

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent of: Robin Elenga, et al.
U.S. Patent No.: 11,152,882 Attorney Docket No.: 50095-0180IP1
Issue Date: October 19, 2021
Appl. Serial No.: 16/806,925
Filing Date: March 2, 2020
Title: OSCILLATING-RESONANT-MODULE CONTROLLER

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DECLARATION OF DR. BLAKE HANNAFORD

I hereby declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I further declare that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of the Title 18 of the United States Code.

Dated: 30-May-2024

By: 
Blake Hannaford, Ph.D.

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I, Dr. Blake Hannaford, declare that:

I. ASSIGNMENT

1. I have been retained as a technical expert by counsel on behalf of Apple (“Apple” or “Petitioner”). I understand that Apple is requesting that the Patent Trial and Appeal Board (“PTAB” or “Board”) institute an *inter partes* review (“IPR”) proceeding of U.S. Patent No. 11,152,882 (“the ’882 patent”) (APPLE-1001). I have been asked to provide my independent analysis of the ’882 patent in light of the prior art publications cited below.

2. I received no compensation for this declaration beyond my normal hourly compensation based on my time actually spent analyzing the ’882 patent, the prior art publications cited below, and the issues related thereto, and I will not receive any added compensation based on the outcome of any IPR or other proceeding involving the ’882 patent.

II. QUALIFICATIONS AND BACKGROUND INFORMATION

3. I have summarized in this section my educational background, career history, and other qualifications relevant to this matter. I have also included a current version of my curriculum vitae as Appendix A.

4. I received a B.S. in Engineering and Applied Science from Yale University in 1977. I received an M.S. in Electrical Engineering and Computer Science from the University of California, Berkeley in 1982. I received a Ph.D. in

Electrical Engineering and Computer Science from the University of California, Berkeley in 1985.

5. I am a Professor in the Department of Electrical Engineering at the University of Washington. I also hold appointments as an Adjunct Professor of Bioengineering, an Adjunct Professor of Mechanical Engineering, and an Adjunct Professor of Surgery at the University of Washington. I have been a member of the faculty at the University of Washington for approximately 34 years.

6. During my teaching career, I have taught and performed research in the general areas of embedded computing, controls, robotics, human computer interfaces, and applications of these technologies, including to surgical telerobotics. I have taught over fifty course offerings at the undergraduate and graduate levels, including courses related to consumer electronics design, control systems, embedded and real-time software design, and haptic enabled systems. I have been an advisor for numerous graduate research projects including sensing in mobile devices, position sensors, the application of accelerometers to human carried devices, and sensors for multi-finger haptics.

7. I have published extensively over my career including numerous peer-reviewed and cited publications and papers. I have also contributed to books as an author and an editor. These publications are listed in my CV. I am named as an inventor on at least twenty-one U.S. patents, including multiple patents related to

haptic interfaces and a pen-based input device.

8. I have many highly cited publications in the area of haptic interfaces and their use by human users. For example, my co-authored paper Hannaford, Blake and Jee-Hwan Ryu, *Time-domain passivity control of haptic interfaces*, IEEE TRANSACTIONS ON ROBOTICS AND AUTOMATION 18, 1 (2002) has 871 citations on Google Scholar. Another paper Brittany Redmond, Rachel Aina, Tejaswi Gorti, and Blake Hannaford. "*Haptic characteristics of some activities of daily living*," in IEEE HAPTICS SYMPOSIUM at 71-76 (2010) measured force and torque recordings of several writing tasks with pen and pencil, opening and closing a jar, and dialing and texting with a cell phone.

9. The paper Jacob Rosen, Mark MacFarlane, Christina Richards, Blake Hannaford, and Mika Sinanan, *Surgeon-tool force/torque signatures-evaluation of surgical skills in minimally invasive surgery*, in MEDICINE MEETS VIRTUAL REALITY at 290-296 IOS Press (1999) describes forces measured during animal surgeries by both expert and novice surgeons during training. In Jacob Rosen, Jeffrey D. Brown, Lily Chang, Marco Barreca, Mika Sinanan, and Blake Hannaford, *The BlueDRAGON-a system for measuring the kinematics and dynamics of minimally invasive surgical tools in-vivo*, in PROCEEDINGS 2002 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION (Cat. No. 02CH37292), vol.2, at 1876-1881 (2002), we describe a system for measuring force and movement of

surgical instruments in 6 directions simultaneously for collecting data on surgical skill.

10. With my student Nancy Greivell, I studied application of ferrofluids to fluid pumps, reported in Nancy E. Greivell and Blake Hannaford, *The design of a ferrofluid magnetic pipette*, IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING 44, no. 3, 129-135 (1997).

11. In addition to my extensive academic research and teaching experience, I have also engaged in the industry. Since 1986, I have been involved in the research and design of devices that improve the interaction between humans and computer systems including robotics and control devices. While a Supervisor at the Jet Propulsion Laboratory at Caltech, I gained a deep understanding and developed expertise in Man-Machine Systems and human factors engineering in computer-based systems. Since that time, I have expanded my involvement with human computer interfaces to include research, teaching, and design in the areas of human-computer interfaces and embedded computing. In 2014-15 I worked for Google-X as it created a new Alphabet company Verily. While there I worked, among other things, on haptic interfaces for surgical robots, and evaluated similar technologies from other companies.

12. I have patented several haptic devices or control methods including US 9,104,271B1, US RE375281E1, US 5,642,469, US 7,027,965B2, US

6,437,770.

13. A detailed list of my other professional activities, memberships, and speaking engagements is included in my CV, which is attached as Appendix A.

14. Based on my experience and education, I believe that I am qualified to opine as to the knowledge and level of skill of one of ordinary skill in the art at the time of the alleged invention of the '882 patent (which I further describe below) and what such a person would have understood at that time, and the state of the art during that time. Based on my experiences, I understand and know of the capabilities of persons of ordinary skill in this field during the 2000s and specifically during the time of the alleged invention of the '882 patent. Indeed, I taught, participated in organizations, and worked closely with many such persons in the field during that time frame.

A. Legal Principles

15. I have been informed about certain legal principles regarding patentability and related matters under United States patent law, which I have applied in performing my analysis and arriving at my technical opinions in this matter.

1. Anticipation

16. I have been informed that a patent claim is invalid as “anticipated” if every element of a claim, as properly construed, is found either explicitly or

inherently in a single prior art reference. Under the principles of inherency, I understand that if the prior art necessarily functions in accordance with, or includes the claimed limitations, it anticipates.

17. I have been informed that a claim is invalid if the claimed invention was known or used by others in the U.S., or was patented or published anywhere, before the Applicant's invention. I further have been informed that a claim is invalid if the invention was patented or published anywhere, or was in public use, on sale, or offered for sale in this country, more than one year prior to the filing date of the patent application (the so-called critical date). I have also been informed that a claim is invalid if an invention described by that claim was described in a U.S. patent granted or an application for a patent (or in a published application for a U.S. patent) that was filed by another in the U.S. before the date of invention for such a claim.

2. Obviousness

18. I have been informed that a patent claim is invalid as "obvious" in light of one or more prior art references if it would have been obvious to a person of ordinary skill in the art at the time of the alleged invention ("POSITA"; refer to ¶¶ 27-28 below), taking into account (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called "secondary considerations" of non-obviousness,

which include: (i) “long felt need” for the claimed invention, (ii) commercial success attributable to the claimed invention, (iii) unexpected results of the claimed invention, and (iv) “copying” of the claimed invention by others.

19. The application that led to the ’882 patent (U.S. Appl. No. 16/806,925) was filed on March 2, 2020 as a continuation-in-part of U.S. Application No. 15/043,584 filed February 14, 2016, which claims the benefit of Provisional Application No. 62/116,144, filed February 13, 2015. For purposes of my analysis here, I have applied a date of February 13, 2015 as the date of the alleged invention in my obviousness analysis, although in many cases the same analysis would hold true even if the date of the alleged invention occurred earlier than February 13, 2015.

20. I have been informed that a claim can be obvious in light of a single prior art reference or multiple prior art references. To be obvious in light of a single prior art reference or multiple prior art references, there must be a reason that would have prompted a POSITA to modify the single prior art reference, or combine two or more references, in a manner that provides the elements of the claimed invention. This reason may come from a teaching, suggestion, or motivation to combine, or may come from the reference(s) themselves, the knowledge or “common sense” of a POSITA, or from the nature of the problem to be solved, and this reason may be explicit or implicit from the prior art as a whole.

I have been informed that, under the law, the predictable combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. I also understand it is improper to rely on hindsight in making the obviousness determination.

3. Claim Construction

21. I understand that, for purposes of my analysis in this *inter partes* review proceeding, the terms appearing in the patent claims should be interpreted according to their “ordinary and customary meaning.” In determining the ordinary and custom meaning, the words of a claim are first given their plain meaning that those words would have had to a POSITA. I understand that the structure of the claims, the specification, and the file history also may be used to better construe a claim insofar as the plain meaning of the claims cannot be understood. I have followed this approach in my analysis.

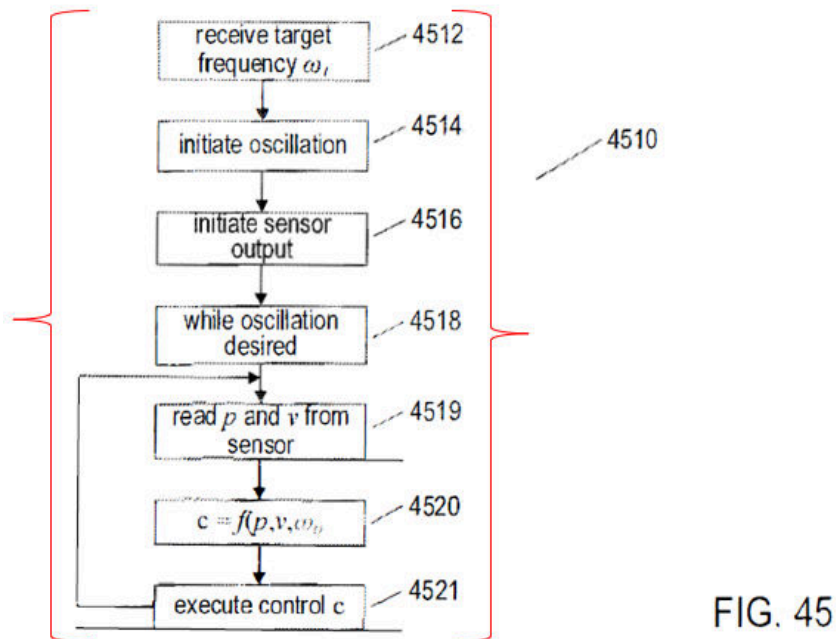
22. I have also been informed that, according to 35 U.S.C. § 112, it is permissible for a claim element to be “expressed as a means or step for performing a specified function without the recital of structure, material, or acts in support thereof, and such claim shall be construed to cover the corresponding structure, material, or acts described in the specification and equivalents thereof.”

23. I also understand that the words of the claims should be interpreted as they would have been interpreted by a POSITA at the time the alleged invention

was made (not today). I have used the date of February 13, 2015 for reasons explained in ¶ 19 (above) and ¶¶ 27-28 (below). However, the plain meanings/interpretations that I employed in my analysis below would have also been correct if the date of invention was anywhere within the mid-2010s. I have been informed by Counsel that the '882 patent is the subject of litigation in federal district court in which claims or terms of the '882 patent have been proposed by the parties. I have reviewed the proposed constructions from federal district court, including Patent Owner's Identification of Proposed Constructions (APPLE-1033) and Apple's Proposed Claim Constructions (APPLE-1034). As I discuss herein, the claims are obvious in view of the prior art under either construction.

24. **“control component”** – I understand that Petitioner has interpreted “control component” as a means-plus-function term. APPLE-1012, 3-8; APPLE-1013, 13. The language of independent language recites the “control component” performs a specified function—“receives control signals input to the oscillating resonant module, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.” The specific portions of the specification that describes the structure corresponding to these functions are the processor/logic circuitry that performs the algorithm shown in

Fig. 45 and described at 31:19–32:13; and equivalents thereof. APPLE-1001, Fig. 45, 31:19-58; APPLE-1013, 13, 17. The '882 Patent's FIG. 45 algorithm is shown below:



APPLE-1001, Fig. 45 (Annotated).

25. For the purpose of analyzing the prior art grounds according to this means-plus-function interpretation, I have treated “control component” as including the processor/logic circuitry that performs the algorithm shown in Fig. 45 and described at 31:19–32:13, and equivalents thereof. *See* APPLE-1001, 31:43-49.

26. I understand that Patent Owner has argued in co-pending litigation that “control component” is a means-plus-function limitation, and has argued a slightly different interpretation. In particular, I understand Patent Owner proposes

the corresponding structure of “control component” includes an oscillator circuit; microcontroller with internal or external memory; processor; CPU; microprocessor; and equivalents thereof. Patent Owner further argues that, where the corresponding structure is a processor, CPU, or microprocessor, the processor / CPU / microprocessor is programmed with an algorithm comprising the following steps: (a) receive a target frequency; (b) receive sensor outputs indicating (1) position of the mass, or (2) position and velocity of the mass; and (c) generate control outputs based on the target frequency and the current position and velocity of the mass. APPLE-1011, 1-2; APPLE-1016, 23-24. I have considered Patent Owner’s means-plus-function interpretation in the analysis herein. To be clear, the prior art demonstrates the elements of the claims under either interpretation.

B. Person of Ordinary Skill in the Art

27. A person of ordinary skill in the art at the time of the ’882 patent (a “POSITA”) would have had a degree in mechanical engineering, electrical engineering, physics, or a related technical field, and at least 2-3 years of experience related to the design or development of vibration-generating systems; additional years of experience could substitute for the advanced-level degree. In view of the pertinent prior art discussed herein, my analysis would be the same applying a slightly higher or lower level of skill.

28. I have used the claimed priority date of the application that led to the

'882 patent as the point in time from which my analysis from the perspective of a POSITA is based—February 13, 2015—but my analysis would be similar even if the date was slightly earlier or later.

C. Materials Considered

29. My analyses set forth in this declaration are based on my experience in the field of linear actuators, including haptic interfaces. Based on my above-described experience in the field, I believe that I am considered to be an expert in the field. Also, based on my experiences, I understand and know of the capabilities of persons of ordinary skill in this field during the 2010s and specifically during the time before the alleged priority date (February 13, 2015) for the '882 patent, and I taught, participated in organizations, and worked closely with many such persons in the field during that time frame.

30. As part of my independent analysis for this declaration, I have considered the following: the background knowledge/technologies that were commonly known to persons of ordinary skill in this field during the time before the alleged priority date for the '882 patent; my own knowledge and experiences gained from my work experience in the field; and my experience in working with others, including teaching and advising others in the field. In addition, I have analyzed the following publications and materials:

APPLE-1001 U.S. Patent No. 11,152,882 to Robin Elenga, et al. (“the

'882 Patent")

APPLE-1002	Excerpts from the Prosecution History of the '882 Patent (“the Prosecution History”)
APPLE-1005	U.S. Patent Publication No. 2013/0237751 (“Alexander”)
APPLE-1006	U.S. Patent Publication No. 2008/0246532 A1 (“Cospers”)
APPLE-1007	U.S. Patent No. 7,843,277 (“Gregorio”)
APPLE-1008	U.S. Patent Publication No. 2008/0001484 (“Fuller”)
APPLE-1009	U.S. Patent No. 5,952,806 (“Muramatsu”)
APPLE-1010	U.S. Patent Application Publication No. 2008/0294984 to Erin B. Ramsay, et al. (“Ramsay”)
APPLE-1011	Resonant Systems Proposed Claim Constructions, 7-23- cv-00077 (WDTX) (Feb. 15, 2024)
APPLE-1012	Apple, Inc. Proposed Claim Constructions, 7-23-cv- 00077 (WDTX) (Feb. 15, 2024)
APPLE-1013	Apple, Inc. Opening Claim Construction Brief, 7-23-cv- 00077 (WDTX) (March 21, 2024)
APPLE-1014	U.S. Patent No. 7,005,811 (“Wakuda”)
APPLE-1016	Resonant Systems, Inc.’s Responsive Claim Construction Brief, 7-23-cv-00077 (WDTX) (April 11, 2024)

31. This declaration refers to selected portions of the cited references for the sake of brevity. These references are examples. It should be understood that a POSITA would have viewed the references cited herein in their entirety and in combination with other references cited herein or cited within the references themselves. The references used in this declaration, therefore, should be viewed as being considered herein in their entireties. Of course, I have also considered the claims of the '882 patent. The following table provides a quick sheet enumerating claim elements for ease of reference:

Claim	Identifier	Claim Language
1	[1pre]	An oscillating resonant module comprising:
	[1a]	an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;
	[1b]	a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;
	[1c]	one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time; and
	[1d]	a control component that receives control signals input to the oscillating resonant module, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

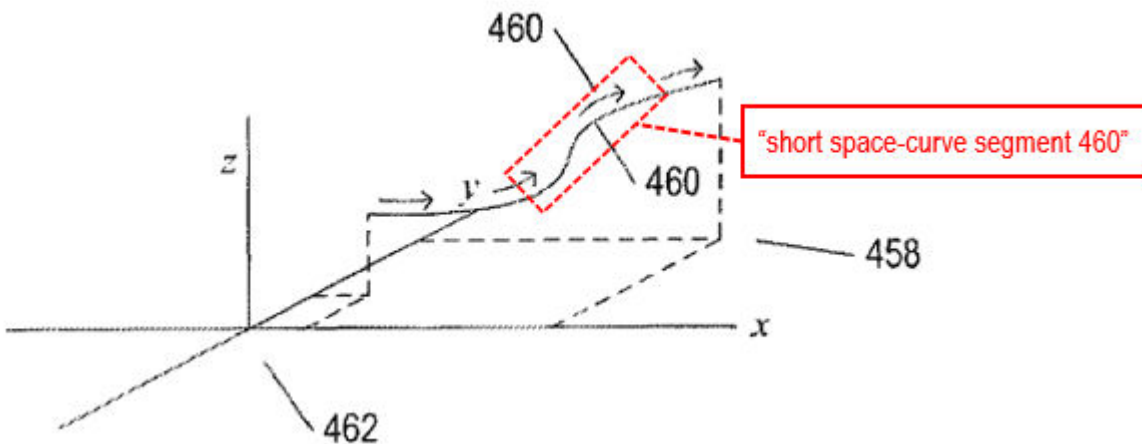
Claim	Identifier	Claim Language
2	[2]	The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more: mechanical sensors; electromagnetic sensors; and optical sensors.
3	[3]	The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor outputs, the velocity of the mass from the positions of the mass at two or more points in time.
4	[4]	The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass.
5	[5]	The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.
6	[6]	The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.
10	[10pre]	A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:
	[10a]	a controller; and
	[10b]	the one or more oscillating resonant modules, each oscillating resonant including:
	[10c]	an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;
	[10d]	a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth

Claim	Identifier	Claim Language
		along the oscillation path that represents a segment of a space curve;
	[10e]	one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time, and
	[10f]	a control component that receives control signals input to the oscillating resonant module by the controller, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.
17	[17]	The physical device of claim 1 further comprising: a controller, within the physical device, that receives control signals input to the physical device, and outputs control signals to one or more of the one or more oscillating resonant modules to controls the vibration response produced by the one or more oscillating resonant modules.
19	[19]	The physical device of claim 17 wherein the controller passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module.
20	[20]	The physical device of claim 17 wherein the controller controls the one or more oscillating resonant modules to each produce a vibration response, the vibration responses produced by the oscillating resonant modules together producing a resonant-frequency vibration mode in the physical device.

III. OVERVIEW OF THE '882 PATENT

A. Brief Description

32. The '882 Patent is directed to an “Oscillating-resonant-module controller.” APPLE-1001, Title. In more detail, the '882 Patent “is directed to various types of oscillating resonant modules (‘ORMs’)” that “can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces.” APPLE-1001, Abstract. The “vibrational forces are produced by back-and-forth oscillation of a weight or member.” *Id.* The back-and-forth oscillation of the weight or member occurs from the member’s movement along an oscillation path. *Id.* The oscillation path represents “a segment of a space curve.” *Id.*, 3:5, 4:57-58, 32:53-54. Figure 4C of the '882 Patent is described to “illustrate[] a general space-curve segment path.” *Id.*, 6:12.



APPLE-1001, Fig. 4C (Annotated)

33. A controller controls one or more ORM's to produce driving oscillations based on a frequency of the driving oscillations with respect to time. *Id.*, Abstract. The driving oscillations, in turn, elicit a desired vibration response in

the device or system where an ORM is included. *Id.* For example, to achieve a desired vibration response “the ORMs convert input energy, such as an electrical current, to mechanical vibration.” *Id.*, 19:35-38.

34. The ’882 Patent describes “[c]ombining an ORM **with feedback control**, so that the driving frequency produced by the ORM falls close to the resonant frequency of a device in which the ORM is included.” *Id.*, 4:62:65. For example, the ORM can “use[] continuous feedback control to optimize the vibrational force produced by the ORM by continuously seeking to operate the ORM at a frequency as close as possible to the resonant frequency for the ORM.” *Id.*, 9:32-36.

35. The ORM includes “one or more electromechanical sensors.” *Id.*, 7:62-8:1. The ’882 Patent indicates that “[v]arious types of Hall effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.” *Id.*, 32:10-14. I note that patent owner further confirmed this during prosecution of the application leading to the ’882 patent. *See* APPLE-1002, 146-148.

B. Prosecution History of the ’882 Patent

36. The ’882 Patent issued on October 19, 2021 from U.S. Patent Application No. 16/806,925 (“the ’925 application”), which was filed on March 2, 2020. *See* APPLE-1002. The ’925 application was allowed after Applicant

responded to an initial office action by amending the independent claims to recite, among other features, “an oscillation path, which represents a segment of a space curve, along which a point within a mass moves.” *Id.*, 139, 141. I note that the Examiner provided reasons for allowance in the Notice of Allowance:

Claims 1-16 and 21-24 are allowable among other elements and details, but for at least the reason “an oscillation path, which represents a segment of a space curve, along which a point within a mass moves; [and] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along an the oscillation path that represents a segment of a space curve” in combination with the remaining of the claimed subject matter. *Id.*, 123.

37. During prosecution, Applicant indicated that the challenged claims of the '882 Patent are directed to the “direct sensing” embodiment of Fig. 45.

APPLE-1002, 145 (“The current application provides ... **a discussion of direct sensing of the position of an oscillator** within an oscillating resonant module **by direct-position-sensing sensors within the oscillating resonant module.**”); 154 (“The third element of claim 1, ‘one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time,’ is discussed in the above-quoted paragraphs, beginning with a reference to ‘direct sensor 4504,’ that occurs in the second sentence of the first of the above-quoted paragraphs from the current application.”). I further note that, when attempting to

distinguish the claims over the prior art, Applicant argued that “direct[] position sensing of an oscillator within an ORM **was unknown at the time of filing of the current application.**” *Id.*, 151. I disagree with that statement. Based on my knowledge and experience in the field, and as I discuss in more detail herein, direct position sensing of an oscillator within an ORM was known prior to the ’882 patent.

38. In response to patent owner’s statements, a notice of allowance was issued, without consideration of the art and combinations discussed herein. Contrary to the Examiner’s stated reasons for allowance, the prior art discussed herein demonstrates that direct position sensing was well-known at the time of filing the application that issued as the ’882 Patent, along with the “space curve” and other elements of the Challenged Claims mistakenly believed by the Examiner to be missing from the prior art.

IV. OVERVIEW OF THE CITED REFERENCES

A. Overview of Alexander

39. Alexander describes an actuator that includes a “mover” that “reciprocates” (oscillates) inside a “cylindrical stator.” *Id.*, [0005], cl. 18, [0052]-[0060]. For example, “[t]he stator may be a series of cylindrical electrical coils butted up end to end to form a long cylinder of separate coils, and the mover may be a tube of permanent magnets that slides inside the cylinder of coils.” *Id.*,

[0024]. The actuator includes “a feedback controller with a sensor for sensing the motion of the mover.” *Id.*, [0005]. Alexander describes the mover travels “along a curvilinear path.” APPLE-1005, Abstract, claim 18, FIG. 7A.

40. Alexander describes the feedback “controller” is “operable to control the relative motion between [the] stator and [the] mover,” “and to accept input from the user to modify the motion of the mover.” *Id.*, Abstract, [0005], [0021]-[0028]. Alexander’s “controller” includes “a module to measure the magnetic flux observed by the sensor and use that as feedback to control the motion of the mover relative to the stator.” *Id.*, Abstract. Alexander’s device includes a position sensor, and “[a] variety of different position sensors may be used,” including “contact and non-contact position sensors.” *Id.*, [0034]; [0029]-[0033], [0035]-[0048].

