45. Nordrum, Amy (17 March 2017). "Smartphone Accelerometers Can Be Fooled by Sound Waves" (<https://spectrum.ieee.org/tech-talk/telecom/security/smartphone-accelerometers-can-be-fooled-by-sound-waves>). *IEEE Spectrum: Technology, Engineering, and Science News*. Retrieved 13 March 2019.
-

Retrieved from "<https://en.wikipedia.org/w/index.php?title=Accelerometer&oldid=1172977300>"

■