41. In Alexander’s “feedback control system,” the “position sensor measures the position of the [mover] and reports the position of the [mover] to the main drive and control electronics.” *Id.*, [0034]. These electronics then “control the current that is driven through the coils, creating a feedback system that allows precise control of the position of the [mover].” *Id.* Thus, based on Alexander’s “feedback control of the mover position, a variety of position and motion parameters of the [actuator] can be controlled by the control system, including: mover stroke, mover speed, and mover acceleration.” *Id.*, [0037], [

42. Alexander describes “software” that can be programmed “to determine the beginning mover position at startup of the device, to more accurately determine subsequent positions” and the use of “additional sensors for more precise control.” *Id.*, [0036]. Alexander’s “software that controls the motor position ... has several distinct steps,” and can be used to control “speed and acceleration, jerk, snap, vibration, rotation, or any other pertinent, controllable motion parameters.” *Id.*, [0038]. Alexander’s software controls also “generat[e] motion profiles,” including “complex motion profiles” that are “described” using “[a] mathematical formula” or “a series of data points (speed, position, acceleration)” that “could be stored in a lookup table.” *Id.*, [0038], [0039].

B. Overview of Cosper

43. Cosper describes a “method for control over mechanical resonant system[s]” and is generally directed to “oscillating mechanical systems, that operate in an oscillatory mode at or near their mechanical resonant frequency.” APPLE-1006, Title; [0003], [0009]-[0011], [0049]-[0050]; FIG. 1. In particular, Cosper describes “systems and methods for automatically driving (*e.g.*, controlling energy applied) and maintaining oscillation of an assembly,” *i.e.*, a mechanical resonant system, “at or near a resonant frequency of the assembly system.” *Id.*, Abstract, [0009]. I note that Cosper expresses broad applicability of the subject of oscillation that it maintains at resonance without limiting to any specific

application. *See, id.*, Abstract; [0012] (“Any appropriate subassembly may be used with the systems and methods described herein.”); [0049]-[0056].

44. Cospo’s mechanical resonant system (or “assembly system”) generally includes “a mass and a bias member,” where the bias member “may also be referred to as a spring or elastomeric member.” *Id.*, [0009], *see* [0049], claim 1. The combination of the “mass and bias member” is described alternatively in Cospo as a “subassembly,” “a moveable subassembly,” or “a resonant subassembly.” *Id.*, [0048], [0049]-[0053], [0056], *see* claim 1. For example, Cospo describes that its mechanical resonant system “include[s] a mass and spring mechanism (subassembly),” “where the mass is a part of the mechanism which will oscillate when driven.” *Id.*, [0048].

45. Cospo’s mechanical resonant system also includes “a control system” “used to control oscillation of ... [the] subassembly.” *Id.*, [0012]. Cospo’s control system “may be embodied as control circuits or drive circuits of a controller.” *Id.*, [0010]. For example, Cospo describes “a controller (including a control circuit).” *Id.*, [0012]. Cospo’s “controller [is] operable to receive a signal from a sensor associated with a position or motion of the subassembly, and generate a drive signal for driving the subassembly in response to the received signal from the sensor.” *Id.*, Abstract; [0009]-[0012]. Multiple sensors are included to monitor parameters of the moving mass and provide data to the control

circuit, including sensors configured to measure position, velocity, and/or acceleration, or other related data of the moving mass. APPLE-1009, [0050] (“detect position, velocity, acceleration, etc. for the subassembly” or “load or driving force applied”); [0054]; [0058]; [0069]; [0125]; [0127]; cls. 1-2, 7, 12, 17, 23, 28; Abstract (“position or motion”). “Feedback on the position, velocity, and/or acceleration of the mass” is input to the controller, and the controller processes the feedback signal and generate drive signals “to maintain mechanical oscillation at the mechanical resonant frequency of the system.” *Id.*, [0008]-[0010]; *Id.*

46. Cosper’s controller can “monitor the motion of the subassembly and adjust or modulate the driving force over time to maintain the subassembly at or near a resonant frequency.” *Id.* For example, Cosper’s “mass may be set in motion via an electromagnetic control and drive circuit. Feedback on the position, velocity, and/or acceleration of the mass may be input to the controller. The controller is operable to process the feedback signal and generate drive signals that are processed to maintain mechanical oscillation at the mechanical resonant frequency of the system.” *Id.*, [0010]. Thus, Cosper’s control methodology can “automatically maintain the resonant frequency of a mass and spring mechanism at a desired frequency set-point.” *Id.*, [0011]. In Cosper “[a]ny variation in the mechanical resonant system that affects its resonant frequency is sensed and

tracked by [the] controller, so that the mechanical resonant system is driven and continues to oscillate at the new resonant frequency.” *Id.*, [0008].

47. As noted above, Cosper’s controller can include a control component such as “[a] drive circuit” that: i) is “incorporated with the controller or separate thereto;” ii) “maintains the amplitude of oscillation of the subassembly at a desired amplitude set-point;” iii) “allow[s] for an amplitude set-point input for oscillation amplitude adjustability;” iv) “compensate[s] for mechanical, electrical[,] or magnetic parameter changes that” “alter the mechanism’s oscillation amplitude set-point;” and v) “can vary the resonant frequency of a mass and spring mechanism by altering the system’s restoring force electromagnetically.” *Id.*, [0011], *see* [0010].

C. Overview of Gregorio

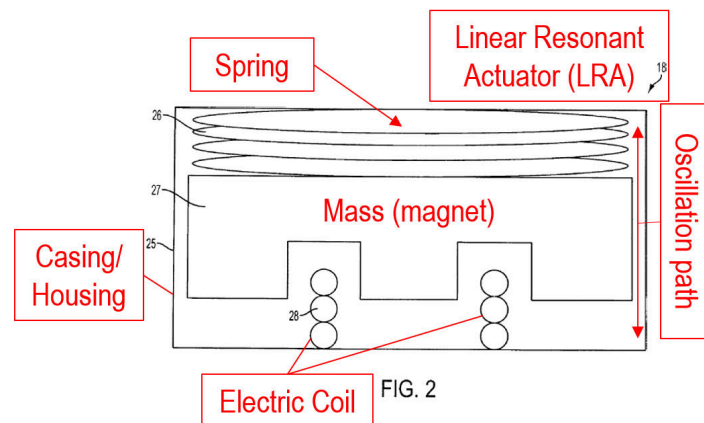
48. U.S. Patent No. 7,843,277 to Pedro Gregorio, et al. is titled “Haptic Feedback Generation Based On Resonant Frequency.” Gregorio was filed on December 16, 2008 and issued as a patent on November 30, 2010.

49. Gregorio describes “a system that drives an LRA [Linear Resonant Actuator] to generate vibrotactile haptic feedback on a user interface or other area of a device.” APPLE-1004, 2:3-5. Because “each LRA may have a different resonant frequency” and such a resonant frequency may change “due to different uses of a device or due to manufacturing tolerances,” Gregorio’s system is

configured such that “the resonant frequency of the LRA can be determined during a drive period and the drive signal can be adjusted to maximize the haptic feedback based on the determined resonant frequency.” *Id.*, 3:1-11, 3:58-64, 2:5-9.

50. Gregorio’s “haptically-enabled system 10” can be “a handheld device, such as a cellular telephone, PDA, computer tablet, etc. or may be any other type of device that provides a user interface and includes a haptic effect system that includes one or more LRAs.” APPLE-1004, 3:1-4. The system 10 “includes a touch sensitive surface 11 or other type of user interface mounted within a housing 15, and may include mechanical keys/buttons 13.” *Id.*, 2:10-14, Figure 1.

51. Gregorio’s actuator “includes a casing,” “a magnet/mass,” “a linear spring,” “and an electric coil.” *Id.*, 3:13-14. “Magnet 27 is mounted to casing 25 by spring 26” and electric “[c]oil 28 is mounted” at a bottom or lower interior section “of casing 25 underneath magnet 27.” *Id.*, 3:14-16. These components are shown in Fig. 2, for example.



APPLE-1007, Fig. 2 (Annotated)

52. Gregorio describes that “[i]n operation, when current flows [through] coil 28 a magnetic field forms around [the] coil,” “which in interaction with the magnetic field of magnet 27 pushes or pulls on magnet 27.” *Id.*, 3:17-21.

53. Gregorio also describes corresponding techniques for generating “haptic feedback” “based on [a] resonant frequency.” *Id.*, Title. Gregorio’s haptic feedback system includes “processor 12,” “memory 20,” “actuator drive circuit 16,” and “LRA actuator 18.” *Id.*, 2:18-20. “Processor 12 can decide what haptic effects are to be played and the order in which the effects are played based on high level parameters,” and “output[] the control signals to drive circuit 16 which includes electronic components and circuitry used to supply LRA 18 with the required electrical current and voltage to cause the desired haptic effects.” *Id.*, 2:25-28, 2:36-39. “Memory 20 stores instructions executed by processor 20.” *Id.*, 2:44-45. In one example, “memory 20 includes an LRA Drive with Resonant Frequency Determination module 22 which are instructions that, when executed by processor 12, generate drive signals for LRA 18 while also determining the resonant frequency of LRA 18 and adjusting the drive signals accordingly.” *Id.*, 2:45-50.

54. In generating haptic feedback, Gregorio’s system performs “a continuous loop during a drive cycle that includes a drive period and a monitoring

period.” APPLE-1004, 4:15-20. The system “constantly and dynamically determines the resonant frequency of LRA 18 while during a monitoring period of a drive signal cycle.” *Id.*, 3:65-67. In particular, “during the monitoring period (approximately 10%) of the drive cycle, drive circuit 16 ‘listens’ or monitors and receives magnetic back EMF (*i.e.*, the voltage generated by the [magnet’s] internal motion inside [the coil of] LRA 18) from LRA 18.” *Id.*, 4:24-28. The received back EMF (“electromagnetic force”)¹ is “used to determine the resonant frequency of the LRA.” *Id.*, 4:2-5. “The subsequent drive pulses are then adjusted to account for the resonant frequency.” *Id.*, 6:8-9.

55. Instead of monitoring back EMF signals, the system can use “a sensing coil, Hall sensor, optical sensor or other type of sensing device that is located in proximity to mass 27 for detecting the position of mass 27. In this embodiment, the sensing device will provide a sensed position signal that can be used as the monitoring signal to provide information about the position of the mass 27 instead of the back EMF signal generated by the mass and drive coil of the LRA

¹ Although Gregorio describes that “EMF” stands for “electromagnetic field” (APPLE-1004, 4:3), I understand the term is typically understood as meaning “electromagnetic force.”

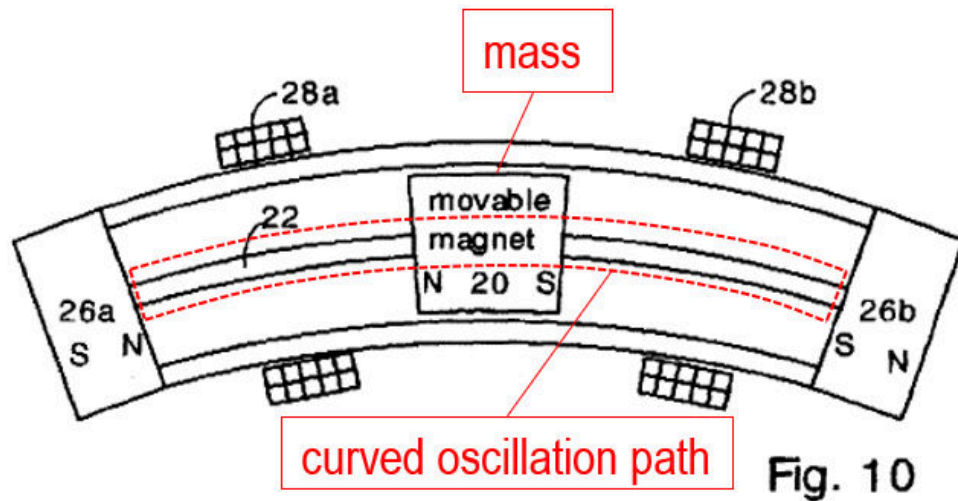
itself.” APPLE-1004, 4:7-14.

D. Overview of Fuller

56. Fuller describes “electromagnetic vibrators” that have “a movable magnet that oscillates axially under the influence of an axial field coil.” APPLE-1008, [0001]. For example, Fuller describes the “vibrator has at least one field coil for causing the movable magnet to move in the axial direction” and “[m]agnetic bumpers [that] are disposed on opposite ends of the vibrator, and are oriented to repel the movable magnet.” *Id.*, [0006], Abstract. Fuller further describes that, “[w]hen excited by the field coil, the movable magnet will oscillate between the bumper magnets and create vibrations.” *Id.*, [0006].

57. Fuller describes that the movable magnet travels along a “curved” pathway. APPLE-1008, [0006], Abstract. For example, “[w]hen an alternating current is provided in the field coil, the movable magnet oscillates linearly in the axial direction, bumping against the magnetic field of the bumper magnets and thereby creating vibration.” *Id.*, Abstract. Fuller discloses that, “[i]n its simplest construction, the movable magnet is disposed between the bumper magnets and *travels along a linear or curved axial pathway.*” *Id.*, [0006]. Fuller’s movable magnet can be “disposed on an axial shaft to linearly constrain the motion of the movable magnet.” *Id.*, Abstract. Fuller’s “axial shaft can extend the full length of the vibrator, and *can be straight or curved.*” *Id.*, [0008]. For example, Fuller’s

“movable magnet *moves along a pathway that has a curved shape.*” *Id.*, cl. 9.



APPLE-1008, Fig. 10 (Annotated).

58. I note that Fuller expresses advantages associated with a “curved” oscillation path, explaining that a “curved” path is “preferred,” in some applications. APPLE-1008, [0051]. Fuller indicates that “[t]his is because the curved embodiment will produce rotating vibrations in two directions,” in comparison to linear embodiments that produce linear vibrations in only one direction. *Id.* Based on my knowledge and experience in the field, and my review of Fuller, a POSITA would have recognized that vibrations in two directions would have been applicable to a range of applications, including to provide associated sensations in haptic systems.

E. Overview of Muramatsu

59. Muramatsu is directed to a force sense controller that includes an actuator for exerting a force on an object. The system includes a mass, magnet, or

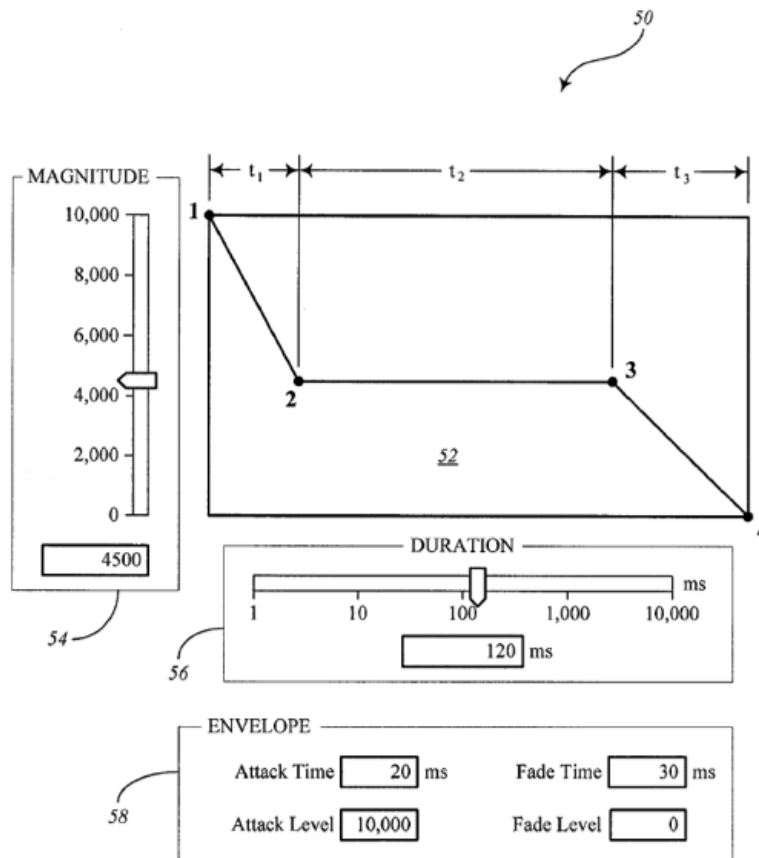
plunger, a sensor for generating a signal indicating a current position of the moving object, “and a controlling unit connected to the actuator and the sensor.” APPLE-1009, Abstract.

60. The controlling unit includes “a multiplexer,” “a data processor,” “and data tables.” APPLE-1009, 4:41-42. The multiplexer “is connected to the sensors 1d of the [] actuators,” and “positional signals Sx are supplied in parallel from the sensors 1d” of the actuators to the multiplexer. *Id.*, 4:42-45. The positional signals Sx are supplied from the multiplexer to the data processor. *Id.*, 4:46-48. The data processor “calculates a current plunger velocity X' on the basis of the current plunger position X and the previous plunger position.” *Id.*, 4:48-50. For example, the “controlling unit calculates a current velocity” “to determine the direction of motion, and selects one of the data tables assigned to the direction of the motion for reading out a target reaction force.” *Id.*

F. Overview of Ramsay

61. Ramsay provides techniques for “enabling a regular user of an end user device, such as a cellular telephone, to customize parameters associated with haptic effects applied to the user by the end user device.” APPLE-1010, Abstract. For example, “the user may access programmable haptic design software 30 via GUI 24.” *Id.*, [0032]. “[P]arameters or characteristics of a haptic output or haptic track” that are modifiable “include a frequency of vibration and amplitude of

vibration. Also, the frequency and amplitude can be set to change over time.” *Id.*, [0030], [0033], [0035], [0046]. By way of example, Figure 4 illustrates a “graphical user interface (GUI) 50” that includes a magnitude adjusting mechanism 54, duration adjusting mechanism 56, and an envelope adjusting mechanism 58.” *Id.*, [0053]. In addition, Ramsay can “enable[] the user to enter one or more frequencies for the haptic track or even continually changing frequencies to be played along the length of the haptic track.” *Id.*, [0046].



APPLE-1010, Figure 4

62. With Ramsay’s system, users have “the power to create customized

haptic effects,” “similar to those available to a professional haptic designer.”

APPLE-1006, [0015]. For example, users can not only create and modify haptic parameters such as “a frequency of vibration and amplitude of vibration” in each haptic track, but also “combine or mix different haptic tracks together if desired to provide a fuller haptic experience.” *Id.*, [0030]. Ramsay can “allow[] the user to combine haptic tracks to play simultaneously, to overlap in time for a portion of the time, to play end-to-end, or even to start a subsequent track after a short pause at the end of a first track.” *Id.*, [0047]. Further, users are enabled “to enter one or more frequencies for the haptic track or even continually changing frequencies to be played along the length of the haptic track.” *Id.*, [0037].

63. Further, Ramsay describes that “ROM 28 may be configured to store a library of preset haptic tracks that can be used as a general starting point for creating new tracks,” and “can also store haptic track files created or modified by the user and can also store mixed track files, which include multiple haptic tracks combined together.” APPLE-1006, [0028]; *see also* [0034], [0042], [0049] (“If end user device 10 does include a haptic actuating device, test playback module 42 can be used to play a haptic track or mixed track that is temporarily stored in temporary storage unit 34.”), [0058] (“certain representations or values describing the aspects of the haptic track can be stored in order to recreate haptic track 44 at a later time.”), [0065] (“the user is enabled to store the modified file.”).

**V. GROUND 1: CLAIMS 1-6, 10, 17, 19, AND 20 ARE OBVIOUS
IN VIEW OF THE ALEXANDER-COSPER COMBINATION**

64. For the reasons I describe in detail below, and based on my review of the '882 patent and its file history, and the prior art references cited herein, a POSITA would have understood that the teachings of Alexander and Cosper render claims 1-6, 10, 17, 19, and 20 obvious according to its plain and ordinary interpretation and under either party's means-plus-function construction proposed in counterpart litigation.

A. The Predictable Combination of Alexander and Cosper

65. Based on my knowledge and experience in the field and my review of Alexander and Cosper, a POSITA would have found it obvious to combine Alexander and Cosper to enhance Alexander's control of the movable mass to facilitate oscillation about a resonant frequency. Alexander's controller uses position sensor feedback to control the motion of its reciprocating magnets. *Id.* Cosper provides additional teachings and implementation details that promote more expansive position sensing and feedback control methodologies to automatically drive and/or maintain oscillation of a mass at a resonant frequency. *Id.*

66. In the combined system based on Alexander and Cosper's teachings, the module includes one or more bias members, such as a spring or elastomeric

member, positioned to act on the mover, based on Cospers' suggestions. I note that the bias member would have been positioned to act between the mover and a fixed component (e.g., housing), and the bias member would have been readily selected with characteristics to facilitate operation at a resonant frequency over at least a portion of the mover's stroke. I further note that Alexander expressly describes that the "spacing and orientations of the magnets may vary based on the design." APPLE-1005, [0025]-[0026]; *see also* [0023] ("at least one magnet").

67. Based on Alexander's express teachings, a POSITA would have readily selected spacing and orientations for a given application, or utilize a single magnet, such that the mover is controlled by the feedback controller to maintain oscillation at a resonant frequency. APPLE-1006, Abstract, [0011], *see also* [0023] ("at least one magnet"), [0048], [0055], [0062], [0066], [0073]-[0075], [0108], [0113], [0123]-[0124]; FIG. 1. Notably, doing so would have been recognized by a POSITA as compatible with Alexander's existing control technique, facilitating resonant oscillation at one or more resonant frequencies, while facilitating operation according to the control settings input by a user, consistent with Alexander's teachings. For example, a POSITA would have known that control inputs based on feedback control (e.g., direction signals), according to Cospers' teachings, would provide an input in Alexander's control, and would be effectively utilized without significantly altering or hindering

Alexander's existing control scheme.

68. The module would have been implemented based on Cosper's control system suggestions of sensor inputs, and related sensed parameters, routed/inputted to the control logic of the control circuit. APPLE-1006, [0010] ("embodied as control circuits or drive circuits of a controller"), [0049]-[0050]. For example, the combined module would have been predictably implemented based on Cosper's "control logic," *e.g.*, "hardware" or "firmware" included with Cosper's "controller or control circuit," in which sensor outputs based on characteristics of the moving mass are output to the control logic, consistent with illustration of these features in FIG. 1 of Cosper, for example. APPLE-1006, [0049]. The controller processes position and/or velocity sensor outputs, for example, such that control signals are generated based on position and/or velocity of the moving mass. APPLE-1006, [0010]. Such information is used, in at least some operating scenarios, to maintain oscillation at a resonant frequency. APPLE-1006, Abstract, [0009]-[0011], [0053], [0106].

69. Based on my knowledge and experience in the field and my review of Alexander and Cosper, a POSITA would have been led to modify Alexander's "feedback control system" to utilize "one or more sensors" that detect "position, velocity, acceleration, etc.," based on Cosper's teachings. APPLE-1006, [0050]. For example, a POSITA would have recognized from Cosper's description that

magnetic flux sensors, (*e.g.*, Cosper’s “electromagnetic sensors” and “induction sensors,”) capable of measuring magnetic fields to provide indications of magnetic flux, effectively measure position and other parameters. Alternatively or additionally to Alexander’s sensors, a POSITA would have found it obvious to utilize one or more other types of sensors that directly detect “position, velocity, acceleration,” in accordance with Cosper’s suggestions. *Id.*, [0053] (“optical sensors, mechanical sensors, electromagnetic sensors”), [0035] (“another type of sensor”). I note that Alexander expressly describes that “a variety of different position sensors may be used.” APPLE-1005, [0034], *see also* [0005]; [0035]-[0036]; [0040]. As one example, based on Alexander and Cosper’s suggestions, a POSITA would have readily implemented the system to include a position sensor and a velocity sensor.

70. Based upon my knowledge and experience in this field and my review of Alexander and Cosper, multiple reasons would have led a POSITA to combine teachings of Alexander and Cosper.

71. As a first reason, a POSITA would have been motivated to combine the teachings of Alexander with the teachings of Cosper to provide the option of oscillation at or near a resonant frequency. APPLE-1006, Abstract, [0005]-[0008], [0009]-[0011], [0053]-[0055], [0056], [0106] (“user control”). Based on my knowledge and experience in the field and my review of Alexander and Cosper, a

POSITA would have recognized from Cosper's description the advantage of facilitating increased system movement for a reduced or minimal amount of energy, in at least some operating scenarios (e.g., when oscillating over at least a portion of the available stroke). APPLE-1008, [0036]. For example, Cosper expressly described that benefit "to move and control a mechanical system at or near its resonant frequency to achieve the maximum system movement for a reduced or minimal amount of energy." APPLE-1006, [0005]-[0006]. Other references reflected the POSITA's knowledge of such benefits. *See, e.g.*, APPLE-1008, [0036] ("Resonant operation will tend to increase the amplitude of the vibrations produced by the movable magnet, and increase the energy efficiency and force output of the vibrator."). By doing so, the system would benefit from efficient operation, extending operational time on a single charge/battery life. Moreover, doing so would have increased magnitude with reduced input when operating in the resonant condition. A POSITA would have understood such features to enhance user satisfaction with the device.

72. As a second reason, a POSITA would have been led to combine Alexander and Cosper based on Cosper's description of further implementation details and similar suitable design alternatives relevant to position sensor-based feedback systems that control oscillating actuators. Both Alexander and Cosper describe a movable magnet mass that oscillates based in part on a magnetic field,

and both Alexander and Cosper relate to feedback controls that use sensors to control the oscillation of the movable magnet or mass, including based on positions of the movable mass. APPLE-1005, Abstract, [0005], [0023]; APPLE-1006, [0010]. Indeed, Alexander describes monitoring position and velocity of the movable mass based on sensor inputs (*e.g.*, including based on a fixed sensor or a sensor “mounted to the mover”). APPLE-1005, [0036]. Alexander also expresses objectives of improving precision of oscillation output by implementing effective position sensing for feedback control. APPLE-1005, [0003], [0004]. A POSITA would have recognized Cosper, including based on its teachings of “one or more sensors” that detect “position, velocity, acceleration” as providing suitable design details and alternatives. *Id.*, [0053]. A POSITA would have effectively implemented position sensors for feedback control, based on Cosper’s teachings and advancing Alexander’s stated objectives of improving precision of oscillation output. APPLE-1005, [0003], [0004].

73. I note further that, in evaluating Alexander, a POSITA would have been further motivated to consider related publications, such as Cosper, at least based on Alexander’s express teaching that its actuators include “a feedback controller with a sensor for sensing the motion of the mover.” *Id.*, APPLE-1005, [0005]. Alexander’s description of feedback controls, including position sensors, for sensing and controlling position and motion of its mover/mass, *e.g.*, a magnet

mover, directly overlaps with the substantially similar subject matter of Cosper's controller, which processes position sensor feedback signals and generates drive signals "to maintain mechanical oscillation" of its moveable subassembly at or near a resonance frequency. *Id.*, [0034]; APPLE-1006, [0009], [0010].

74. A POSITA would have thus been led to consult Cosper and would have found it obvious to combine teachings from Cosper's "control system" with Alexander's teachings, such that the system controls oscillation of a subassembly, mover, or magnet mass to operate at a resonant frequency. APPLE-1006, [0012]. Utilizing "one or more sensors" that detect "position, velocity, acceleration," and providing such outputs to the control logic would have predictably enhanced Alexander's feedback control system, reliably delivering sensor outputs to the controller, facilitating precise feedback controls. Moreover, combining Alexander and Cosper would have added a further layer of reliability to operation of Alexander's device, facilitating derivation by the controller of position, velocity, etc., based on a particular sensor, in the event another sensor failed.

75. As a third reason, combining the teachings of Alexander with Cosper would have merely involved combining prior art elements according to known methods to yield predictable results. Cosper, like Alexander, discloses a "controller [is] operable to receive a signal from a sensor associated with a position or motion of" a subassembly, and aspects of Cosper's sensor configuration and

control would have been readily implemented in Alexander. APPLE-1006, [0009]. A POSITA would have readily implemented, with a reasonable expectation of success, a bias member and associated control techniques to facilitate operation at a resonant frequency, without significantly altering or hindering Alexander's operation. Likewise, a POSITA would have reasonably expected success in implementing one or more sensors according to Cosper's suggestions, especially because elements of the combined system would each perform similar functions they had been known to perform prior to the combination. For example, the actuator would still perform the same back-and-forth oscillation of its mover/mass, consistent with Alexander's teachings, as it did prior to the combination with Cosper. APPLE-1006, [0054], [0010].

76. Indeed, the combination is predictable, in part, because elements of the combined system would each perform similar functions they had been known to perform prior to the combination. Alexander's actuator would still perform the same back-and-forth oscillation of its mover/mass as it did prior to the combination with Cosper, with updates to account for control logic and exemplary sensors for position sensing (e.g., electromagnetic and induction sensors), in accordance with Cosper's suggestions. APPLE-1006, [0054], [0010].

77. I further note, based on my knowledge and experience in the field and my review of Alexander and Cosper, a POSITA would have included a bias

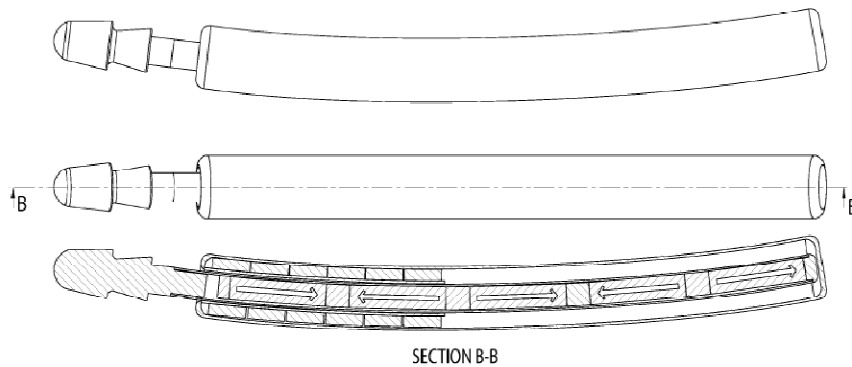
member to facilitate resonant operation, and corresponding control, to be a matter of design choice implemented with a reasonable expectation of success. Such configurations were conventional in the timeframe prior to the '882 patent, and Alexander confirms such design choices were within the purview of a POSITA's knowledge. *See, e.g.*, APPLE-1007, 3:12-28, FIG. 2; APPLE-1008, [0007], [0025], [0048]-[0050], FIGS. 8-9; APPLE-1014, 2:29-54, 3:64-4:5, 5:25-50, 7:26-30, FIGS. 1A-1B; *see also* APPLE-1005, [0025] ("The spacing and orientations of the magnets may vary based on the design"); [0060].

B. Analysis of Alexander and Cosper with Respect to Claims 1-6, 10, 17, 19, and 20

78. As shown in this section, the Alexander-Cosper combination, when predictably combined for at least the reasons described above, provides all elements of claim 1.

[Ipre] An oscillating resonant module comprising:

79. The Alexander-Cosper combination includes an oscillating resonant module (ORM). Alexander describes an actuator having a "mover" that "reciprocates" (oscillates) back and forth inside a "cylindrical stator." APPLE-1005, [0005], [0023]; FIGS. 1A, 7A, 9A. An example of a device that includes an oscillating resonant module is shown in FIG. 7A, of Alexander, for example.



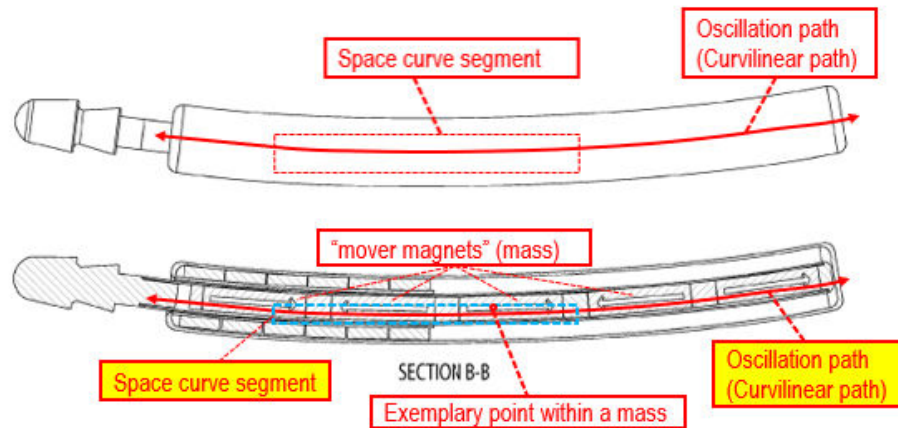
APPLE-1005, Fig. 7A

80. The oscillation of Alexander’s reciprocating mover causes a “vibration” response that has a corresponding “motion profile” that includes “speed, position, acceleration,” “vibration frequency, and vibration magnitude.” *Id.*, [0039]. As I discussed above (refer to the Alexander-Cosper combination), the module includes a bias member, based on Cosper’s suggestions, and the vibration is controlled to operate at a resonant frequency.

[1a] an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

81. The Alexander-Cosper ORM includes an oscillation path, such as the “curvilinear path” described by Alexander. The “curvilinear path” represents a segment of a space curve, along which a point within one of the masses (e.g., on of Alexander’s masses) moves. APPLE-1005, [0022], [0050], claim 18. I note that Alexander expressly indicates that the actuator “operates along a curvilinear path” such that a “mover” (including magnet movers/masses) “reciprocates” inside a

“cylindrical stator” along a curved path. *Id.* An example curved path is illustrated in FIG. 7A, of Alexander.



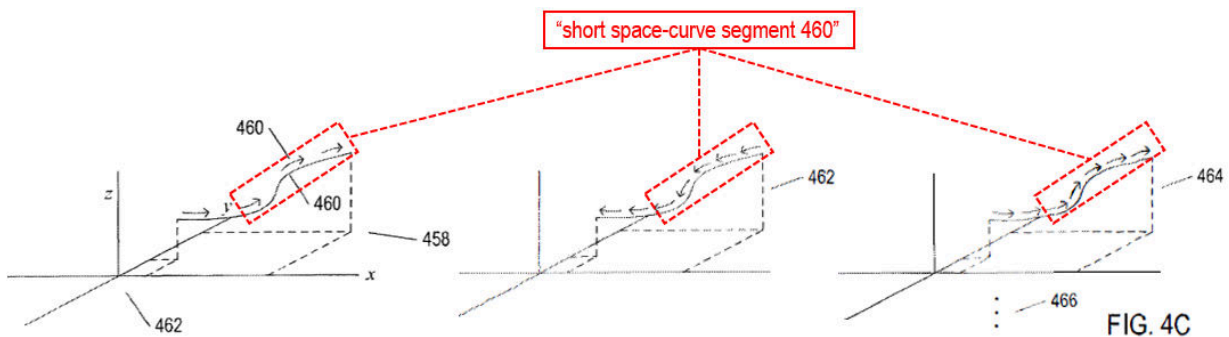
APPLE-1005, Fig. 7A (Annotated)

82. Alexander’s mover produces “curvilinear motion” as the mover or mass of the actuator moves or oscillates along its oscillation path. *Id.*, [0050]; FIG. 7A. Alexander expressly teaches the “actuator operates along a curvilinear path,” for example, when its mover oscillates and vibrates “back and forth during its stroke inwards or outwards.” *Id.*; *see also, id.*, claim 18, [0022],² [0037].

83. Alexander’s back and forth (e.g., left to right) oscillation of its mover magnets along a curved segment of its oscillation path are like the Fig. 4C depictions of space curve segments in the ’882 Patent. The ’882 Patent’s Fig. 4C

² I note that Alexander uses the term “linear” motion as encompassing curved motion—“may be curvilinear motion.” APPLE-1005, [0022].

(reproduced below) illustrates “a short space-curve segment 460” and describes that its “weight or mass” “oscillate[s] back and forth along such a space-curve-segment path.” APPLE-1001, 6:12-20, Fig. 4C. In each plot of Fig. 4C, the weight or mass moves from left to right along the path, as indicated by the small, curved arrows such as curved arrow 460. *Id.*, Fig. 4C.



APPLE-1001, Fig. 4C (Annotated). As indicated above, the mover operates along a curvilinear path as its actuator produces the curvilinear motion, in accordance with Alexander’s teachings. APPLE-1005, claim 18, [0022], [0050]. From at least this overlapping subject matter, the combination plainly provides, and it would have been apparent and obvious to a POSITA, that Alexander’s “curvilinear path” represents a segment of a space curve, along which Alexander’s mover magnet (or mass) moves. Indeed, the overlapping depictions of Alexander’s Fig. 7A and the ’882 patent’s Fig. 4C plainly demonstrate that the claimed “oscillation path” would have been obvious over the Alexander-Cosper combination.

84. I note that Alexander’s straightforward teachings related to its

“curvilinear” oscillation path do not appear to have been identified by the Examiner during original prosecution. *See, e.g.*, APPLE-1002, 168-185. This relevant teaching of Alexander was never addressed in the prosecution history.

[1b] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

85. The Alexander-Cosper combination’s ORM includes “a mass” provided by at least a portion of one of the mover magnet(s). The mass is “driven by energy,” such as current provided to the electromagnet coils describe by Alexander, supplied to the oscillating resonant module (ORM) to oscillate back and forth along the oscillation path that represents a segment of a space curve (e.g., the “curvilinear path”).

86. The Alexander-Cosper combination’s actuator “comprises a stator containing more than one coil, a **mover** containing more than one magnet,” and “a power supply operable to **provide current to said coils** of [the] stator.” APPLE-1005, Abstract; [0050] (“the stator and mover could be designed in a curved configuration”).

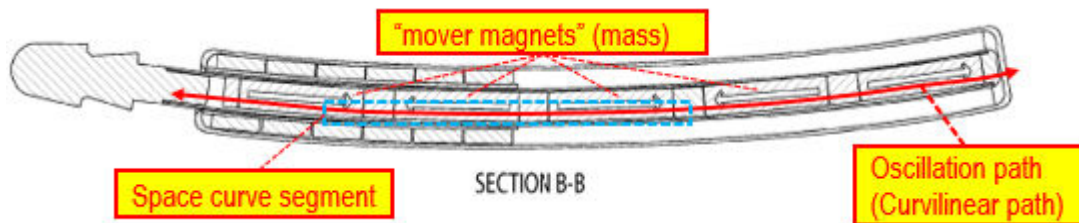
87. Alexander describes the module includes multiple “mover magnets 18.” APPLE-1005, [0036]. In the combined system, each of the “mover magnets”, or portions of the magnets, provide a mass, as recited by Element [1b]. *Id.*. The mover/mass is driven by energy supplied to Alexander’s actuator to

oscillate inside the cylindrical stator. APPLE-1005, Abstract, [0005], [0023]. For example, Alexander describes the actuator includes “main drive and control electronics” that “control the current that is driven through the coils,” which creates “a feedback system that allows precise control of the position” of the mover. *Id.*, [0034].

88. Like the '882 Patent that recites that its “ORMs convert input energy, such as an electrical current, to mechanical vibration” (APPLE-1001, 19:36-38), Alexander describes its stator coils convert input energy, such as current through the coils, to mechanical vibration when the energy drives or “vibrate[s] the mover back and forth during its stroke inwards or outwards.” APPLE-1005, [0037], [0024], [0052]. The energy or electrical current “driven through” the coils can be from a “battery internal to the housing” of the actuator. APPLE-1005, [0052]. The “mover slides inside of the coil assembly, and electrical current applied to the stator [coils] creates a magnetic field that reacts against the magnets inside of the magnet tube.” APPLE-1005, [0024]. The “magnetic field causes the mover to slide one way or the other through the coil assembly.” *Id.* The energy or electrical current “driven through” the coils can be from a “battery internal to the housing” of the actuator. APPLE-1005, [0052]. The “mover slides inside of the coil assembly, and electrical current applied to the stator [coils] creates a magnetic field that reacts against the magnets inside of the magnet tube.” APPLE-1005,

[0024]. The “magnetic field causes the mover to slide one way or the other through the coil assembly.” *Id.*

89. In accordance with Alexander, the actuator has a “curved configuration” in which the mover/mass is driven by the energy (e.g., electrical current) to oscillate “through the coil assembly” and along the curvilinear path. APPLE-1005, [0050], Fig. 7A; discussed above regarding Analysis of Element [1a].



APPLE-1005, Fig. 7A (Annotated)

90. The energy supplied to the actuator coils thus drives its mover/mass to oscillate back and forth along an oscillation path of the actuator that represents a segment of a space curve, as recited by Element [1b].

[1c] one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time; and

91. As I discussed previously, the Alexander-Cosper combination’s provides an oscillating resonant module that includes one or more sensors. For example, the module includes position sensors, based on Alexander and/or Cosper’s teachings. The position sensors output indications of the positions of the

mass within the oscillation path at specific points in time, in order to provide position feedback used to control oscillation.

92. Specifically, Alexander describes “a sensor for sensing the motion of the mover.” APPLE-1005, [0005]. The “position sensor measures the position” of the mover (or tube) and “reports the position” of the mover (or tube) “to the main drive and control electronics.” *Id.*, [0034]. Alexander teaches that “[a] variety of different position sensors may be used,” including “contact and non-contact position sensors.” *Id.*, [0034]. As one example, the “position sensor” includes a “magnetic flux sensor” that “**sense[s] the magnetic flux at a position on the mover** to determine the location of the mover in the stator.” *Id.*, [0035], [0036]. The sensor senses the magnetic flux at a position on the mover due to the mass (magnet) of the mover. I note that Alexander describes the mover’s “[p]osition **is directly measured**” such as by “using possibly two magnetic field sensors.” *Id.*, [0040].

93. I note that, during original prosecution of the application leading to the '882 patent, the Patent Owner asserted that “Alexander does not provide an enabling description of anything related to determining either the positions or the velocities of an oscillating mass within an ORM.” APPLE-1002, 159. I disagree with this assertion because it overlooks Alexander's description and the basic knowledge and skill of a POSITA. A POSITA would have recognized, from

Alexander's description, multiple options for readily implementing its position sensor(s) to measure and report a mover's position. *Id.*, [0034]-[0036], [0040]-[0046]. For example, Alexander describes that a "flux sensor may be placed at one end of the mover, or at another position along the length of the mover." *Id.*, [0035] ("more than one flux sensor" and "a flux sensor [is] combined with another type of sensor.") *Id.*

94. A POSITA would have readily implemented Alexander's teachings, positioning such position sensors proximate one or both ends of the mover. Likewise, such teachings would have been readily implemented in a curvilinear configuration (e.g., shown in FIG. 7B). *See, e.g.*, APPLE-1005, [0060]. A POSITA would have readily recognized that communication between the sensor and controller in Cosper and in Alexander, as well as in the Cosper-Alexander combination, would have been readily implanted according to standard and widely known sensor connection techniques.

95. I note that Cosper further demonstrates communication between position sensors that monitor the movable component and controller components. For example, Cosper describes "sensor input for inputting the parameter into the control logic of control circuit 12," which also can include "sensor input conditioning and processing logic." APPLE-1006, [0049], [0054], FIG. 1.

96. The position sensors in the combined system "measure[]" and

“report[]” a corresponding mover’s position, and thus output indications of the position of the mass within the oscillation path at specific points in time, as recited in Element [1c]. For example, Alexander describes the “magnetic field sensors **return a repeating wave pattern that can be used to calculate** the [mover’s] **position** within one phase of the magnets (a magnet-spacer-magnet-spacer set).” APPLE-1005, [0040]. Indeed, Alexander’s position sensors output indications represented at least by the “repeating wave pattern” returned to Alexander’s main drive and control electronics. Beyond Alexander’s teachings of its position sensors, Element [1c] is disclosed by the combination in view of Cosper’s teachings. Cosper describes using one or more position sensors that directly detect “position, velocity, acceleration, etc.” APPLE-1006, [0050].

97. As I discussed above, based on my knowledge and experience in the field and my review of Alexander and Cosper, a POSITA would have been led to include one or more position sensors in accordance with Cosper’s suggestions, as an alternative to or in addition to Alexander’s sensors. In particular, the system includes one or more magnetic flux sensors, (*e.g.*, Cosper’s “electromagnetic sensors” and “induction sensors,”) that provide indications of magnetic flux to measure position. APPLE-1006, [0050]. Moreover, a POSITA would have been led to include one or more other suitable types of sensors that directly detect “position, velocity, acceleration,” such as “optical sensors, mechanical sensors,

electromagnetic sensors” positioned to measure position and/or velocity of the mover magnet, in the combined system. APPLE-1006, [0053], [0035] (“another type of sensor”).

98. Claims 1 and 10 each recite “a mass” two times. I note that Alexander and Cospers disclose both a single mass and two masses, and thus address the claims despite recitation of “a mass” two times.

[1d] a control component that receives control signals input to the oscillating resonant module, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

99. The Alexander-Cospers combination includes a control component as recited by Element [1d] according to each of the parties’ claim constructions proposed in the counterpart litigation. I first address how the Alexander-Cospers combination provides Element [1d] according to the plain and ordinary meaning. I then address additional aspects demonstrating how Alexander-Cospers provides Element [1d] according to each means-plus-function interpretation proposed in the counterpart litigation.

100. The Alexander-Cospers combination includes a control component provided by a “feedback controller” in view of Alexander and Cospers’ teachings. Alexander describes the “feedback controller ... control[s] the relative motion between” the stator and the mover. APPLE-1005, Abstract, [0005]. A “position

sensor measures the position of the [mover] and reports the position of the [mover] to the main drive and control electronics.” *Id.*, [0034]. I note that Alexander’s feedback controller is described alternatively, and interchangeably, as a “controller,” “control system,” “[a] feedback control system,” and/or “a feedback system.” *See id.*, Abstract, [0005], [0037], [0025], [0034]. These electronics “control the current that is driven through the coils, creating a feedback system that allows precise control of the position of the [mover].” *Id.* Thus, based on “feedback control of the mover position, a variety of position and motion parameters of the linear [actuator] can be controlled by the control system, including: mover stroke, mover speed, and mover acceleration.” *Id.*, [0037]. Alexander’s feedback controller can also “accept input from [a] user to modify the motion of the mover.” *Id.*, [0005].

101. Alexander’s “controller” includes “a module to measure the magnetic flux observed by the sensor and use that as feedback to control the motion of the mover relative to the stator.” *Id.*, Abstract. Alexander describes the module as “a control module” that communicates with its controller and is “operable to read” “linear actuator motion profile from” memory to apply a “linear actuator motion profile” to the linear actuator. APPLE-1005, claim 11.

102. The Alexander-Cosper combination provides a control component that *receives control signals input to the oscillating resonant module*. For

example, the actuator includes a feedback controller that “accept[s] input from [a] user to modify the motion of the mover.” APPLE-1005, [0005]. In particular, Alexander’s “controller is operable to receive commands from a user to modify the motion of said linear actuator.” *Id.*, claim 10. The commands represent control signals, and Alexander’s control circuits translate the user/control inputs to control signals. I note that the ’882 Patent itself acknowledges that “[m]any different types of control inputs can be used to shape the vibration response of an ORM,” and that the logic circuitry “receives input signals and translates them into oscillations.” APPLE-1001, 26:14-15; 26:22-23.

103. The Alexander-Cosper combination discloses a control component that *receives outputs from the one or more sensors*. The position sensor(s) (e.g., in accordance with Alexander and/or Cosper’s suggestions) “reports the position” of the mover “to the main drive and control electronics.” APPLE-1005, [0034], [0035], [0040]. For example, the magnetic flux sensor can “sense the magnetic flux at a position on the mover to determine the location of the mover in the stator.” *Id.*, [0035]. The combined Alexander-Cosper system “reports” the mover’s position as outputs (e.g., output indications) from the one or more sensors that are received by the control module. APPLE-1004, [0034].

104. The combined Alexander-Cosper system “reports” the mover’s position as outputs (e.g., output indications) from the one or more sensors that are

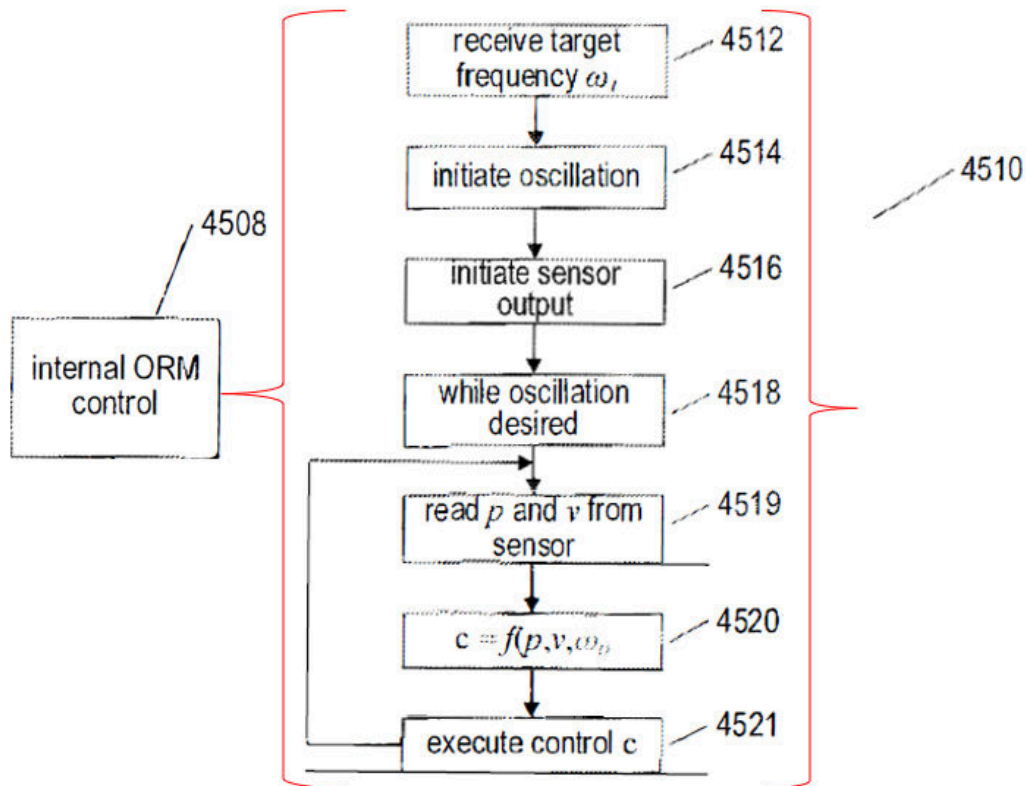
received by Alexander's control module. APPLE-1004, [0034]. For example, Alexander's position sensors output a "repeating wave pattern" that is returned to (and received by) the main drive and control electronics of Alexander's control module/component. APPLE-1005, [0040].

105. The Alexander-Cosper combination discloses a control component that controls oscillation of the mass to produce a vibration response according to the received control signals by using the received sensor outputs to generate control outputs to an actuator that drives the mass to oscillate. For example, I note that Alexander describes "the main drive and control electronics" that receive the position data "control the current that is driven through the coils, creating a feedback system that allows precise control of the position of the [mover]." APPLE-1005, [0034]. Thus, based on Alexander's teachings, using "feedback control of the mover position, a variety of position and motion parameters of the linear motor can be controlled by the control system, including: mover stroke, mover speed, and mover acceleration." *Id.*, [0037]. In the Alexander-Cosper combination, "[f]eedback on the position, velocity, and/or acceleration of the mass may be input to the controller" that "process[es] the feedback signal and generate[s] drive signals that ... maintain mechanical oscillation" at the resonant frequency of the system. APPLE-1006, [0010].

106. The Alexander-Cosper combination includes the claimed control

component according to either party's means-plus-function construction proposed in the counterpart litigation. As I described above, the control component of the Alexander-Cosper combination performs the following functions, as recited by Claim 1: receiving control signals input to the oscillating resonant module; receiving outputs from the one or more sensors; and controlling oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

107. Under the first means-plus-function, the structure for performing these functions is: the processor/logic circuitry that performs the algorithm shown in Fig. 45 of the '882 Patent (reproduced below), and described at column 31, lines 19-column 32, lines 13, and equivalents thereof. *See* APPLE-1001, Fig. 45, 31:19-58.



APPLE-1001, Fig. 45 (Annotated)

108. The Alexander-Cosper combination discloses the claimed control component under the first means-plus-function construction presented at §II.A, as discussed above, executing the control-flow shown in the '882 Patent's Fig. 45, as well as processor/logic circuitry capable of performing the process flow. APPLE-1001, 31:29. The Alexander-Cosper combination's feedback controller is a processor/logic circuitry. For example, Alexander specifically describes a "processor" and "software." APPLE-1005, [0040], [0052] ("PCB").

109. For example, the combined system performs steps 4512 and 4514 of the '882 Patent's FIG. 45 control-flow diagram. In step 4512, the '882 Patent

describes that “a target frequency ω_t is received,” and in step 4514, the “control initiates oscillation of the mass.” APPLE-1001, 31:19-33. The Alexander-Cosper combination discloses each of these functions. For example, the processor/logic circuitry of the combined Alexander-Cosper system receives control signals input to the oscillating resonant module. In particular, Alexander’s “control module” “receive[s] commands” from a user. APPLE-1005, claim 16. The received “commands are used by [the] controller to control the motion of” Alexander’s actuator. *Id.*

110. Receiving the commands includes receiving a target frequency, as recited with respect to step 4512. I note that Alexander describes the controller can “accept input from the user to modify the motion of the mover.” *Id.*, [0005]; *see also*, cl. 10 (“controller is operable to receive commands from a user to modify the motion of said linear actuator.”). In particular, Alexander describes certain “complex motion profiles” that “include: speed, position, acceleration (or a max allowed acceleration), **vibration frequency**, and vibration magnitude,” and the “motion profiles” are subject to “user control.” *Id.*, Abstract, [0039]. A user can control a motion profile by, for example, modifying the “vibration frequency” value such that Alexander’s controller receives a target frequency (*e.g.*, as a new or modified target frequency). To be clear, I note that a POSITA would have recognized from Alexander that receipt of the target frequency may occur via any

of a variety of means, including direct input or indirect input by the user (e.g., via entry at the interface), or based on computations based on other inputs, that direct the target vibration frequency.

111. The control component of the combined system additionally discloses receiving a target frequency based on Cosper. Cosper describes “user control[s]” are “provided to select or adjust the resonant frequency that the mirror (and/or illumination source) oscillates.” APPLE-1006, [0106]. Based on my knowledge and experience in the field and my review of Alexander and Cosper, a POSITA would have found it obvious to use input received via the user controls to generate a target frequency, based on express description of user selection/adjustment. For example, based on input received via the user controls, a target frequency is received in order to effectuate the user input that selects/adjusts the resonant frequency at which the actuator oscillates.

112. To be clear, the control component of the combination performs step 4514, in which the “control initiates oscillation of the mass.” APPLE-1001, 31:19-33. For example, a target frequency is received (e.g., based on user input), and the module initiates oscillation according to the relevant motion profile to generate vibration according to the target frequency associated with the user input. APPLE-1005, [0059], Abstract (“user control over the linear actuator motion profiles”).

113. The combined system performs steps 4516, 4518, and 4519 of the 882

Patent's FIG. 45 control-flow diagram. The '882 Patent describes that, in step 4516, "the control logic initiates sensor output," and in step 4519, the "control logic reads the position and velocity data from the sensor." APPLE-1001, 31:33-38. This occurs "while oscillation desired" (step 4518). *Id.*; FIG. 45.

114. The processor/logic circuitry of the combined Alexander-Cosper system initiates sensor output (4516). Alexander's "position sensor measures the position" of the mass/mover, and outputs the associated signal to the control logic. *Id.*; APPLE-1005, [0034], discussed above regarding Analysis of Element [1c]; *see also* APPLE-1006, [0050] (describing "control logic may be contained within a controller or control circuit" and receives "feedback inputs from one or more sensors.").

115. The combined Alexander-Cosper system receives outputs from the one or more sensors when at least one sensor "reports the position" of the mass/mover "to the main drive and control electronics" of Alexander's control module. APPLE-1005, [0034]. In particular, the control logic (e.g., suggested by Alexander's control module) reads position and velocity data from the sensor(s) (4519). The "position" of the mover "is directly measured using possibly two magnetic field sensors" and the "**speed** and acceleration (and possibly jerk and snap) are **calculated from position over time.**" APPLE-1005, [0040] ("repeating wave pattern" that are received and/or read by Alexander's control module),

[0047]. To be clear, Alexander also monitors “direction,” together with speed. *See, e.g.,* APPLE-1005, [0038] (software and/or control module “determine[s] the desired position of the rod” (or mover) and describes that “[t]he slope of the line **at that position would determine the desired velocity.**”).

116. As I discussed above regarding the combination of Alexander and Cosper, alternatively or additionally, the position sensors include Cosper’s “one or more sensors” (*e.g.*, “electromagnetic” and/or “induction sensors”) that “**detect position, velocity**, acceleration, etc.” of its bias and/or mass. APPLE-1006, [0050]. Each of position and velocity sensor signals are read from the one or more sensors, and used in the feedback control. *Id.*

117. Operation of the module continues, with the control logic receiving position and velocity data from the sensor and generating control signals. These functions are carried out while the device is in use, such as until user input is received ending or adjusting operation, thereby disclosing step 4518. APPLE-1005, [0005], [0039], [0055].

118. The combined system performs steps 4520 and 4521 of the ’882 Patent’s FIG. 45 control algorithm. The ’882 Patent describes that, for step 4520, “the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v ,” and, for step 4521, “the computed control is executed by the controller.” APPLE-1001, 31:33-38.

119. The processor/logic circuitry of the combined Alexander-Cosper system uses the received sensor outputs to generate control outputs to the actuator that drives the mass to oscillate. For example, Alexander's actuator "control system" uses "**feedback control of the mover position**" to control "a variety of position and motion parameters." APPLE-1005, [0037]. Further, Alexander's motion profiles "include: **speed, position, acceleration,**" "**vibration frequency,** and vibration magnitude," for controlling oscillation and/or vibration of a mass/magnet. *Id.*, Abstract, [0039].

120. In the Alexander-Cosper combination, "[f]eedback on the **position, velocity,** and/or acceleration **of the mass may be input to the controller**" that "process[es] the feedback signal and generate[s] drive signals that ... **maintain mechanical oscillation**" at the resonant frequency of the system. APPLE-1006, [0010]. The combined system therefore discloses control signals are computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v , as recited with respect to step 4520.

121. Moreover, in accordance with Cosper's suggestions, the "control system" provides "a **control for increasing the oscillation rate,**" which includes "**increasing to a new resonant frequency**), or any other **appropriate control.**" *Id.*, [0053]. Cosper's control system therefore provides appropriate control that includes increasing to a target frequency represented by a new resonant frequency.

Id. Thus, the combined Alexander-Cosper system discloses a controller (e.g., Alexander's feedback controller) and a computed control (e.g., control signals, in accordance with Cosper) that is executed by the controller.

122. The processor/logic circuitry of the combined Alexander-Cosper system controls oscillation of the mass to produce a vibration response according to received control signals by using the sensor outputs to generate the control outputs to the actuator. In particular, Alexander's "control module" receives control signals in the form of "commands" that are used to "control the motion," e.g., oscillation or vibration, of Alexander's mover. APPLE-1005, cl. 16; *see also* APPLE-1006, [0052] (describing "control circuit" that "receives one or more inputs on the position or motion (or both) of" its mass and "output[s] signals to the force transducer" for driving the mass).

123. The Alexander-Cosper combination also address [1d] according to the interpretation of "control component" advanced by Patent Owner in the counterpart litigation. Based on the reasons I discuss above, Alexander-Cosper's controller is configured to (a) receive a target frequency; (b) receive sensor outputs indicating (1) position of the mass, or (2) position and velocity of the mass; and (c) generate control outputs based on the target frequency and the current position and velocity of the mass.

[2] The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more: mechanical sensors; electromagnetic sensors; and optical sensors.

124. The Alexander-Cosper combination includes a “position sensor” provided by a “magnetic flux sensor” for sensing “the magnetic flux at a position on the mover to determine the location of the mover in the stator.” APPLE-1005, [0035]. Moreover, Alexander further describes alternative approaches including “more than one flux sensor” and that “a flux sensor could be combined with another type of sensor.” *Id.* The “[p]osition” of its mover/mass “is directly measured using possibly two magnetic field sensors.” *Id.*, [0040]. Alexander’s “magnetic flux sensor[s]” or its “magnetic field sensors” teaches at least the “electromagnetic sensors” of the challenged claims.

125. Additionally, the Alexander-Combination provides [2] based on Cosper’s suggestions. As I discussed above, a POSITA would have additionally found it obvious to configure the actuator using one or more “optical sensors, mechanical sensors, electromagnetic sensors,” in accordance with Cosper. Discussed above regarding, VIII.A (Alexander-Cosper combination). To accomplish the sensing for its feedback control, Cosper states that “any appropriate sensor may be used, including (but not limited to) **optical sensors, mechanical sensors, electromagnetic sensors**, or the like,” just like the sensors recited by the ’882 patent. APPLE-1006, [0127].

[3] The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor outputs, the velocity of the mass from the positions of the mass at two or more points in time.

126. Alexander describes software, which runs on its control module and/or feedback controller, that “determines the actual **position, speed, and acceleration** (or trajectory)” of the actuator’s mover/magnet. APPLE-1005, [0040]. The “position” of Alexander’s mover “is directly measured using possibly two magnetic field sensors” and the “**speed and acceleration** (and possibly jerk and snap) **are calculated from position over time.**” *Id.*

127. In particular, in the combined system, the control module receives outputs from the sensors (*e.g.*, magnetic field sensors, and/or other position sensors) that indicate positions of the mass at two or more points in time. *Id.*, [0040], *see* [0035], [0036]. The control module calculates the speed and acceleration from the received position data, thereby providing determination of velocity. APPLE-1005, [0040], [0038] (“determine[s] the desired position of the rod” (or mover) and describes that “[t]he slope of the line at that position would determine the desired velocity.”). To be clear, Alexander also monitors “direction,” together with speed, providing a velocity determination. *See, e.g.*, APPLE-1005, [0038], [0040]. I discussed this further in my Analysis of Element 1(d) (step 4519) above.

[4] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass.

128. The Alexander-Cosper combination includes control outputs provided by, for example, the controller outputs that drive oscillation that are output by Alexander's processor/logic circuitry to the actuator. These control outputs are computed as the output value of a function that takes, as input, the current position of the mass. In particular, the combination computes control outputs in this manner, based on Alexanders description of force/frequency output calculations that provide a function, and these calculations are performed using the current position of the mass as input. Alexander expressly indicates that the actuator "control system" uses "feedback control of the **mover position**" to control "a variety of position and motion parameters." APPLE-1005, [0037], [0039].

129. Further, Alexander describes motion profiles that include "**position**," among other parameters (e.g., speed, acceleration), for controlling oscillation and/or vibration of a mass/magnet. *Id.*, Abstract, [0039]. Based on the actual position (e.g., determined from the position sensor), the software is configured to "calculate the required force vector . . . to correct the actual position, speed, and acceleration to match the desired parameters. *Id.*, [0047] (controller "determines the desired position [and] then generates a scaling factor" for "moving towards or away from" a particular setpoint, which represents "the force it needs to exert on

the rod” (or mover)).

130. I note that claim 4 is additionally disclosed by the Alexander-Cosper combination in a second manner based on Cosper’s suggestions. Cosper describes position feedback is “**input to the controller**” to “generate drive signals that ... **maintain mechanical oscillation**” at a target frequency (e.g., resonant frequency), indicating the control outputs are computed based on a function that uses the current position of the mass as input. APPLE-1006, [0010]. Indeed, based upon my knowledge and experience in this field, the general use of a function as described in the ’882 patent is an obvious and well-known mathematical concept. Based on Cosper’s suggestions, a POSITA would have readily utilized a function, taking position of the mass as input, effectuating Alexander’s described control objectives. I note that the ’882 patent recites only a basic description of function that receives an input (the mass/mover’s position) and generates an output (control outputs for controlling oscillation of the mass). The use of a function, and its implementation to carry out a control scheme, was known to a POSITA.

[5] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

131. The processor/logic circuitry of the combined Alexander-Cosper system uses current position and velocity of the mass to generate control outputs.

As I discussed above in the analysis of Claim [4], the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass. The Alexander-Cosper combination's control outputs are additionally computed using a function that takes as input the current velocity of the mass. Alexander expressly indicates that the actuator "control system" uses "**feedback control of the mover position**" to control "a variety of position and motion parameters." APPLE-1005, [0037]. For example, Alexander describes motion profiles that include "**position**" and "**speed**" (velocity) among other parameters (e.g., acceleration), for controlling oscillation and/or vibration of a mass/magnet. APPLE-1005, Abstract, [0039]. Based on the actual position and speed (e.g., determined from the position sensor), the software is configured to "calculate the required force vector ... to correct the actual position, speed, and acceleration to match the desired parameters." *Id.*, [0047] (controller "determines the desired position [and] then generates a scaling factor" for "moving towards or away from" a particular setpoint, which represents "the force it needs to exert on the rod" (or mover)).

132. Beyond Alexander's express disclosure, claim 5 is additionally provided in the combined system based on Cosper. Cosper describes "[f]eedback on the **position, velocity**, and/or acceleration of the mass" is "**input to the controller**" to "generate drive signals that ... maintain mechanical oscillation" at a

target frequency (e.g., resonant frequency) indicating the control outputs are computed based on function that uses the current position and current velocity of the mass as input. APPLE-1006, [0010].

[6] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

133. The Alexander-Cosper combination includes control outputs provided by the outputs that drive oscillation, as I discussed above regarding Element [1d]. The control outputs are output by the processor/logic circuitry of the module and are computed, for example, from pre-computed values (e.g., data points stored in a lookup table) indexed by the current position of the mass and the current velocity of the mass.

134. Alexander describes that the “control module” reads “actuator motion profile[s] from” “memory to apply” the “actuator motion profile[s] to said linear actuator.” APPLE-1005, cl. 11. Alexander’s “motion profiles could be described in a variety of ways.” *Id.*, [0039]. For example, “[a] mathematical formula is one option, or simply a series of data points (speed, position, acceleration) could be **stored in a lookup table.**” *Id.* In particular, Alexander’s “motion profile could be described as a series of data points that include: speed, position, acceleration (or a max allowed acceleration), vibration frequency, and vibration magnitude.” *Id.*

The “final calculated desired position speed and acceleration would be combined from data tables, and the user adjusted scaling factors/limits.” *Id.* In accordance with Alexander’s suggestions, the controller computes control outputs, including control outputs that generate the required force to “correct the actual position, speed, and acceleration to match the desired parameters.” *Id.*, [0047]; *see also* cl. 11 (Alexander’s “control module” reads “actuator motion profile[s] from” “memory to apply” the “actuator motion profile[s] to said linear actuator”).

135. Based on my knowledge and experience in the field, and my review of Alexander and Cosper, a POSITA would have recognized, and found obvious, from Alexander’s description of pre-computed lookup tables that the required control outputs are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass. As I discussed previously, such control outputs are computed using both current position and current velocity of the mass. And Alexander expressly describes the use of lookup tables by its controller for position-based feedback control. APPLE-1005, [0038], [0039], [0046].

136. A POSITA would have recognized that the lookup tables, as described by Alexander, facilitate efficient and repeatably determination of a control output when indexed based on current position and velocity. The use of such tables provide a suitable option to effectuate Alexander and Cosper’s feedback control

objectives based on current position and current velocity. I note further that the use of a lookup table would facilitate efficient determination of appropriate outputs based on current position and velocity (e.g., relative to “desired” values”), and/or reduce real-time calculations necessary to determine appropriate outputs. *Id.*

Relatedly, Alexander describes the use of “PID” control, which a POSITA would have recognized as further confirming control is determined using both current position and current velocity, and further supports the straight-forward technique of indexing the lookup tables based on current position and current velocity.

137. I note that a POSITA would have understood Alexander as providing at least as much detail with respect to the use of lookup tables indexed by current position and current velocity as the '882 patent. For example, at col. 31, lines 43-49, the '882 patent mentions that “appropriate control is computed based on the target frequency w , and the current position and velocity” which may be made “based on tables with values.” APPLE-1001, 31:43-49. To the extent the '882 patent is sufficient for a POSITA to implement such features, Alexander likewise provides ample description, from which a POSITA would have recognized, and found obvious, control outputs computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

138. Based on my analysis of Alexander and Cosper, the Alexander-Cosper combination discloses Claim [6] in a second manner. Alexander describes using

“lookup tables” that include position and speed (velocity) sensor data, respectively, which provide “current” position and velocity. APPLE-1005, [0046] (“same method as above could be used similarly for speed”). The controller iterates through the lookup tables to compare the “real sensor data to each pair of values in the lookup table,” determining actual position values, which provide pre-computed values as recited by Claim [6]. The control outputs are in turn computed from these pre-computed values in order to determine required values to correct the actual position, speed, and acceleration to match the desired parameters. APPLE-1005, [0047] (the controller “calculate[s] the required force vector (magnitude and direction) to correct the actual position, speed, and acceleration to match the desired parameters”).

[10pre] A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

139. The Alexander-Cosper combination discloses a physical device, such as a “sexual appliance,” that exhibits a vibration response when mechanical driven by one or more resonant actuators included in the physical device. APPLE-1005, Abstract, [0037]-[0038]. For example, Alexander describes a “linear actuator is used in a sexual appliance with user control over the linear actuator motion profiles.” APPLE-1005, Abstract.

140. For example, in the combined system Alexander’s “mover,

reciprocating forwards and backwards, provides the motion” and vibration response when the sexual appliance is mechanical[ly] driven by “drive signals” that “**maintain mechanical oscillation**” of the physical device, as taught by Cosper. APPLE-1005, [0052]; APPLE-1006, [0010].

[10a] a controller; and

141. The Alexander-Cosper combination includes a controller provided by a “user interface” and associated components. Alexander describes the “user interface” components “allow handheld **control** of the motor motion parameters via buttons, touch screen input, or other input means known in the art.” Based on my knowledge and experience in the field, a POSITA would have understood such features as providing a controller, especially because they facilitate control (e.g., by a user) of the vibration output. APPLE-1005, [0055].

142. I note that the “user interface” components are implemented, in part, by a “PCB.” APPLE-1005, [0052] (“PCB 10 may include . . . user input capabilities.”), [0010], Fig. 8A. The PCB includes circuitry (e.g., “user input capabilities”) for a controller that receives control signals input to the physical device and outputs control signals to the oscillating resonant actuator of the combined system.

[10b] the one or more oscillating resonant modules, each oscillating resonant including:

143. As I discussed in Ground 1 above regarding Analysis of Element [1pre], Alexander-Cosper renders obvious [10b].

[10c] an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

144. As I discussed in Ground 1 above regarding Analysis of Element [1a], Alexander-Cosper renders obvious [10c].

[10d] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

145. As I discussed in Ground 1 above regarding Analysis of Element [1b], Alexander-Cosper renders obvious [10d].

[10e] one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time, and

146. As I discussed in Ground 1 above regarding Analysis of Element [1c], Alexander-Cosper renders obvious [10e].

[10f] a control component that receives control signals input to the oscillating resonant module by the controller, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

147. As I discussed previously (refer to analysis of [1d], the Alexander-Cosper combination provides a control component that receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more

of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

148. Additionally, in the Alexander-Cosper combination, the control component receives control signals input to the oscillating resonant module *by the controller*. The “user interface” components provide a *controller* as recited by Element [10f] and allow a user to “control individual parameters, such as stroke length, speed, acceleration, or motion profile and store them in internal memory in the motor control system.” APPLE-1005, [0055]. Moreover, the “user interface” components allow a user to “switch between different ‘profiles.’” When a user interacts with the “user interface,” the control component receives control signals from the “user interface” components to implement the selected parameter, profile, etc. As I discussed above, the “user interface” can be implemented, in part, via the PCB. APPLE-1005, [0052].

149. I note that Alexander’s description and configuration is just like the ’882 Patent. The ’882 Patent describes “user controls” to select vibration parameters or modes, and that the “user controls generate signals input to the CPU.” APPLE-1001, 8:4-19, cl. 19 (“controller **passes** at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module”). Likewise, in Alexander, when the user selects a parameter or profile, a control signal is generated that passes to the control

component processor/logic circuitry (as I discussed regarding [1d]), which in turn effectuates the user selection.

[17] The physical device of claim 1 further comprising: a controller, within the physical device, that receives control signals input to the physical device, and outputs control signals to one or more of the one or more oscillating resonant modules to controls the vibration response produced by the one or more oscillating resonant modules.

150. As I discussed above (refer to [10a]), the Alexander-Cosper combination includes a controller, provided by “user interface” components, within the physical device. The “user interface” components receive control signals input to the physical device. APPLE-1005, [0055]. For example, the “user interface” components include “buttons, touch screen input, or other input means” that allow a user to “control individual parameters, such as stroke length, speed, acceleration, or motion profile and store them in internal memory in the motor control system.” APPLE-1005, [0055]. The “user interface” components also allow a user to “switch between different ‘profiles.’” *Id.*, [0055].

151. When user input is received at the “user interface,” the “user interface” components output control signals to the Alexander-Cosper control component. For example, when user input is received to switch vibration “profiles,” a corresponding output control signal is provided to control the vibration response produced by the one or more oscillating resonant modules. For example, the “user interface” components output a control signal associated with

the received user input (e.g., selecting a particular “profile”) so that the control component generates vibration to effectuate the selected “profile.” I note here again that Alexander’s teachings are just like the ’882 patent’s example, in which the “CPU receives inputs from the user controls 706 that together comprise a user interface,” and the “The user controls generate signals input to the CPU.” APPLE-1001, 8:4-19, cl. 19.

152. I further note that the terms “the physical device” and “the one or more oscillating resonant module” lack antecedent bases. For my analysis here, I have attempted to interpret the claim to the best of my ability, though I believe the lack of antecedent basis raises questions about the scope of the claim.

[19] The physical device of claim 17 wherein the controller passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module.

153. In the Alexander-Cosper combination, the controller (e.g., “user interface” components) passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module. For example, when user input is received by the “user interface” components, the “user interface” components output control signals associated with the received user input (e.g., selected “profile” or parameter) to the “processor 12” to effectuate the vibration output, thereby passing at least a portion of the received control signals (e.g., associated with the selected “profile” or parameter)

that the “haptic effect” can be effectuated by the actuator. APPLE-1005, [0005], [0039], [0052], [0055], cl. 16.

[20] The physical device of claim 17 wherein the controller controls the one or more oscillating resonant modules to each produce a vibration response, the vibration responses produced by the oscillating resonant modules together producing a resonant-frequency vibration mode in the physical device.

154. I understand that Patent Owner has advanced an interpretation in which Claim 20 encompasses one module, despite reciting “the oscillating resonant modules.” Based on Patent Owner’s interpretation, the Alexander-Cosper combination plainly provides the features of claim 20. In the combined system, the controller, provided by the “user interface” components, for example, controls the oscillating resonant module to produce a vibration response. As discussed above, the Alexander-Cosper combination is implemented with a bias member and feedback control to maintain oscillation at a resonant frequency, based on Cosper’s teachings. The vibration response by the module thus produces a resonant-frequency vibration mode in the physical device, in accordance with Cosper’s suggestions to operate at a resonant frequency.

155. To be clear, even if claim 20 were interpreted to require multiple modules, a POSITA would have found use of multiple modules obvious in view of Alexander and Cosper. A POSITA would have found the use of multiple modules to be an obvious manner for implementing the systems described by Cosper to

further its objective of providing a desired vibration response, with a reasonable expectation of success. Moreover, a POSITA would have recognized the use of multiple modules as an obvious design choice that amounts to mere duplication of parts.

VI. GROUND 2A: CLAIMS 1-5, 10, 17, 19, AND 20 ARE OBVIOUS IN VIEW OF GREGORIO

156. I understand that Patent Owner has taken a position that the claimed oscillation path encompasses a linear path. For the reasons I describe in detail below, and based on my review of the '882 patent and its file history, and the prior art references cited herein, a POSITA would have understood that the teachings of Gregorio render claims 1-5, 10, 17, 19, and 20 obvious according to Patent Owner's proposed interpretation.

[1pre] An oscillating resonant module comprising:

157. Gregorio provides an oscillating resonant module. Gregorio describes a "resonant actuator" that provides "[h]aptic feedback generation based on resonant frequency." APPLE-1007, Abstract ("resonant actuator"); cl. 16. The module includes a moveable magnet that oscillates according to the actuator control. APPLE-1007, 2:10-20; 3:12-28; 3:44-64.

[1a] an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

158. Gregorio provides Element [1a] according to Patent Owner's position

in the co-pending litigation that the claimed oscillation path encompasses a “linear” path. Gregorio describes a mass (at least a portion of “magnet 27”) that moves by electromagnetic force exerted on the mass by the magnetic field around the coil 28. APPLE-1007, 3:12-22. For example, during operation of Gregorio’s resonant actuator “current flows thru [sic] coil 28” and “a magnetic field forms around coil 28,” which “in interaction with the magnetic field of magnet 27[,] pushes or pulls on magnet 27.” APPLE-1007, 3:12-22 (“One current flow direction/polarity causes a push action and the other a pull action. Spring 26 controls the up and down movement of magnet 27.”). The moveable magnet 27 can be considered as including two masses, such as a portion at the top of magnet 27 and a portion at the bottom of magnet 27. Each of these portions of the material of magnet 27 provide a mass that a point within which moves along the oscillation path.

[1b] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

159. Gregorio’s mass is driven by energy, provided by “electrical current,” for example, supplied to the oscillating resonant module, such that the mass (e.g., a portion of magnet 27) oscillates back and forth along the oscillation path that represents a segment of a space curve. APPLE-1007, 1:29-30, 2:36-39 (supply the actuator “with the required electrical current and voltage to cause the desired

haptic effects.”), 3:12-21.

160. For example, Gregorio describes that “[i]n operation, when current flows thru coil 28 a magnetic field forms around coil 28 which in interaction with the magnetic field of magnet 27 pushes or pulls on magnet 27. One current flow direction/polarity causes a push action and the other a pull action.” APPLE-1007, 3:17-21. Thus, the mass/magnet **“is driven back and forth”** to oscillate along Gregorio’s oscillation path, by energy such as the “current” flowing through Gregorio’s coils. APPLE-1007, 1:29-30, 3:18.

161. The energy or current supplied to Gregorio’s coil 28 causes the back-and-forth oscillation of the magnet along the oscillation path. APPLE-1007, 3:12-22; 2:36-39. Gregorio’s system includes “an actuator drive circuit” that generates “drive signal pulses” that “are applied to LRA 18.” APPLE-1007, 2:19-20.

Gregorio indicates that the drive signal pulses provide the corresponding energy/current that flows through Gregorio’s coils to form the magnetic field that pushes and pulls on Gregorio’s mass/magnet. *See id.*, 5:45-55. The push and pull action exerted on Gregorio’s mass/magnet corresponds to a driving action caused by the magnetic field around Gregorio’s coil, and the corresponding energy supplied to Gregorio’s coils via its resonant actuator.

[1c] one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time; and

162. Gregorio provides one or more sensors, such as its “Hall sensor, optical sensor or other type of sensing device,” that output indications, including sensed position signals, of the positions of the mass/magnet within the oscillation path at specific points in time. For example, the one or more sensors output indications at least during certain portions of the operational cycle, (e.g., during each monitoring and/or sampling period). In more detail, Gregorio describes the resonant actuator includes a “Hall sensor, optical sensor or other type of sensing device that is located in proximity to mass 27 for detecting the position of mass.” APPLE-1007, 4:7-10, 4:10-13 (“sensing device will provide a sensed position signal that can be used as the monitoring signal to provide information about the position[s] of the mass.”). The “sensing device,” (e.g., a Hall sensor or optical sensor) provides “a sensed position signal,” disclosing at least one of the sensors and the output indications, as recited by Element [1c]. I note that Gregorio expressly indicates the sensed position signal is capable of providing information about the “position[s] of the mass,” essentially mirroring the claim language of [1c].

163. Gregorio discloses “circuitry” “adapted to apply the drive pulses to a resonant actuator during the drive period, and receive a signal that comprises a position of the mass from the resonant actuator during the monitoring period.”

APPLE-1007, 6:55-58, 1:43-46. Indeed, Gregorio also discloses “receiving a signal

that comprises a position of the mass from the resonant actuator during the monitoring period,” where “the signal is generated by a sense coil in proximity to the mass.” APPLE-1007, 6:18-26; 6:46-47. Gregorio’s resonant actuator drive cycles can be “executed as a continuous loop” “that includes a drive period and a monitoring period.” *Id.*, 4:18-20. Gregorio’s sensor output indications are received over at least a monitoring period, such that the sensing device provides a “sensed position signal” at specific points in time. *Id.*, 6:55-58, 1:43-46. Measurements at consecutive points or periods in time provide an indication of position that facilitate feedback control, and velocity determination, effectuating Gregorio’s control objectives. *Id.*

164. To be clear, I note that a POSITA would have recognized from Gregorio, and found it obvious, that the sensed position signals are provided at specific points in time because doing so would have predictably facilitated characterization of the movement of the mass based on positions of the mass at the specific points in time. Indeed, such position signals at specific points in time would have been recognized as facilitating derivation of velocity consistent with Gregorio’s description of using velocity in its feedback control scheme.

[1d] a control component that receives control signals input to the oscillating resonant module, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

165. Gregorio includes a control component as recited by Element [1d] according to each of the parties' claim constructions proposed in the counterpart litigation. I first address how Gregorio provides Element [1d] according to the plain and ordinary meaning. I then address additional aspects demonstrating how Gregorio provides Element [1d] according to each means-plus-function interpretation proposed in the counterpart litigation.

166. Gregorio includes a control provided by the processor/logic circuitry in accordance with Gregorio's teachings, including at least the portion of the software executed by the "processor 12" that generates control outputs based on the control signals, together with the "actuator drive circuit." For example, Gregorio describes the "haptic feedback system" includes "a processor" coupled to "a memory" and "an actuator drive circuit," which is coupled to the oscillating actuator. APPLE-1007, 2:18-20, 2:36-53; FIG. 1. The module further includes software (included as part of "LRA Drive with Resonant Frequency Determination module 22") that "generate drive signals" for the actuator and "adjust[s] the drive signals accordingly". *Id.*

167. Gregorio's processor/logic circuitry receives control signals input to the oscillating resonant module. Gregorio describes a user interface device, such as a cellular telephone that includes a "[t]ouch surface" that "recognizes touches." *See* APPLE-1007, Fig. 1, 2:36-39. Gregorio further indicates that the "[t]ouch

surface” recognizes “the position and magnitude of touches on the surface,” and “data corresponding to the touches is sent to [its] processor 12.” *Id.*, 2:53-63. I understand that Patent Owner has applied the control signal to a signal corresponding to the touch interface. Based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have plainly recognized that Gregorio demonstrates this functionality. For example, a signal corresponding to the touches is received by the control component, which “interprets the touches and in response generates haptic effect signals.” In more detail, a POSITA would have recognized from Gregorio’s description that a system processor (e.g., the “processor that operates the entire system”), for example, recognizes the position/magnitude of touch input and provides corresponding control signals to the control component. APPLE-1007, 2:18-59.

168. Gregorio’s processor/logic circuitry receives outputs from the one or more sensors. As I discussed above, Gregorio describes various sensors that are used for “detecting the position of mass 27,” such as “a sensing coil, Hall sensor, optical sensor or other type of sensing device.” APPLE-1007, 4:7-10. The sensing devices “provide a sensed position signal that can be used as the monitoring signal to provide information about the position of the mass.” *Id.*, 4:10-13. In order to effectuate feedback control, the sensed position signals are received by the processor/control circuitry for processing in determining control outputs. APPLE-

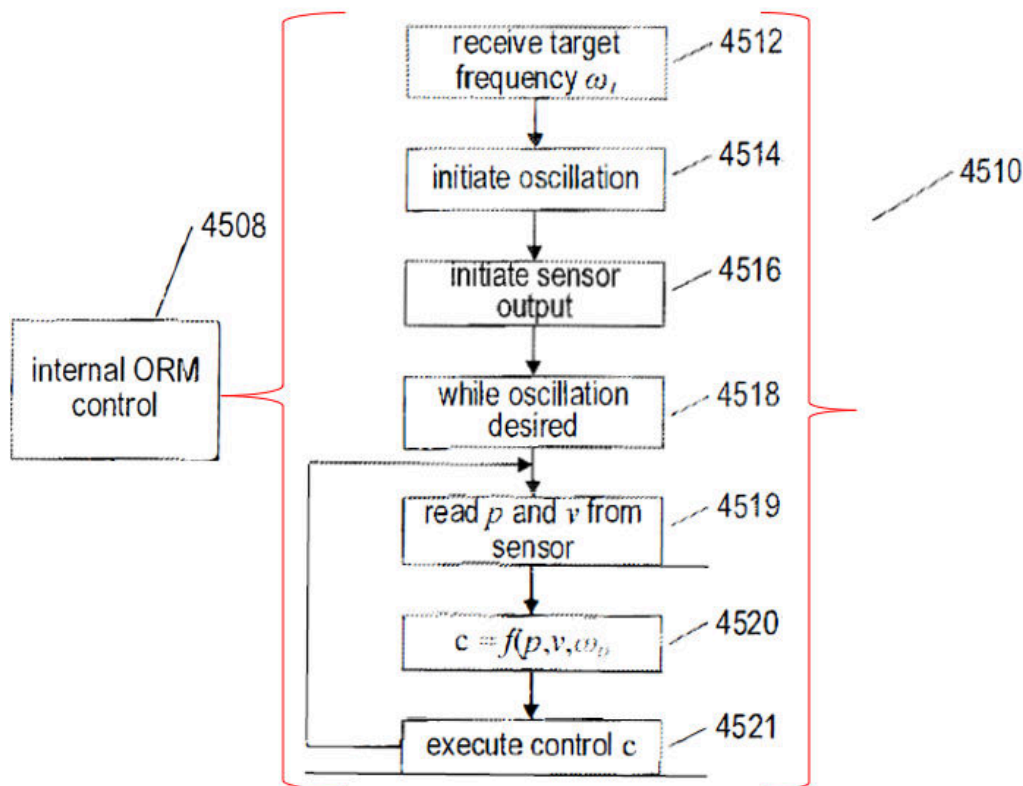
1007, cl. 11 (“circuitry [that] is adapted to ... receive a signal that comprises a position of the mass from the resonant actuator.”), 4:5-14, 4:15-36, 4:41-48, 6:5-9.

169. Gregorio’s control component controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate. For example, the control component receives data corresponding to the touch input indicative of a “haptic effect” to be generated and receives sensor outputs, such as the sensed position of “magnet 27.” Based on these inputs, the control component generates control outputs in the form of “control signals”/“drive pulses,” for example, to an actuator that drives the mass to oscillate. Indeed, Gregorio describes that the “[p]rocessor 12 outputs the control signals to drive circuit 16 which includes electronic components and circuitry used to supply” the actuator with “electrical current and voltage to cause the desired haptic effects.” APPLE-1007, 2:36-53; *see also* Abstract; 1:24-46, 6:55-58.

170. I further note that Gregorio includes the claimed control component under each means-plus-function construction proposed by the parties in counterpart litigation (refer to analysis of, §II.A). As described above, the control component performs each of the claimed functions, as recited by Claim 1: receiving control signals input to the oscillating resonant module; receiving outputs from the one or more sensors; and controlling oscillation of the mass to produce a vibration

response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

171. Under the first means-plus-function, the structure for performing these functions is: the processor/logic circuitry that performs the algorithm shown in Fig. 45 of the '882 Patent (reproduced below), and described at column 31, lines 19-column 32, lines 13, and equivalents thereof. *See* APPLE-1001, Fig. 45, 31:19-58.



APPLE-1001, Fig. 45 (Annotated)

172. Gregorio executes the control-flow shown in the '882 Patent's Fig. 45 via processor/logic circuitry capable of performing the process flow (e.g., by the

control component discussed above). APPLE-1001, 31:29.

173. For example, Gregorio performs steps 4512 and 4514 of the '882 Patent's FIG. 45 control-flow diagram. In step 4512, the '882 Patent describes that "a target frequency ω_t is received," and in step 4514, the "control initiates oscillation of the mass." APPLE-1001, 31:19-33. Gregorio describes software that "determines the resonant frequency" of the actuator. APPLE-1007, 2:45-53. The determined resonant frequency serves as a target frequency that is received by software of the control component. Based on the determined resonant frequency, the control software "adjust[s] the drive signals accordingly." *Id.* As Gregorio expressly mentions, it was well known for target (e.g., resonant) frequencies to be "dynamically determined and controlled so that drive signals that generate the haptic effects can be most effective and efficient." *Id.*, 1:31-36 (Gregorio's "BACKGROUND" on state of the art).

174. To be clear, the control component disclosed by Gregorio performs step 4514, in which the "control initiates oscillation of the mass." APPLE-1001, 31:19-33. For example, upon receiving a target frequency, such as the determined resonant frequency, Gregorio's drive circuit initiates oscillation at that frequency to generate the desired haptic effect.

175. The '882 Patent describes that, in step 4516, "the control logic initiates sensor output," and in step 4519, the "control logic reads the position and

velocity data from the sensor.” APPLE-1001, 31:33-38. This occurs “while oscillation [is] desired” (step 4518). *Id.*; FIG. 45. Gregorio performs each of these steps as shown and described with respect to the ’882 Patent’s FIG. 45 control-flow diagram.

176. Gregorio’s processor/logic circuitry initiates sensor output (step 4516). Gregorio’s resonant actuator includes at least one “sensing device” for “detecting the position of mass.” APPLE-1007, 4:7-10. In order to effectuate feedback control, the control logic initiates sensor output such that Gregorio’s sensing devices “provide a sensed position signal that can be used as the monitoring signal to provide information about the position[s] of the mass.” *Id.*, 4:10-13.

177. The processor/logic circuitry reads position and velocity (speed) data from the sensor (step 4519). This continues while oscillation is desired (step 4518). As I mentioned above, Gregorio’s resonant actuator includes at least one “sensing device” for “detecting the position of mass,” and the sensing devices “provide a sensed position signal that can be used as the monitoring signal to provide information about the position[s] of the mass.” APPLE-1007, 4:7-13. Gregorio’s control component receives outputs from the one or more sensors when Gregorio’s sensed position signals are received by its control component as outputs of its sensing devices (*e.g.*, a Hall sensor). In particular, Gregorio’s control

component reads position data and reads (or derives) velocity data from the sensor(s) (step 4519).

178. Based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have recognized from Gregorio's description, and found obvious, to determine velocity from the available position data. *Id.* Computation of velocity based on the change in position over time, such as comparing a difference in current and previous positions over a time, is a fundamental principal recognized by a POSITA. Such a value is readily computed based on position information available from the position sensors. A POSITA would have been led to utilize this basic computation when using a position sensor in accordance with Gregorio's description. Moreover, a POSITA would have recognized that computing velocity in this manner would have beneficially provided the controller with additional information relevant to the current motion of the movable mass, providing an alternative source of velocity information, enhancing system redundancy and promoting overall reliability. *Id.* The control logic continues to receive position and velocity data from the sensor, and generates control signals, while the haptic effect is generated, disclosing step 4518.

179. The combined system performs steps 4520 and 4521 of the '882 Patent's FIG. 45 control algorithm. The '882 Patent describes that "the appropriate control is computed based on the target frequency ω_t and the current

position and velocity of the moving mass p and v ” (step 4520) and “the computed control is executed by the controller” (step 4521). APPLE-1001, 31:33-38.

Gregorio’s processor/logic circuitry uses the received sensor outputs to generate control outputs to the actuator that drives the mass to oscillate. As I discussed above, Gregorio’s control component “receive[s] a signal that comprises **a position of the mass from the resonant actuator**,” and, based on Gregorio’s description, a POSITA would have recognized that the system obtains a current speed (velocity) of the mass (e.g., based on current and previous positions over time). APPLE-1007, Abstract, 6:55-58, 1:43-46, cl. 11. Additionally, Gregorio describes obtaining a “derivative of the **speed** of the mass (“ dv/dt ”)” corresponding to vibration amplitude. *Id.*, 4:42-48. The vibration amplitude, which Gregorio indicates as a function of the speed, is used to compute the appropriate control signal, thereby indicated that the control component provides control signals computed based on the target frequency ω_t (determined resonance frequency) and the current position (sensed by the Hall sensor) and velocity (speed) of the moving mass, as recited with respect to step 4520. APPLE-1007, 2:3-9 (“adjusted to maximize the haptic feedback based on the determined resonant frequency.”).

180. I note that Gregorio provides a control component according to Patent Owner’s means-plus-function interpretation for the same reasons. Patent Owner proposes an algorithm in which the control component is configured to (a) receive

a target frequency; (b) receive sensor outputs indicating (1) position of the mass, or (2) position and velocity of the mass; and (c) generate control outputs based on the target frequency and the current position and velocity of the mass. APPLE-1011, 1-2; APPLE-1016, 23-24. Because Gregorio's control component carries out each of the steps recited in FIG. 45, it likewise performs each of these functions, as I described above.

181. I further note that according to Patent Owner's proposed means-plus-function interpretation, an algorithm is not required where the logic circuitry does not include a processor. APPLE-1016, 19-20 ("there is no need to identify an algorithm"). Based on Patent Owner's interpretation, Gregorio thus discloses Element [1d] in a second manner. For example, Gregorio describes a control component provided by a "circuit" that provides the "functionality of FIG. 3." APPLE-1007, 4:66-5:4, 5:5-55, 2:18-35. In particular, Gregorio indicates that "[i]n the embodiment of FIG. 4, the driving signal is generated primarily in hardware as opposed to FIG. 3 which can be generated by any combination of software (via module 22) or hardware." APPLE-1007, 4:66-5:4. The circuit thus "provides more specific functionality sufficient to perform the claimed function without additional special programming," according to Patent Owner's interpretation in which the algorithm is not required. As the circuit provides the same functionality that Gregorio describes with respect to FIG. 3, and that I

discussed above, it provides each of the functions of Patent Owner's means-plus-function interpretation, including (a) receive a target frequency; (b) receive sensor outputs indicating (1) position of the mass, or (2) position and velocity of the mass; and (c) generate control outputs based on the target frequency and the current position and velocity of the mass.

[2] The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more: mechanical sensors; electromagnetic sensors; and optical sensors.

182. Gregorio's module includes at least one electromagnetic sensor "Hall sensor, optical sensor or other type of sensing device that is located in proximity to mass 27 for detecting the position of mass," disclosing at least electromagnetic sensors. APPLE-1007, 4:7-13. Gregorio describes the "sensing device will provide a sensed position signal that can be used as the monitoring signal to provide information about the position[s] of the mass." *Id.*, 4:10-13. Based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have recognized that Gregorio's "Hall sensor" is a type of hall effect sensor that detects the presence and magnitude of a magnetic field using the Hall effect, where the output signals or indications of the Hall sensor can be directly proportional to the strength of the magnetic field detected by the Hall sensor, and thus provides an electromagnetic sensor. I note that the '882 patent itself specifically identifies a "Hall-effect" sensor. APPLE-1001, 32:9-13, cl. 9.

[3] The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor outputs, the velocity of the mass from the positions of the mass at two or more points in time.

183. Gregorio's processor/logic circuitry determines the velocity of the mass (e.g., Gregorio's speed of the mass) from the positions of the mass (e.g., Gregorio's position sensor) at two or more points in time. As I discussed above, the relationship of velocity as a change in position over time is a fundamental principle known and used by a POSITA. The use of position to determine velocity would have been readily apparent, and obvious to a POSITA, based on Gregorio's description of determining position, and the use of velocity in computing its control outputs. APPLE-1007, 4:10-14, 4:43-48. Even if Gregorio did not expressly describe such features, based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have been led to determine the velocity of the mass from the positions of the mass at two or more times when the system uses a position sensor that provides a sensed position signal. *Id.* Doing so would have been recognized as a suitable technique for determining velocity based on the available position data.

[4] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass.

184. Gregorio's control component receives sensor outputs provided by "sensed position signals," for example, which indicate the positions of the mass, as

I discussed above. APPLE-1007, cl. 11; 4:10-12. Based on the “sensed position signals, Gregorio’s control component generates control outputs, provided by “control signals”/“drive pulses,” for example, that drive the magnet 27 to oscillate. APPLE-1007, 2:36-53; *see also*, Abstract; 1:24-46; cls. 1-2. In particular, Gregorio explains “receiving a signal that comprises a position of the mass” and “modifying an amplitude of one of the drive pulses **in response to** the signal” that comprises the position of the mass. To be clear, a POSITA would have recognized that these control outputs are computed by the control component as the output value of a function. Gregorio describes a software module (e.g., “LRA Drive with Resonant Frequency Determination module”) that “generate drive signals.” The “derivative of the speed of the mass,” computed from position sensor data, as I discussed above, is used to calculate the control outputs, indicating use of a function. A POSITA would have readily recognized from Gregorio’s description of these calculations that the outputs are computed as the output value of a function, which is a conventional way of calculating values in a control system.

[5] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

185. Gregorio’s control component receives sensor outputs provided by “sensed position signals,” for example, which indicate the positions of the mass,

and predictably calculates velocity based on current positions at two or more points in time, as I discussed above regarding claims [2]-[4]. APPLE-1007, cl. 11; 4:10-12. Additionally, as I mentioned above, Gregorio's control component computes control outputs by a function that includes a "derivative of the **speed** of the mass (dv/dt)" corresponding to vibration amplitude, which in turn is used to determine a "drive pulse" sized to "cancel the difference between the present amplitude and the desired amplitude." APPLE-1007, 4:42-65, cl. 11. Accordingly, Gregorio plainly calculates control outputs using, as input, both the current position of the mass and the current velocity of the mass. Here again, I note that, based on Gregorio's description (e.g., col. 4) of using position and velocity in determining control outputs, a POSITA would have recognized, and found obvious, that they values are calculated using a function.

[10pre] A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

186. Gregorio discloses a "handheld device," thereby providing a physical device as claimed. APPLE-1007, 3:1-11. The "handheld device" exhibits a vibration response when mechanically driven by an oscillating resonant module included in the physical device. APPLE-1007, 2:10-17, 3:1-4. In particular, Gregorio describes "[s]ystem 10 **may be a handheld device**, such as a cellular telephone, PDA, computer tablet, etc. or may be any other type of device that

provides a user interface **and includes a haptic effect system** that includes one or more [resonant actuators].” *Id.*, 3:1-4. “Internal to [Gregorio’s] system 10 **is a haptic feedback system that generates vibrations on system 10.**” *Id.*, 2:14-17.

The haptic feedback system that generates vibrations on system 10 provides an oscillating resonant module, as I discussed above (refer to Analysis of [1pre] and [1a]-[1d]).

[10a] a controller; and

187. I understand that Patent Owner has interpreted the Challenged Claims as encompassing touch input on a touch screen of a device associated with haptic output. Based on such an interpretation, Gregorio includes a controller provided by its “touch surface” and associated components. For example, Gregorio describes a “[t]ouch surface” that “recognizes the position and magnitude of touches.” APPLE-1007, 2:54-67; *see also* 2:10-17, 3:1-11. “The data corresponding to the touches is sent to processor 12,” which “in response generates haptic effect signals.” *Id.* A POSITA would have recognized, from Gregorio’s description, that the “touch surface” and associated components provide a controller that receive touch input, processes the touch input (e.g., position and magnitude), and outputs corresponding control signals that direct haptic output (e.g., “haptic effect signals”).

[10b] the one or more oscillating resonant modules, each oscillating resonant including:

188. As I discussed in Ground 2A above regarding Element [1pre], Gregorio renders obvious Element [10b].

[10c] an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

189. As I discussed in Ground 2A above regarding Element [1a], Gregorio provides an oscillation path, which represents a segment of a space curve, along which a point within a mass moves.

[10d] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

190. As I discussed in Ground 2A above regarding Element [1b], Gregorio provides a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve.

[10e] one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time, and

191. As I discussed in Ground 2A above regarding Element [1c], Gregorio provides one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time.

[10f] a control component that receives control signals input to the oscillating resonant module by the controller, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response

according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

192. As I discussed in Ground 2A above regarding Element [1d], Gregorio provides a control component, as recited by Element [10f]. I note that Gregorio's control component receives control signals input to the oscillating resonant module by the controller, according to Patent Owner's interpretation. For example, as I discussed above regarding Element [10a], the "touch surface" and associated components provide a controller that receive touch input, processes the touch input (e.g., position and magnitude), and outputs corresponding control signals that direct haptic output (e.g., "haptic effect signals."). Gregorio's control component, a "processor 12," for example, receives the control signals associated with the "data corresponding to the touches" and implements the "haptic effect" based on the touch. APPLE-1007, 2:54-67; *see also* 2:10-17, 3:1-11.

[17] The physical device of claim 1 further comprising: a controller, within the physical device, that receives control signals input to the physical device, and outputs control signals to one or more of the one or more oscillating resonant modules to controls the vibration response produced by the one or more oscillating resonant modules.

193. Gregorio describes a "touch surface" and associated components, which provide a controller within the physical device, according to the interpretation I discussed above (refer to Ground 2A, Analysis of [10a]). The "touch surface" receives control signals input to the physical device associated

with the user touch when the user interacts with Gregorio's "handheld" device in a manner to produce haptic output. APPLE-1007, 2:54-67; *see also* 2:10-17, 3:1-11. The "touch surface" components output control signals to effectuate haptic effect associated with the "data corresponding to the touches." The output is directed to Gregorio's control component, including "processor 12," for example, which in turn outputs a corresponding vibration response produced by the one or more oscillating resonant modules based on the received signals.

194. As I noted previously (Ground 1, [17]), the terms "the physical device" and "the one or more oscillating resonant module" lack antecedent bases. For my analysis here, I have attempted to interpret the claim to the best of my ability, though I believe the lack of antecedent basis raises questions about the scope of the claim.

[19] The physical device of claim 17 wherein the controller passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module.

195. Based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have recognized that the "touch surface" components passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module. For example, the "touch surface" components output control signals associated with the "data corresponding to the touches" to the "processor 12" of an oscillating resonant

module so that the “haptic effect” can be effectuated by the actuator. APPLE-1007, 2:54-67; *see also* 2:10-17, 3:1-11. Thus, the input received at the “touch surface” provides a control signal associated with the “position,” “magnitude,” etc., of the received touch, such that at least a portion of the received control signals input to the physical device are passed to the one or more oscillating resonant module so that the “haptic effect” has parameters corresponding to the input to the physical device.

[20] The physical device of claim 17 wherein the controller controls the one or more oscillating resonant modules to each produce a vibration response, the vibration responses produced by the oscillating resonant modules³ together producing a resonant-frequency vibration mode in the physical device.

196. Gregorio describes that its “handheld device” includes “more than one” actuator. APPLE-1007, 3:1-11. Gregorio further explains that the “more than one” actuators can each “have a different resonant frequency” and “create a wide range of haptic effects on the device.” As I discussed in the preceding paragraphs, Gregorio’s “touch surface” components control the one or more oscillating resonant modules to each produce a vibration response based on the received input. In particular, control signals associated with the “data corresponding with the touches,” for example, are generated so that a “haptic

³ *Supra*, Ground 1, cl. 1, fn. 9.

effect” corresponding to the received touch input is output by the actuator.

APPLE-1007, 2:54-67. This can include particular haptic output based on “multi-touch contacts,” or other input, for example. Here again, I note that Gregorio provides resonant oscillating modules in which the respective modules are controlled to operate at a resonant frequency. As a result, the generated output produces a resonant-frequency vibration mode in the “handheld device.”

**VII. GROUND 2B: CLAIMS 1-5, 10, 17, 19, AND 20 ARE OBVIOUS
IN VIEW OF THE GREGORIO-FULLER COMBINATION**

197. For the reasons I describe in detail below, and based on my review of the '882 patent and its file history, and the prior art references cited herein, a POSITA would have understood that the teachings of Gregorio and Fuller render claims 1-5, 10, 17, 19, and 20 obvious according to its plain and ordinary interpretation and under either party’s proposed interpretation of “control component.”

A. The Predictable Combination of Gregorio and Fuller

198. Based on my knowledge and experience in this field and my review of Gregorio and Fuller, a POSITA would have found it obvious to combine Gregorio and Fuller to implement an actuator so that a movable mass travels along a curved oscillation path. For example, a POSITA would have been motivated to implement Gregorio’s actuator in accordance with Fuller’s suggestions for utilizing

a “curved” oscillation path. Gregorio and Fuller describe similar actuator systems, and Fuller expressly describes both “linear” and “curved” embodiments that “operate[] in the same manner.” APPLE-1008, [0051]. In my opinion, there are several reasons why a POSITA would have found it obvious to combine the teachings of Gregorio and Fuller.

199. As a first reason, a POSITA would have been motivated to implement a curved oscillation path, in accordance with Fuller’s suggestions, in Gregorio’s feedback device, to facilitate generation of vibration output in multiple directions. A POSITA would have recognized from Fuller’s teachings that such a configuration facilitates an expansive vibration response, including vibrations that produce particular sensations “transmitted from the housing or other support to an external environment.” APPLE-1008, ¶[0005]. Fuller expressly describes the advantage of vibrations “in two directions” associated with a curved path, and that the curved path is “preferred” in some applications, and a POSITA would have been motivated to impart such vibration in a “handheld device” described by Gregorio, especially where Gregorio explicitly describes an objective to “create a wide range of haptic effects on the device.” APPLE-1008, [0051], APPLE-1007, 3:9-10.

200. Moreover, a POSITA would have been led to combine Gregorio and Fuller to avail Gregorio of such benefits expressly described by Fuller, utilizing a

curved path without significantly changing the components or overall configuration of Gregorio's original device. Indeed, Fuller describes that its "electromagnetic vibrator can be very small and energy efficient," and "well suited for use in portable electronic devices" such as "cell phones." *Id.*, Abstract. For example, Fuller describes actuator configurations that "may be used in a variety of different electronic devices such as providing a 'silent ringer' vibration in a cell phone or other communicating device." *Id.*, [0005] ("smaller than "the size of a quarter").

201. Thus, a POSITA would have recognized that implementing Gregorio's actuator with a curved oscillation path, as taught by Fuller, would have been suitable and readily implemented in Gregorio's handheld electronic device. *Id.*; see APPLE-1007, 2:10, 3:1-2 (describing "haptically-enabled system[s]" for "handheld device[s], such as a cellular telephone"), FIG. 1.

202. As a second reason, a POSITA would have additionally been motivated to combine Gregorio and Fuller to implement the actuator system in a known manner that produces suitable haptic feedback. Gregorio relates to a movable magnet mass that oscillates based in part on a magnetic field and includes feedback controls that use sensor outputs to resonantly control the vibratory oscillation of the movable magnet at a resonant frequency. APPLE-1007, Abstract, 2:3:53. Fuller demonstrated the conventional knowledge of implementing such an

actuator system, including by positioning the movable magnet to oscillate along a curved path. APPLE-1008, ¶[0036]. A POSITA would have had reason to consult Fuller when reviewing Gregorio's disclosure, including for implementation details of the path of the movable component. In evaluating Gregorio, a POSITA would have been motivated to consider related publications, such as Fuller, based on Gregorio's explicit indication that its description of feedback controls and resonant frequency vibration directly overlaps with the substantially similar subject matter of Fuller. A POSITA would have predictably looked toward other teachings such as Fuller, especially where Fuller describes a moveable magnet actuator suitable for "[v]irtually any application where a vibrator is required." APPLE-1008, [0005].

203. As a third reason, a POSITA would have been motivated to combine Fuller with Gregorio to optionally utilize one or more "tabs" made of a "low friction material." Based on Fuller's express description of advantages of such a configuration, a POSITA would have recognized benefits of a "low friction material" in promoting smooth and consistent movement of the moveable magnet in a "central position within the enclosure," and preventing movement in an unintended direction, especially in configurations "lacking [an] axial shaft." APPLE-1008, [0042].

204. As a forth reason, based on my knowledge and experience in the field and my review of Gregorio and Fuller, combining the teachings of Gregorio with

Fuller would have merely involved combining prior art elements according to known methods to yield predictable results. Fuller, like Gregorio, describes an actuator having a movable magnet, utilizing feedback control, to generate predictable motion of the movable magnet. APPLE-1008, [0012], [0033], [0038]; APPLE-1007, Abstract, 1:6-8, 1:39-65; 1:1-3:11. Notably, the oscillation path of Gregorio's actuator and the curved oscillation path of Fuller's vibrator have small form factors that are similarly sized to induce vibrations and oscillations in the same handheld devices such as cell phones. A POSITA would have been motivated to combine the teachings of Gregorio with the teachings of Fuller to realize, in Gregorio, a movable magnet that is capable of moving along a curved path, as described by Fuller, while the structure and control would remain largely as described by Gregorio. APPLE-1008, [0051] ("the curved embodiment can alternately have compression springs 60[,], 64 ... and other features described above" with respect to linear embodiments). The combination of Gregorio and Fuller would have been predictable and foreseeable because 1) Gregorio and Fuller disclose a movable magnet or mass that oscillates under the influence of a magnetic field, and 2) the combination merely involves incorporating a curved path, in accordance with Fuller's express suggestions. Fuller specifically indicates that a "curved" configuration "operates in the same manner" as a "linear" configuration. APPLE-1008, [0051].

205. Moreover, Gregorio's resonant actuator would still perform the same back-and-forth oscillation of a mass or weight as it did prior to the combination with Fuller, with updates to account for a curved oscillation path, any such updates being readily implemented as a manner of routine implementation. *Id.*, [0051] ("the curved embodiment can alternately have compression springs 60 64 ... and other features described above" with respect to linear embodiments). Indeed, implementations of curved oscillation paths were known at the time of filing the application that issued as the '882 Patent. *See, e.g.*, APPLE-1005, FIG. 7A; Analysis of Ground 1.

B. Analysis of the Gregorio-Fuller Combination with Respect to Claims 1-5, 10, 17, 19, and 20

206. As shown in this section, the Gregorio-Fuller combination, when predictably combined for at least the reasons described above, provides all elements of claim 1.

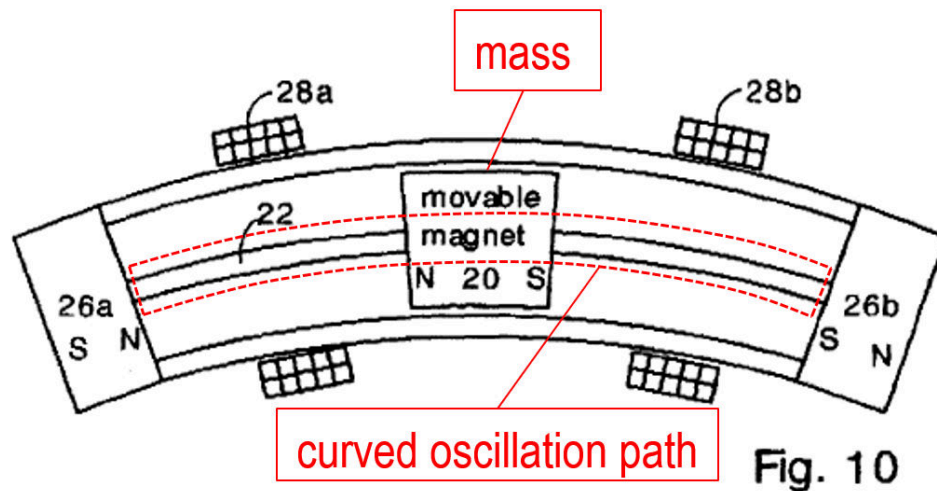
[1pre] An oscillating resonant module comprising:

207. As I discussed in Ground 2A above regarding Analysis of Element [1pre], the Gregorio-Fuller combination renders obvious [1pre].

[1a] an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

208. The Gregorio-Fuller combination provides an oscillation path, which represents a segment of a space curve, along which a point within a mass (one of

the magnets) moves. Gregorio describes a mass (e.g., at least a portion of “magnet 27”) that moves by way of push and pull action that occurs from electromagnetic force exerted on the mass by the magnetic field around the coil 28. APPLE-1007, 3:12-22. During operation of Gregorio’s resonant actuator “current flows thru [sic] coil 28” and “a magnetic field forms around coil 28,” which “in interaction with the magnetic field of magnet 27[,] pushes or pulls on magnet 27.” *Id.*, 3:12-22 (“[o]ne current flow direction/polarity causes a push action and the other a pull action. Spring 26 controls the up and down movement of magnet 27.”). In the combination, the oscillation path represents a segment of a space curve. In particular, the oscillation path includes a “a curved path” that a point within the magnet (e.g., magnet 27) moves. *Id.*; APPLE-1008, [0005], Fig. 10.



APPLE-1008, Fig. 10 (Annotated)

209. The “curved” oscillation path provides a segment of a space curve

along which a point within a mass moves. In particular, a point within a portion of the magnet moves along the curved path as it oscillates back and forth, in accordance with Fuller.

[1b] a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

210. In the Gregorio-Fuller combination, a mass (one of the magnets) is driven by energy (electrical current) supplied to the oscillating resonant module, such that the mass (one of Gregorio's magnet 27) oscillates back and forth along the curved oscillation path, as taught by Fuller (e.g., as I discussed above regarding the Gregorio-Fuller combination).

211. For example, in the combined system, Gregorio's mass/magnet **"is driven back and forth"** to oscillate along the Gregorio-Fuller curved oscillation path, by energy such as the "current" flowing through Gregorio's coils. APPLE-1007, 1:29-30, 3:18; *see also* APPLE-1008, [0007], [0025], [0052]; APPLE-1007, FIG. 2, 3:12-28. The energy or current supplied to Gregorio's coil 28 causes the back-and-forth oscillation of the magnet(s) along the curved oscillation path of the Gregorio-Fuller combination. APPLE-1007, 3:12-22; 2:36-39.

212. In the Gregorio-Fuller combination, a mass (a different portion of the magnet) is driven by energy (e.g., electrical current) supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that

represents a segment of a space curve. Refer to analysis of §IV.B.3 (Gregorio-Fuller combination). I note that Fuller describes its actuator configuration, including the “curved” oscillation path, “**can be very small**” and “**well suited**” for use in devices” like “**cell phones.**” APPLE-1007, Abstract. In the Gregorio-Fuller combination, Gregorio’s magnet/mass would have oscillated back and forth along the “curved” oscillation path. APPLE-1008, [0005]; *see* APPLE-1007, 2:10, 3:1-2 (describing “haptically-enabled system[s]” for “handheld device[s], such as a cellular telephone”), FIG. 1.

[1c]-[20]

213. As I discussed above in Ground 2A regarding the Analysis of [1c]-[20], Gregorio-Fuller similar renders obvious [1c]-[20].

VIII. GROUNDS 2C & 2D: RAMSAY IN COMBINATION WITH GREGORIO (2C) OR GREGORIO-FULLER (2D) RENDERS OBVIOUS CLAIMS 1-5, 10, 17-20

214. For the reasons I describe in detail below, and based on my review of the '882 patent and its file history, and the prior art references cited herein, a POSITA would have plainly understood that the teachings of Gregorio and Ramsay (Ground 2C), and Gregorio, Fuller, and Ramsay (Ground 2D), each provide all elements of claims 1-5, 10, 17-20, as I discuss in more detail below.

215. Ramsay provides a user interface of an end user device that allows a user to configure haptic parameters, as I discussed above in the Overview of

Ramsay. A user can provide inputs to the device to select/modify haptic output, and the input is processed and used in generating corresponding haptic effects. Ramsay thus further informs features related to “control signals” that are input to a controller, which in turn outputs corresponding control signals to a control component.

216. In Grounds 2C and 2D, I thus explain an additional manner in which the prior art renders obvious claims 1-5, 10, and 17-20 with respect to the “control signal” features of the Challenged Claims. I first explain the combination of Gregorio-Ramsay and Gregorio-Fuller-Ramsay, and then how the combinations address the elements of the claims. To be clear, a POSITA would have been motivated to combine Ramsay with either of Gregorio or Gregorio-Fuller for the same reasons, as I discuss below.

A. The Predictable Combination of Gregorio-Ramsay (2C) & the Predictable Combination Gregorio-Fuller-Ramsay (2D)

217. Based on my knowledge and experience in the field, and my review of Gregorio, Fuller, and Ramsay, a POSITA would have predictably combined the handheld device (e.g., Gregorio’s “handheld device”) to allow a user to customize parameters associated with haptic effects, based on Ramsay’s teachings.

218. In particular, Ramsay would have modified Gregorio’s (or Gregorio-Fuller’s) haptically-enabled system to embed “[s]oftware and systems,” according

to Ramsay's teachings, "to lead a user through the process of entering and/or modify parameters and characteristics of haptic tracks," using Gregorio's "processor that operates the entire system." APPLE-1010, [0015], [0025]-[0028].

In the combined system, a user can "interact with programmable haptic design software 30 by input and output mechanisms of GUI," sending control signals from the system processor to the specific haptic processor to effectuate the user-selected parameters, as taught by Ramsay. APPLE-1010, [0037].

219. A POSITA would have been motivated and found it obvious to modify Gregorio's haptic feedback system to be user-configurable, based on Ramsay's suggestions, for several reasons.

220. A POSITA would have been motivated to avail the system of functionality to allow users to create/customize haptic effects. In particular, as discussed in Ramsay, a POSITA would have recognized that the capability of modifying characteristics of haptic feedback was normally limited to professional haptics designers, and that end users "typically [did] not have the option on the device itself to modify characteristics of haptic feedback." APPLE-1010, [0014]. Therefore, a POSITA would have looked for references like Ramsay to expand the functionalities of then-existing haptic devices and allow end users to have capabilities to freely create and customize haptic effects to their liking. APPLE-1010, [0014]-[0015].

221. Moreover, a POSITA would have recognized from Ramsay's teachings, the benefit of allowing users to "create or modify the haptic effect files directly on the device." APPLE-1010, [0053]-[0057], [0014]-[0018]. A POSITA would have recognized that the resulting system benefits from Ramsay's GUI that displays haptic tracks and offers various, easy-to-use mechanisms for adjusting haptic parameters. APPLE-1010, [0053]-[0057]. Relatedly, the Gregorio-Ramsay combination would enable the resulting system to "provide a fuller haptic experience" by allowing users to "combine or mix different haptic tracks together if desired," furthering Gregorio's stated objective of to "create a wide range of haptic effects on the device." APPLE-1010, [0030].

222. A POSITA would have had a reasonable expectation of success in making the proposed modifications given that Gregorio and Ramsay describe similar techniques for controlling a linear actuator to produce desired output. APPLE-1007, 2:3-9; APPLE-1010, [0026]. Indeed, a POSITA would have recognized that the Gregorio-Ramsay combination requires only routine knowledge of software implementation techniques, which were well within the POSITA's skill. The modification to Gregorio based on Ramsay's teachings merely involves implementing Ramsay's software solutions in Gregorio's hardware setup without substantially changing Gregorio's other structures.

223. In particular, the combination would modify Gregorio's system only

to the extent that it is necessary to implement Ramsay’s software tools, and Gregorio’s system would otherwise remain unchanged and perform its intended operations. In fact, the Gregorio and Ramsay references, originally assigned to the same company, share similar structures and operations that are compatible. A POSITA would have recognized that the purposes intended by Gregorio and Ramsay (e.g., providing haptic feedback and, more specifically, a “wide range of haptic effects on the device” (APPLE-1007, 3:8-10)) are compatible, and the Gregorio-Ramsay (and Gregorio-Fuller-Ramsay) combination would have accomplished those in a similar way that each of Gregorio and Ramsay achieves.

224. Moreover, the intended operations in each of Gregorio and Ramsay would be achievable in parallel to receive the benefits described by each reference. As such, combining Gregorio and Ramsay was merely the application of known techniques (Ramsay’s software solution for user’s customization of haptic effects) to a known device (Gregorio’s haptically-enabled system) ready for improvement to yield predictable results.

B. Analysis of Gregorio-Ramsay (2C) & Gregorio-Fuller-Ramsay (2D) with Respect to Claims 1-5, 10, 17, 19, and 20

[1pre]-[1c]

225. For the reasons I discussed in Grounds 2A-2B above regarding Elements [1pre]-[1c], Gregorio-Ramsay and Gregorio-Fuller-Ramsay renders

obvious Elements [1pre]-[1c].

[1d] a control component that receives control signals input to the oscillating resonant module, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

226. Each of the Gregorio-Ramsay and Gregorio-Fuller-Ramsay combinations provide a control component that includes “processor 12,” separate from a “processor that operates the entire system.” APPLE-1007, 2:18-59. A POSITA would have recognized from Gregorio’s straightforward description that the system includes both a “processor that operates the entire system” and a “processor 12” that is dedicated to haptic effects. APPLE-1007, 2:24-25 (“Processor 12 may be the same processor that operates the entire system 10, or may be a separate processor.”). In the combined system, the control component (e.g., including “processor 12”) receives control signals (e.g., from the “processor that operates the entire system”) input to the oscillating resonant module, in accordance with Ramsay’s suggestions, such as when a user provides input selecting/modifying haptic parameters.

227. To be clear, I note that the control component provides each of the features recited by Element [1d], according to each of the proposed interpretations of “control component,” for the reasons I discussed above in the analysis of Element [1d] in Ground 2A.

[10pre] A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

228. For the reasons I discussed in Grounds 2A-2B above regarding Element [10pre], Gregorio-Ramsay and Gregorio-Fuller-Ramsay renders obvious Element [10pre].

[10a] a controller; and

229. As I discussed above, the Gregorio-Ramsay and Gregorio-Fuller-Ramsay combinations include a controller provided by its “processor that operates the entire system.” APPLE-1007. The controller receives user input to select haptic parameters, as suggested by Ramsay, in order to process the received user input. APPLE-1010, [0022] (“processor” in communication with “haptic actuating device”), [0026] (“Haptic actuating device 18 may include any suitable combination of electrical or electro-mechanical components for providing haptic effects to a user.”), [0028]-[0030] (“Certain parameters or characteristics of a haptic output or haptic track can be created, entered, changed, modified, etc. For example, the modifiable parameters may include a frequency of vibration and amplitude of vibration.”) [0031]-[0043], [0044]-[0048], [0049] (“sends a selected haptic track or mixed track from temporary storage unit 34 to haptic actuating device 18, which can then play the track for the user.”), [0053]-[0059], FIGS. 2-4.

[10b]-[10e]

230. For the reasons I discussed in Grounds 2A-2B above regarding Elements [10b]-[10e], Gregorio-Ramsay and Gregorio-Fuller-Ramsay renders obvious Elements [10b]-[10e].

[10f] a control component that receives control signals input to the oscillating resonant module by the controller, receives outputs from the one or more sensors, and controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

231. In the Gregorio-Ramsay/Gregorio-Fuller-Ramsay combinations, the control component (e.g., including “processor 12” separate from “processor that operates the entire system”) receives control signals input to the oscillating resonant module by the controller (e.g., “processor that operates the entire system”).

232. Based on my knowledge and experience in the field and my review of Gregorio and Ramsay, a POSITA would have recognized that user input selecting or modifying haptic parameters, based on Ramsay’s teachings (e.g., along with other input touch input received by the device) is handled by the system processor. When user input selecting or modifying haptic parameters is received, the system processor in turn outputs control signals to effectuate the user-entered haptic parameters that are received by the control component (separate “processor 12”).
APPLE-1007, 2:18-35, 2:54-59.

233. I note that Gregorio expressly indicates touch input is sent to another processor within the system, which a POSITA would have recognized as the processor that operates the entire system. APPLE-1007, 2:18-35, 2:54-59. In addition to being understood by a POSITA based on Gregorio's straightforward description, such a configuration would have been recognized as a suitable architecture to facilitate touch input, which in turn results in communication to the oscillating resonant module to generate haptic output according to the parameters selected by the touch input.

234. Here again, I note that the control component provides each of the features recited by Element [10f], according to each of the proposed interpretations of "control component," for the reasons I discussed above in the analysis of Element [1d] in Grounds 2A/2B.

[17] The physical device of claim 1 further comprising: a controller, within the physical device, that receives control signals input to the physical device, and outputs control signals to one or more of the one or more oscillating resonant modules to controls the vibration response produced by the one or more oscillating resonant modules.

235. In the Gregorio-Ramsay/Gregorio-Fuller-Ramsay combinations, a controller (e.g., "processor that operates the entire system," including "touch surface" and associated components), is included within the physical device, as I discussed above regarding Element [10a].

236. In operation, a user can select and modify haptic parameters, in

accordance with Ramsay's teachings, as I discussed above. When the user makes such selections/modifications, through input at the "touch interface," for example, the system processor (which handles touch input) receives control signals input to the physical device. APPLE-1007, 2:54-67, 2:10-17, 3:1-11; APPLE-1010, Abstract, [0030], [0036]-[0038]. The system processor and associated components, in turn, outputs control signals that are associated with the user-selected/modified haptic parameters (e.g., specifying the haptic parameters) to the control component.

237. The control component includes the "processor 12" responsible for haptic output. Via the control signals output by the system processor to "processor 12," the system processor controls the vibration response produced by the one or more oscillating resonant modules.

[19] The physical device of claim 17 wherein the controller passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module.

238. Based on my knowledge and experience in the field and my review of Gregorio, a POSITA would have recognized that the system processor passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module. For example, the system processor outputs control signals associated with the user-selected haptic parameters so that the "haptic effect" having the selected parameters can be

effectuated by the actuator. APPLE-1007, 2:54-67; *see also* 2:10-17, 3:1-11.

Thus, the input received at the interface of the device provides a control signal associated with the user-selected parameters (e.g., frequency, magnitude, etc.) such that at least a portion of the received control signals input to the physical device are passed to the one or more oscillating resonant module so that the “haptic effect” has parameters corresponding to the input to the physical device.

[20] The physical device of claim 17 wherein the controller controls the one or more oscillating resonant modules to each produce a vibration response, the vibration responses produced by the oscillating resonant modules together producing a resonant-frequency vibration mode in the physical device.

239. Gregorio describes that its “handheld device” includes “more than one” actuator. APPLE-1007, 3:1-11. Additionally, Gregorio describes that the actuators that can “have a different resonant frequency” and “create a wide range of haptic effects on the device.” *Id.* In the Gregorio-Ramsay/Gregorio-Fuller-Ramsay combinations, the system processor controls the one or more oscillating resonant modules to each produce a vibration response. Control signals are associated with the user-selected parameters are output by the system processor so that corresponding “haptic effect” is generated. As I discussed above, the respective modules are controlled to operate at a resonant frequency (e.g., potentially different resonant frequencies) and produce a resonant-frequency vibration mode in the “handheld device.”

240. To be clear, as I discussed above regarding Claim [20] in Ground 1, I understand that Patent Owner has interpreted Claim [20] as encompassing devices that have only a single oscillating resonant module. Based on Patent Owner's interpretation, the Gregorio-Ramsay and Gregorio-Fuller-Ramsay combinations plainly provides the features of claim 20.

IX. GROUNDS 2E & 2F: MURAMATSU IN VIEW OF GREGORIO (2E) OR GREGORIO-FULLER (2F) RENDER OBVIOUS CLAIMS 3-6

241. For the reasons I describe in detail below, and based on my review of the '882 patent and its file history, and the prior art references cited herein, a POSITA would have understood that the teachings of Gregorio and Muramatsu, and Gregorio, Fuller, and Muramatsu, render claims 3-6 obvious according to its plain and ordinary interpretation and under either party's proposed construction of "control component."

A. The Predictable Combination of Gregorio and Muramatsu (2E) & the Predictable Combination of Gregorio, Fuller, and Muramatsu (2F)

242. Based on my knowledge and experience in the field and my review of Gregorio and Fuller, a POSITA would have been motivated to implement the Gregorio and Gregorio-Fuller systems in accordance with Muramatsu's suggestions computing control outputs from position and/or velocity of a moving object, and using pre-computed values in lookup tables. APPLE-1009, 4:41-50,

5:21-28, 9:57-10:2, Fig. 1. Based on my knowledge and experience in the field, such techniques were known and conventional, and represent the knowledge of a POSITA. Muramatsu demonstrates this conventional knowledge of computing control outputs based on sensor outputs and control signals, using a function that receives the position and/or velocity as inputs, or based on precomputed values in a data table. APPLE-1009, 5:21-28, 9:57-10:2.

243. In the combined system, Gregorio's processor/logic circuitry determines the velocity of the moveable component (e.g., "magnet 27) based on current and previously measured positions of the movable magnet. APPLE-1009, 6:23-27. Additionally, the processor/logic circuitry "includes data tables storing [precomputed] parameters" and uses the parameters stored in the tables (an index) to compute the control outputs for driving oscillation. *Id.*, 5:21-28, 9:57-10:2.

Based on my knowledge and experience and my review of Gregorio and Muramatsu, the tables would have been indexed based on current position and velocity of the movable magnet. Gregorio describes the use of position and velocity in its control determination of control outputs that "cancel the difference between the present amplitude and the desired amplitude." Thus, consistent with Gregorio's existing control scheme, the lookup tables would have been indexed based on these values. APPLE-1007, 5:58-61; APPLE-1009, 4:40-60.

244. Based upon my knowledge and experience in this field and my

review of Gregorio, Fuller, and Muramatsu, multiple reasons would have led a POSITA to combine teachings of Gregorio and Muramatsu, and Gregorio, Fuller, and Muramatsu.

245. As a first reason, a POSITA would have been motivated to combine Muramatsu with Gregorio and Gregorio-Fuller to calculate velocity based on position sensor measurements. Gregorio describes sensed position data, and generating control outputs based on position and velocity. A POSITA would have thus found it obvious to determine velocity from the readily-available position data simply based on current and previous positions. Even if not apparent from Gregorio alone, a POSITA would have predictably looked to other teachings, such as Muramatsu to implement and further Gregorio's feedback control objectives—Muramatsu expressly demonstrates the POSITA's knowledge of a controller that "calculates a current velocity X' on the basis of the current position X and the previous position." APPLE-1009, 6:23-27. Utilization of position measurements at multiple (e.g., two) points would have been recognized as a conventional and reliable technique for determining velocity, and facilitating effective characterization of the motion of Gregorio's moveable magnet(s) for use in the feedback control system. APPLE-1005, [0038].

246. As a second reason, a POSITA would have been motivated to combine Muramatsu with Gregorio/Gregorio-Fuller to utilize "data tables" when

determining control outputs. Based on my knowledge and experience in the field and my review of Gregorio and Muramatsu, a POSITA would have recognized, from Muramatsu's description, that the use of data tables would have facilitated efficient processing by using predetermined relationships stored in the tables between control outputs (affecting the supplied current) and position and velocity. Doing so would have been recognized as a suitable technique to effectuate Gregorio's existing control scheme. APPLE-1009, 5:21-28; 9:57-10:2.

247. Moreover, a POSITA would have recognized, and found obvious based on Muramatsu, that the use of tables in this manner would have facilitated reduced computational power during operation. And, in turn, facilitated reduced overall power consumption and/or less complex/expensive processors/logic circuitry (e.g., because of the reduced computational demands). To be clear, lookup tables were a conventional technique and a POSITA recognized the ability to utilize tables for almost any computation, including computing appropriate control outputs (e.g., based on current position and velocity).

248. As a third reason, a POSITA would have found it obvious to combine Muramatsu with Gregorio/Gregorio-Fuller because doing so amounted to the application of known techniques (Muramatsu's calculations based on known relationships between position and, velocity, and the use of "data tables") to a known system (the primary Gregorio system that utilizes sensor feedback for

vibration control) ready for improvement to yield predictable results (benefits articulated above). Muramatsu expresses the known relationship between position and velocity, and associated techniques for determining velocity from position, as well as the concept of “data tables” for determining a value.

249. A POSITA would have readily recognized the applicability of such techniques to Gregorio’s system. Moreover, a POSITA would have had a reasonable expectation of success. The control scheme of the combined systems operates consistent with Gregorio, and the modifications to implement Muramatsu’s techniques for determining velocity and use of data tables, for example, would have been primarily software based. Moreover, each of Gregorio, Fuller, and Muramatsu relates to systems that include sensors for detecting motion of a moving component, and processing the sensor data for control.

B. Analysis of the Combinations (2E & 2F) with Respect to Claims 3-6

250. As shown in this section, the Gregorio-Fuller-Muramatsu combination, when predictably combined for at least the reasons described above, provides all elements of claim 1.

[3] The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor outputs, the velocity of the mass from the positions of the mass at two or more points in time.

251. Based on my knowledge and experience in the field, and my review of

Gregorio, Fuller, and Muramatsu, the Gregorio-Muramatso/Gregorio-Fuller-Muramatsu combinations render obvious Claim [3]. The control component receives sensor outputs (“sensed position signals”) indicating the positions of the mass. APPLE-1007, cl. 11; 4:10-12. For example, the Gregorio sensing device outputs indications for a “sensed position signal” at specific points (*e.g.*, two or more) in time, which indicates a position of the mass. *Id.*

252. In the combined system, the control component “calculates a current velocity X' on the basis of the current position X and the previous position,” in accordance with Muramatsu express teachings. APPLE-1009, 6:23-27; 8:66-9:4 (“vector arithmetic processor 23c respectively calculates current velocities X' and Y' **on the basis of the current position** (X, Y) and the previous positions.”); *see also* APPLE-1009, 4:45-53. I note that such calculation of velocity from position reflects a fundamental relationship between position and velocity. Muramatsu confirms the POSITA’s knowledge of such relationship, and its applicability to such systems.

[4] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass.

253. Based on my knowledge and experience in the field, and my review of Gregorio, Fuller, and Muramatsu, the Gregorio-Muramatso/Gregorio-Fuller-Muramatsu combinations render obvious Claim [4]. The control component

receives sensor outputs provided by Gregorio's "sensed position signals," for example, which indicate the positions of the mass." APPLE-1007, 2:36-53. The control component also generates control outputs, provided by Gregorio's "control signals"/"drive pulses," for example, which are based on the "sensed position signals. *Id.*, see also Abstract; 1:24-46; cls. 1-2 ("receiving a signal that comprises a position of the mass" and "modifying an amplitude of one of the drive pulses in response to the signal"); cl. 11; 4:10-12.

254. To be clear, a POSITA would have readily recognized the use of a function, which is a conventional way to carry out calculation. In particular, the drive signals are computed using a function that takes, as input, the current position of the mass. Muramatsu confirms the knowledge of a POSITA and provides an example of similar calculations implemented using a function. APPLE-1009, 4:40-60 ("The data processor 4 calculates a current plunger velocity X' on the basis of the current plunger position X and the previous plunger position, and in turn calculates a current plunge[r] acceleration X'' on the basis of the current plunger velocity X' and the previous plunger velocity. The data processor 4 further calculates a target force F for each of the linear actuator 1 by using an equation"); 8:5-15 (describing "a vector arithmetic processor 23c" and "data tables 23d" and two driving units 23e and 23f associated with" its linear actuators and that "vector arithmetic processor 23c fetches the first positional signal S_x and the second

positional signal S_y , and determines a first component F_x and a second component F_y in cooperation with the data tables 23d.”).

[5] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

255. Based on my knowledge and experience in the field, and my review of Gregorio, Fuller, and Muramatsu, the Gregorio-Muramatso/Gregorio-Fuller-Muramatsu combinations render obvious Claim [5]. For example, the combinations provide control outputs computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass, as discussed above. As I discussed above, Gregorio’s calculations are carried out using a function, in accordance with Muramatsu’s teachings. APPLE-1009, 4:40-60 (“equation”); 8:5-15. I note here again that the use of a function was a conventional technique known to a POSITA and recognized as a suitable option for calculating various parameters, as demonstrated by Muramatsu. *Id.* To be clear, the function uses current velocity of the mass and current velocity of mass, in accordance with Gregorio’s existing control scheme, and Muramatsu’s teachings of a function. APPLE-1007, 4:42-65, cl. 11; APPLE-1009, 4:40-60; 9:4-9 (the current position X , the current velocity X' and the current acceleration X'' determine a set of parameters for an equation of motion.”).

[6] The oscillating resonant module of claim 3 wherein the control outputs, output by the control component to the actuator, are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

256. Based on my knowledge and experience in the field, and my review of Gregorio, Fuller, and Muramatsu, the Gregorio-Muramatso/Gregorio-Fuller-Muramatsu combinations render obvious Claim [6]. In the combined system, Gregorio's control component includes Muramatsu's suggestions for data tables that store pre-computed control outputs indexed based on current position and current velocity of the movable magnet. APPLE-1009; 4:40-60 ("a set of parameters representative of a target force F , and are stored in the data tables 5 for each of the linear actuators 1").

257. Here again, the use of data tables was known to a POSITA, and Muramatsu demonstrates this conventional technique. As Gregorio uses current position and current velocity in its control determination, the tables would have been computed from pre-computed values indexed by those parameters—the current position and current velocity of the mass. APPLE-1007, 4:10-14 ("the sensing device will provide a sensed position signal that can be used as the monitoring signal to provide information about the position of the mass 27") 4:42-48 ("vibration amplitude is measured based on the derivative of the speed of the mass (' dv/dt ')"); APPLE-1009, 5:21-28 ("target reaction force F corresponding to

the current position X is read out from the data tables 5, and the data processor 4 supplies the target reaction force F”).

258. The combined system thus would have determined the drive signals (e.g., to generate an appropriate drive force that cancels the difference between the present and desired amplitude, in accordance with Gregorio’s control scheme) from pre-computed values for the drive signal indexed by current position and velocity, in accordance with Muramatsu’s suggestions for calculating control outputs based on sets of position and velocity parameters that “are read from the data tables” and used to calculate the control outputs.

X. GROUNDS 2G&2H: RAMSAY AND MURAMATSU IN VIEW OF GREGORIO (2G) OR GREGORIO-FULLER (2H) RENDER OBVIOUS CLAIMS 3-6

259. A POSITA would have found it obvious to combine the teachings of Ramsay and Muramatsu with Gregorio and Gregorio-Fuller as discussed in §§4.A.D (Ramsay combinations), 4.A.E (Muramatsu combinations). The combinations render obvious claims 3-6 for the same reasons as I described above regarding these claims.

XI. CONCLUSION

260. The findings and opinions set forth in this declaration are based on my work and examinations to date.

261. I may continue my examinations. I may also receive additional

documentation and other factual evidence over the course of this IPR that will allow me to supplement and/or refine my opinions. I reserve the right to add to, alter, or delete my opinions and my declaration upon discovery of any additional information. I reserve the right to make such changes as may be deemed necessary.

262. In signing this declaration, I recognize that the declaration will be filed as evidence in an IPR before the PTAB. I also recognize that I may be subject to cross-examination in the case and that cross-examination will take place within the United States. If cross-examination is required of me, I will appear for cross-examination within the United States during the time allotted for cross-examination.

APPENDIX A

Curriculum Vitae

Blake Hannaford, Ph.D.

April 2, 2024
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Educational History

Ph.D. University of California, Berkeley 12/85, Electrical Engineering and Computer Science
Thesis Title: The control of fast human movement: horizontal head rotation M.S. University of California, Berkeley 12/82 Electrical Engineering and Computer Science Thesis Title: Adaptive Linear Prediction of Cardiac Marker Locations
B.S. Yale University 5/77, Engineering and Applied Science (Electrical Engineering)

Employment History

University of Washington (currently on 100% leave) 9/89 -

Department of Electrical and Computer Engineering
Professor, Adjunct Professor of Bioengineering, Adjunct Professor of Mechanical Engineering Adjunct Professor of Surgery: 9/02 - present
0% Core faculty, DxArts center, College of Arts and Sciences.
Professor, Adjunct Professor of Bioengineering, Adjunct Professor of Surgery: 9/98 - 9/02
Associate Professor: 9/93- 8/98
Assistant Professor: 9/89 - 9/93.
Teach courses in embedded computing, control, robotics, and conduct sponsored research in areas of haptic interfaces, and surgical telerobotics.

Meta Reality Labs Research, Redmond Wa (100% time)

3/22 - 4/23
Led a group of 5 research scientists on haptics including electroactive polymer actuators for haptics. Served as a subject matter expert on haptic devices, systems, and perception. Responsible for wristband haptics technology.

Google-X, (now Verily Inc), Mountain View, Ca. (80%)

4/14 - 12/15
Defined and evaluated joint venture between Google Life Sciences (Verily) and Johnson & Johnson Ethicon division in surgical robotics. Joint venture is now launched as Verb Surgical. Developed advanced prototypes including real-time software and hardware design.

Jet Propulsion Laboratory, Caltech 9/88-8/89

Automation and Robotics Section (347)
Supervisor of the group in Man-Machine Systems and Human Factors. Responsible for technical guidance, management, planning and budgeting for a group of 10 (4 Ph.D., 3 B.S., 3 part time). Annual budget \$1.4 M (Funding Source: NASA Code R).

Jet Propulsion Laboratory, Caltech 4/86-9/88

Applied Robotics and Teleoperators Group

Member of Technical Staff: Conducted research and technology development under Dr. Antal Bejczy. Studied the interaction between human operator and advanced telerobotic control devices.

Rush Medical Center, Chicago, IL 10/79 - 8/80

Electronics Engineer. Design, systems integration, programming and construction of a prototype automated red blood cell analyzer. Supervisor: J.W. Bacus, Ph.D.

First Chicago Corporation, Chicago IL. 2/79 - 10/79

Systems Analyst. Advanced Technology Analysis Unit, Corporate Information Systems Planning Division. Analysis, development and programming of a prototype electronic mail system.

Compuserve Inc. 6/77 - 5/78

Computer Engineer: Computer hardware and software design, circuit-switched network software design engineering.

Awards and Honors

- Life Fellow, IEEE, January 2021.
- UW Career Center @ Engineering FACET award for career mentoring of students (student nominated) May 2019.
- Finalist for Best Symposium Paper Award, International Symposium on Medical Robotics, Atlanta, April 2019 (Paper presented by Ph.D. student Yu Hsuan Su).
- Amazon Catalyst Fellow, March 2017
- Nominated for University of Washington Outstanding Teaching Award, March 2014.
- Nominated for EE Department Outstanding Teaching Award, May 2013.
- Nominated for University of Washington Outstanding Teaching Award, March 2012.
- Nominated for EE Department Outstanding Teaching Award, May 2011.
- UW Electrical Engineering Dept. Outstanding Research Advisor Award, May 2010.
- EDGE surgical skills evaluation device, a commercial product licensed from the UW Biorobotics Lab was selected as one of 8 winners of the 2008 Innovation of the year by the Society of Laparoscopic Surgeons, (Medical Device & Diagnostic Industry Magazine, Dec 2008).
- IEEE Fellow for “contributions to haptic interfaces and telerobotic systems.” January, 2006.
- One of Five UWEE Professors who received votes in the UW Alumni Association “Favorite Professor” poll of 2005 Graduates.
- Faculty Service Award, Department of Electrical Engineering, June 2005, “In recognition for excellent service to the department and the community through work in Faculty Recruiting, Educational Administration, and Curriculum Development.”

- “The Blue Dragon, a System for Measuring the Kinematics and the Dynamics of Minimally Invasive Surgical Tools In Vivo,” one of 10 finalists for Wegbreit Best Manipulation Paper Award from among 700 papers presented at IEEE International Conference on Robotics and Automation, Arlington VA, May 2002.
- “Dual Stable Point Model of Muscle Activation and Deactivation,” by Ching-Ping Chou and Blake Hannaford, re-printed in “ONR-Investing in the Future, 1946-1996,” a commemorative volume published on the 50th anniversary of the Office of Naval Research.
- Elected Region 6 Representative IEEE Engineering in Medicine and Biology Society Administrative Committee, 10/96.
- “Early Career Achievement Award”: IEEE Engineering in Medicine and Biology Society, November, 1991
- NASA Group Achievement Award: “The Telerobotics Design Team”, May 1991
- National Science Foundation Presidential Young Investigator Award, 9/90-9/95
- National Institutes of Health Training Grant in Systems and Integrative Biology, 6/81-6/84.

Awards and Honors won by Students

- June 2021, ECE474 top project award to the Booz Allen Hamilton Team, “Human-Powered Submarine Autopilot” project. Students: Chase Deitner, James Lee, Miller Sakmar, and Peter Tsanev. ECE faculty adviser: Blake Hannaford. UW-APL advisers: Cassandra Riel and Benjamin Maurer. Booz Allen Hamilton advisers: Eric Jones, Joe Reck, Nick Valladarez, and Ryan Edwards. Naval Undersea Warfare Center, Division Keyport advisers: Cooper Bowen and Jacob Yakawich.
- July 2019, Timothy Kowalewski, Assistant Professor, U. Minnesota, NSF CAREER award.
- January 2012, Andrew Hill, Mary Gates Undergraduate Research Award.
- April 2010, Sina Nia Kosari, NSERC Ph.D. fellowship (Canadian equivalent of NSF Graduate Fellowship)
- March 2010, Timothy Kowalewski, Best Ph.D. Project Proposal Award, (from 10 candidates presented) NSF-Sponsored American College of Surgeons Ph.D. Consortium, Chicago Illinois.
- March 2009, Brittany Redmond, Mary Gates Undergraduate Research Award.
- June 2007, Mitch Lum. Outstanding Graduate Research Assistant, Department of Electrical Engineering, University of Washington.
- June 2007, Mitch Lum. Spirit of Community Award, Department of Electrical Engineering, University of Washington.
- June 2007, Gina Donlin, Outstanding Undergraduate Research Assistant, Department of Electrical Engineering, University of Washington.
- January 2007, Mitch Lum et al., One of 10 winners of Best Poster Awards, Medicine Meets Virtual Reality, Long Beach, CA 2007.
- January 2006, Ken Fodero et al., One of 10 winners of Best Poster Awards, Medicine Meets Virtual Reality, Long Beach, CA 2006.
- August 2005, William “Pete” Moss (DxARTS) and Brian Cunitz (EE) won honorable mention for their project “The Haptic Theremin,” in the Sensable Developers Challenge announced at Siggraph 2005.

- June 2005, Steven Venema (Ph.D. 1997) promoted to Boeing Associate Technical Fellow.
- March 2002, Ryland Bryant, ME, Volker Schmirgel, EE, Daniel Villa, EE, Bruno Sbinden, ME, Dick Kriesberg, EE, First Place, Lunar Construction Robotics Competition, ASCE Aerospace Division.

Affiliations

Adjunct Professor of Surgery. Adjunct Professor of Bioengineering. Adjunct Professor of Mechanical Engineering. 0% Core Faculty UW Digital Arts Program (DXARTS).

Affiliated Researcher, Intel Research Lab, Seattle. (2000-2010)

Visiting Professor, Department of Surgical Technology, Imperial College, London

Publications since 1995

Refereed Archival Journal Publications

- [1] KR Walley and M Grover and GL Raff and JW Bengt and B Hannaford and SA Glantz. Left ventricular Dynamic Geometry in the Intact and Open Chest Dog *Circulation Research* (50) 1982
- [2] B. Hannaford and M.H. Nam and V. Lakshminarayanan and L. Stark. Electromyographic Evidence of Neurological Controller Signal with Viscous Load *Journal of Motor Behavior* (16) 1984
- [3] B. Hannaford and G. Cheron and L. Stark. The Effects of Applied Vibration on the Tri-Phasic EMG Pattern in Neurologically Ballistic Head Movements *Experimental Neurology* (88) 1985
- [4] B. Hannaford and S.A. Glantz. Adaptive linear predictor tracks implanted radiopaque markers *IEEE Trans. Biomedical Engineering* (BME-32) 1985
- [5] B. Hannaford and C.C. Krischer and L. Stark. A Device for Zero Eye Movement Reading *IEEE Trans. Biomedical Engineering* (BME-32) 1985
- [6] B. Hannaford and L. Stark. Roles of the elements of the Tri-Phasic Control Signal *Experimental Neurology* (90) 1985
- [7] D.S. Holder and W.S. Kim and B. Hannaford and L. Stark. Simulation of The Human Eyeblink using the EMG of Eyelid Musculature as Input *Muscle and Nerve* (In Press) 1985
- [8] N. Akamatsu and B. Hannaford and L. Stark. An Intrinsic Mechanism for the oscillatory contraction of muscle *Biological Cybernetics* (53) 1986
- [9] B. Hannaford and W.S. Kim and S.H. Lee and L. Stark. Neurological Control of Head Movements: Inverse Modeling and Electromyographic Evidence *Math. BioScience* (78) 1986
- [10] B. Hannaford and S. Lehman. Short Time Fourier Analysis of the Electromyogram: Fast Movements and Constant Contraction *IEEE Transactions on Biomedical Engineering* (BME-33) 1986
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- [12] L. Stark and B. Hannaford and C.F. Ramos. Interaction of Descending Control and Stretch Reflex in Fast Voluntary Movements in Man *Society for Neuroscience Abstract* 1986
- [13] B. Hannaford and L. Stark. Late Agonist Burst (PC) Required for Optimal Head Movement: a Simulation Study *Biological Cybernetics* (57) 1987

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- [15] W.S. Kim and S.R. Ellis and M. E. Tyler and B. Hannaford and L. Stark. Quantitative Evaluation of Perspective and Stereoscopic Displays in Three Axis Manual Tracking Tasks *IEEE Trans. Systems Man & Cybernetics* (SMC-17) 1987
- [16] L. Stark and W.S. Kim and F. Tendick and B. Hannaford and S. Ellis. Telerobotics; Display, Control, and Communication Problems *IEEE Journal of Robotics and Automation* (RA-3) 1987
- [17] N. Akamatsu and B. Hannaford and L. Stark. An Intrinsic Mechanism for the Oscillatory Contraction of Muscle *Proc IEEE Intl Conf on Engineering in Med. & Biol* 1989
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- [27] P. Loughlin and J. Pitton and B. Hannaford. Approximating Time-Frequency Density Functions via Optimal Combinations of Spectrograms *IEEE Signal Processing Letters* (1) 1994
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- [29] W.C. Wang and M. Afromowitz and B. Hannaford. Technique for Mechanical Measurements Using Optical Scattering From a Micro-Pipette *IEEE Transactions on Biomedical Engineering* (41) 1994
- [30] B. Hannaford and K. Kuhn. A "Hands-On" Course in Consumer Electronics Design *International Journal of Mechatronics: Special Issue on Mechatronics Education* (5) 1995
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- [161] Sosnovskaya, Yana and Shlizerman, Eli and Hannaford, Blake and Sinanan, Mika N. Comparison of Deep Learning and Signal Processing Methods for Removing a Ringing Artifact from Ultrasound Signals *2023 IEEE Sensors Applications Symposium (SAS)* 2023
- [162] Raines, Allison and Lewis, Andrew and Hwee, Joel and Hannaford, Blake. Inferring Environmental Interactions of Soft Everting Robots From Acoustic Signals *2023 IEEE International Conference on Soft Robotics (RoboSoft)* 2023
- [163] Hwee, Joel and Lewis, Andrew and Raines, Allison and Hannaford, Blake. Kinematic Modeling of a Soft Everting Robot from Inflated Beam Theory *2023 IEEE International Conference on Soft Robotics (RoboSoft)* 2023

Abstracts or non-selective conferences

- [1] P. Buttolo, J. Hewitt, R. Oboe, and B. Hannaford. Force feedback in virtual and shared environments. *Poster: IEEE Intl. conf. on System, Man and Cybernetics*, October 1995.
- [2] J. Brown, J. Rosen, B. Hannaford, and M. Sinanan. A passive mechanical pantograph system for measuring tool position during minimally invasive surgery (poster). *BMES 2000, Biomedical Engineering Society, Annual Meeting. Annals of Bioengineering*, 28, Supplement 1, October 2000.
- [3] J. Rosen, M. Solazzo, B. Hannaford, and M. Sinanan. Task decomposition of minimally invasive surgery for objective evaluation of laparoscopic surgical skills using hidden markov models. *Abstract: BMES 2000, Biomedical Engineering Society, Annual Meeting, Annals of Bioengineering*, 28, Supplement 1, October 2000.
- [4] J.D. Brown, J. Rosen, J. Longnion, M. Sinanan, and B. Hannaford. Design and performance of a surgical tool tracking system for minimally invasive surgery. In *Abstract: Proceedings of the ASME International Mechanical Engineering Congress and Exposition: Advances in Bioengineering, BED*, volume 51, pages 169–170, New York, Nov. 11-16 2001. ASME.
- [5] D. Wilson and B. Hannaford. Robust electronic design: What s that? In *Proc. Frontiers in Engineering Education*, Reno, NV, Oct 10-13 2001.
- [6] G. Klute, J. Czerniecki, and B. Hannaford. ARTIFICIAL MUSCLES: ACTUATORS FOR LOWER LIMB PROSTHESES. In *Proceedings of the 2nd Annual Meeting of the VA Rehabilitation Research and Development Service*, page 107, Washington DC, February 20-22 2000.
- [7] G. Borriello, T. Choudhury, B. Hannaford, N. Kern, and J. Lester. Choosing the right modalities and features for activity recognition. In *Neural Information Processing Systems 2004 Workshop on Multimodal Signal Processing*, Whistler, British Columbia, 2004.
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Books, Chapters, and Editing

- [1] B. Hannaford and A. Okamura. Haptics. In B. Siciliano and O. Khatib, editors, *Springer Handbook of Robotics*. Springer, Berlin, Heidelberg, 2nd edition, 2016.
- [2] B. Hannaford, P. Buttolo, and H. King. Multi-finger haptic displays for characterization of hand response. In R. Balasubramanian and V.J. Santos, editors, *The Human Hand: A Source of Inspiration for Robotic Hand: Springer Tracts in Advanced Robotics (STAR) series*, volume 95, pages 363–388. Springer, Heidelberg, 2014.
- [3] J. Rosen, J. Brown, S. De, B. Hannaford, 'Chapter 24 Macro and Micro Soft Tissue Biomechanics and Tissue Damage: Application in Surgical Robotics ,' In "Surgical Robotics: Systems Applications and Visions", pp. 583-618, Springer, Berlin, Heidelberg, 2011.
- [4] J. Rosen, M. Lum, M. Sinanan, B. Hannaford, 'Chapter 8: Raven: Developing a Surgical Robot from a Concept to a Transatlantic Teleoperation Experiment ,' In "Surgical Robotics: Systems Applications and Visions", pp. 159-197, Springer, Berlin, Heidelberg, 2011.

- [5] L.N.Sekhar, D. Ramanathan, J. Rosen, L.J. Kim, D. Friedman, D. Glozman, K. Moe, T. Lendvay, B. Hannaford, 'Chapter 30 Robotics in Neurosurgery ,' In "Surgical Robotics: Systems Applications and Visions" , pp. 723-742, Springer, Berlin, Heidelberg, 2011.
- [6] J. Rosen, B. Hannaford, R. Satava Editors, Surgical Robotics, Systems, Applications, and Visions Springer Verlag, 2011.
- [7] B. Hannaford and R. Leuschke rendering for Multifinger Haptic Devices In M. Lin and M. A. Otaduy, editors, *Haptic Rendering, Foundations, Algorithms, and Applications*. A.K. Peters, Co. Wellesley, MA, 2008
- [8] B. Hannaford and A. Okamura. Haptics. In B. Siciliano and O. Khatib, editors, *Springer Handbook of Robotics (Winner of two 2008 PROSE awards from the Association of American Publishers.)*. Springer, Berlin, Heidelberg, 2008.
- [9] M. Moreyra, P.H. Marbot, S. Venema, and B. Hannaford. A 5-axis mini direct drive robot for time delayed teleoperation. In V. Graefe, editor, *Intelligent Robots and Systems 1994*, pages 445–462. Elsevier Science, 1995.
- [10] B. Hannaford. Telerobotics. In D. Hemmendinger and A. Ralston, editors, *Encyclopedia of Computer Science*. McMillan, 4th edition, August 2000.
- [11] B. Hannaford. Feeling is believing: Haptics and telerobotics technology. In J.K. Goldberg, editor, *The Robot in the Garden, Telerobotics and Telepistomology on the Internet*. MIT Press, Cambridge, MA, 1999.
- [12] S.C. Venema and B. Hannaford. Telerobotic remote handling of protein crystals via an internet link. In Ken Goldberg and Roland Siegwart, editors, *Beyond Webcams, An Introduction to Online Robots*. MIT Press, Cambridge, MA, 2002.
- [13] J.H. Ryu, D.S. Kwon, and B. Hannaford. Control of a flexible manipulator with noncollocated feedback: Time domain passivity approach. In Antonio Bicchi, Henrik I. Christensen, and Domenico Prattichizzo, editors, *Control Problems in Robotics*, volume 4, pages 121–134. Springer Tracts in Advanced Robotics Series, 2003.
- [14] B. Hannaford, J.H. Ryu, and Y.S. Kim. Chapter 3 stable control of haptics. In Margaret L. McLaughlin, editor, *Touch in Virtual Environments*, pages 47–70. Prentice Hall PTR, IMSC Press Multimedia Series, 2001.
- [15] Hannaford, B. and Buttolo, P. and King, H. (2014) Multi-finger Haptic Displays for Characterization of Hand Response. In: The Human Hand: A Source of Inspiration for Robotic Hand: Springer Tracts in Advanced Robotics (STAR) series,. Springer, Heidelberg., pp. 363-388.

Project Reports

- [1] B. Hannaford, J.H. Ryu, D.S. Kwon, Y.S. Kim, and J.B. Song. Testing time domain passivity control of haptic enabled systems. *University of Washington Department of Electrical Engineering Technical Report number UWEETR-2002-0010*, 19-July- 2002.
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- [3] Blake Hannaford, Diana Friedman, Hawkeye King, Mitch Lum, Jacob Rosen, and Ganesh Sankaranarayanan. Evaluation of RAVEN surgical telerobot during the NASA extreme environment mission operations (NEEMO) 12 mission. *University of Washington Electrical Engineering Department Technical Report*, 2009-0002, 6-Feb- 2009.
- [4] Blake Hannaford and Jesse Doshier. Polishing and measuring distorted spheres for psychophysical experimentation. *University of Washington Electrical Engineering Department Technical Report*, 2009-0004, April 24 2009.
- [5] Blake Hannaford and Sugandhan Venkatachalam. Characterization of test balls for psychophysical experiments. *University of Washington Electrical Engineering Department Technical Report*, 2009-0006, June 5 2009.
- [6] Hawkeye King, Sina Nia Kosari, Blake Hannaford, and Ji Ma. Kinematic analysis of the Raven-II(tm) research surgical robot platform. *University of Washington Electrical Engineering Department Technical Report*, 2012-0006, June 29 2012.(Revised August 2016)
- [7] Danying Hu, Yagnming Li, Mohammad Haghighipanah, and Blake Hannaford. RNA, the ROS node automator: A tool for ROS code generation. *University of Washington Electrical Engineering Department Technical Report*, 2015-0001.
- [8] Dianmu Zhang and Blake Hannaford. Behavior trees as a representation for medical procedures. *ArXiv e-prints*, cs.RO(1711.05412), November 2017.
- [9] Blake Hannaford, Danying Hu, Dianmu Zhang, and Yangming Li. Simulation results on selector adaptation in behavior trees. *ArXiv e-prints*, cs.RO(1606.09219), November 2017.
- [10] Blake Hannaford. Behavior trees as a representation for medical procedures. *ArXiv e-prints*, cs.RO(1801.07864), January 2018.
- [11] Blake Hannaford, R. Bly, I. Humphreys, M. Whipple, and Behavior Trees as a Representation for Medical Procedures. *ArXiv e-prints*, cs.HC(1808.08954), 27-Aug- 2018.
- [12] Dianmu Zhang and Blake Hannaford. IKBT: solving closed-form inverse kinematics with behavior tree. *ArXiv e-prints*, (1711.05412), Mon, 13 Aug 2018 16:48:05 + 0200.

Miscellaneous

Clickable Link: [ArXiv Pre-prints](#)

Patents

[Google Patents Search: Inventor: Blake Hannaford](#)

- [1] B. Hannaford. Method and Apparatus for Multiplexing Switch Signals *US Patent No. 4,884,070* issued 1989
- [2] B. Hannaford and M.R. Moreyra and P.H. Marbot. Five axis direct-drive mini-robot having fifth actuator located at a non-adjacent joint *U.S. Patent 5,528,955* issued 1996
- [3] P. Buttolo and B. Hannaford. Direct Drive Manipulator for pen-based force display *U.S. Patent 5,642,469* issued 1997

- [4] R. Seubert and M.V. Olson and D. Meldrum and B. Hannaford and P. Wiktor and N.A. Friedman and D.B. Snow and R. Kraft. Precision small volume fluid processing apparatus *U.S. Patent 5,785,926* issued 1998
- [5] S.C. Venema and E. Matthes and B. Hannaford. Flat Coil Actuator having Coil Embedded in Linkage *U.S. Patent 6,437,770* issued 2002
- [6] B. Hannaford and J.H. Ryu. Time domain passivity control of haptic interfaces *U.S. Patent 7,027,965* issued 2006
- [7] Diana C. W. Friedman and Blake Hannaford and Devin Karns and Aylin Z. Kim and Louis Kim and Thomas S. Lendvay and Kristen S. Moe and James S. Pridgeon and Jacob Rosen and Laligam Sekhar. Introducer device *US Patent 8,617,197* issued 2013
- [8] R. Adams and Aaron Olwin and B. Hannaford. Gloved human-machine interface *US patent 9,104,271* issued 2015
- [9] R. Bly and B. Hannaford. Soft tissue shield for trans-orbital surgery *US Patent 9,011,326* issued 2015
- [10] Eugene Chen and Aylin Kim and Cang Lam and Blake Hannaford and Randall Bly. Surgical tissue protection sheath *US Patent 8,986,201* issued 2015
- [11] B Hannaford. Image matching to augment reality *US Patent 9,001,252*, issued 2015
- [12] L White and T Kowalweski and T.S. Lendvay and B. Hannaford. Motion and video capture for tracking and evaluating robotic surgery and associated systems and methods *US Patent 9,026,247* issued 2015
- [13] B. Hannaford and E. Rephaeli and C-J Wang. Sensing and Avoiding Surgical Equipment *U.S. Patent 9,486,128* issued 2016
- [14] Howard Chizeck and Fredrik Ryden and Sina Nia Kosari and Blake Hannaford and Nicklas Gustafsson and Hawkeye King. Methods and systems for haptic rendering and creating virtual fixtures from point clouds *US Patent 9,471,142* issued 2016
- [15] Blake Hannaford and Louis Kim and Thomas Lendvay and Kris Moe and James Pridgeon and Jacob Rosen and Laligam Sekhar. Surgical cockpit comprising multisensory and multimodal interfaces for robotic surgery and methods related thereto *US Patent 9,474,580* issued 2016
- [16] Kris Moe and Randall Bly and Blake Hannaford. Surgical instrument input device organization systems and associated methods *US Patent 9,498,194* issued 2016
- [17] Blake Hannaford and Joelle Barral and Eden Rephaeli and Denise Ching and Vikram Bajaj. Heads-up displays for augmented reality network in a medical environment *US Patent 9,538,962* issued 2017
- [18] J. Doshier and D.C.W. Friedman and D. Glozman and B. Hannaford and A.Z. Kim and L Kim and T.S. Lendvay and K.S. Moe and J.S. Pridgeon and J. Rosen and L. Sekhar. Surgical Device *US Patent 9,775,640* issued 2017
- [19] Joelle K. Barral and Benjamin K. Yaffee and Eden Rephaeli and Chia-Jean Wang and Blake Hannaford. Controlled Dissection of Biological Tissue *US Patent 9,833,828* issued 2017
- [20] Diana Friedman and Blake Hannaford and Devin Karns and Aylin Kim and Louis Kim and Thomas Lendvay and Kristen Moe and James Pridgeon and Jacob Rosen and Laligam Sekhar. Introducer Device *US Patent 9,622,828* issued 2017
- [21] Blake Hannaford and Joelle Barral and Christine Ching and Vikram Bajaj. Heads-up displays for augmented reality network in a medical environment *US Patent 9,645,785B1* issued 2017

- [22] B. Hannaford and E. Rephaeli and C-J Wang. Sensing and Avoiding Surgical Equipment *U.S. Patent 9,895,063* issued 2018
- [23] Blake Hannaford and Eden Rephaeli and Joelle K. Barral and Chia-Jean Wang. Biophotonic Surgical Probe *US Patent 10,092,355* issued 2018
- [24] Eugene Chen and Aylin Kim and Cang Lam and Blake Hannaford and Randall A Bly and Jeremy Ciporen and Kristen Moe and Louis Kim and Laligam Sekhar. Surgical tissue protection sheath *US Patent 10,470,647* issued 2019
- [25] Blake Hannaford and Brian Otis. Device Method and System to provide accommdation during a stereoscopic display *US Patent 10,353,219 B1* issued 2019
- [26] Joelle K. Barral and Blake Hannaford and Eden Rephaeli and Christine Denise Ching. Surgery Guidance System *US Patent 10,639,104* issued 2020
- [27] Joëlle Karine Barral and Benjamin Kreil Yaffe and Eden Rephaeli and Chia-Jean Wang and Blake Hannaford. Controlled dissection of biological tissue *US Patent 10,624,663B1* issued 2020

US Published Patent Applications

APP. NO.	Title
20180206709	SURGICAL TISSUE PROTECTION SHEATH
20180055577	MOTION EXECUTION OF A ROBOTIC SYSTEM
20170340390	Computer-Assisted Osteocutaneous Free Flap Reconstruction
20170042409	SURGICAL TISSUE PROTECTION SHEATH
20160349844	Magnetic Attachment Mechanism for Multifinger Haptic Device
20160074123	Surgery Pathway Guidance And Boundary System
20160074123	Surgery Pathway Guidance And Boundary System
20150297309	Methods And Systems For Selecting Surgical Approaches
20150297295	INSTRUMENT ORGANIZATION SYSTEMS AND ASSOCIATED METHODS
20150186730	IMAGE MATCHING TO AUGMENT REALITY
20150157193	SURGICAL TISSUE PROTECTION SHEATH
20150025547	SURGICAL COCKPIT COMPRISING MULTISENSORY AND MULTIMODAL INTERFACE FOR ROBOTIC SURGERY AND METHODS RELATED THERETO
20140313172	SURGICAL INSTRUMENT INPUT DEVICE ORGANIZATION SYSTEMS AND ASSOCIATED METHODS
20140168073	Methods and Systems for Haptic Rendering and Creating Virtual Fixtures from Point Clouds
20140155910	Spherical Motion Mechanism
20140114338	INTRODUCER DEVICE
20130204092	SOFT TISSUE SHIELD FOR TRANS-ORBITAL SURGERY
20130190571	SURGICAL TISSUE PROTECTION SHEATH
20120253360	MOTION AND VIDEO CAPTURE FOR TRACKING AND EVALUATING ROBOTIC SURGERY AND ASSOCIATED SYSTEMS AND METHODS
20120203069	SURGICAL SHIELD FOR SOFT TISSUE PROTECTION
20110257672	INTRODUCER DEVICE
20110238079	Surgical Cockpit Comprising Multisensory and Multimodal Interfaces for Robotic Surgery and Methods Related Thereto
20110118551	COLLATERAL SOFT TISSUE PROTECTION SURGICAL DEVICE
20110118543	SURGICAL DEVICE
20110102605	IMAGE MATCHING TO AUGMENT REALITY
20110020779	SKILL EVALUATION USING SPHERICAL MOTION MECHANISM
20070172803	SKILL EVALUATION
20060243085	Spherical motion mechanism
20030184574	Touch screen interface with haptic feedback device
20020062177	Time domain passivity control of haptic interfaces

Media Coverage

- June 2016, worked with IEEE PR firm on press release which reached 11M people in 228 publications.
- June 2016, Facebook Livestream in cooperation with IEEE which was viewed by over 37,000 people.
- Established [UW Biorobotics Lab Facebook Page](#) to publicize work of all three BRL faculty and their students.

Provisional Patent Applications

Date	Comotion #	Title
07/01/13	45522	Provisional Application filed: METHODS AND SYSTEMS FOR HAPTIC RENDERING ...
08/19/13	46606	Provisional Application filed: Accelerometer based dynamic gravity compensation
11/14/14	47100	"Semi-Autonomous Brain Tumor Ablation with Fluorescently Marked Tumor"
02/04/15	46499	Provisional Application filed: Endoscopic Surgery Pathway Guidance and Boundary System [IP: 46499.03US1]
05/26/15	47339	"U.S. Provisional Application filed: ""Magnetic Attachment Mechanism for Multifinger Haptic Device"" // [IP: 47339.01US1]"
05/17/16	47688	Provisional Application filed: Smart Surgical Navigation [IP: 47688.01US1]
05/12/16	47713	Computer Assisted Maxillary Reconstruction
02/04/16	47346	WO 2016/126934 Methods and Systems for Navigating a Surgical Pathway (YM Li Software)
5/19/17	47839	62/508,847 Drone system for utility line unfouling

Licenses

A license was completed in 2014 between UW and Applied Dexterity for the technologies associated with Raven-II

A license was signed with Simulab Inc. for electromechanical surgeon tracking technology and hidden Markov model based skill assessment technology for measurement of surgical skill in simulators and animal procedures. (2006). As of 2012 this product is now commercialized with the first 10 systems being delivered to customers in May2012.

Startup Companies

SPI Surgical Inc. SPI was formed with Jacob Rosen, 4 MD's, and entrepreneur Aylin Kim in 2009. Two invention disclosures in 2010 were transferred to startup SPI Surgical in 2012. SPI has won over \$1M in SBIR/STTR funding.

CSATS Formed by Thomas Lendvay, M.D., and two of my Ph.D. students to commercialize crowd sourcing technologies for surgical skill evaluation. Acquired by Ethicon, J&J 2018.

Applied Dexterity Inc. Applied Dexterity was formed in Dec. 2012 with Jacob Rosen and David Drageske to commercialize the Raven Surgical Robotic Research Platform (www.applieddexterity.com). It has sold over 20 research surgical robotics systems.

Web Sites

- [Biorobotics Lab Page](#) (redesigned in 2010)

Other Scholarly Activity

Blogs and Media

July 27, 2017, "The Marriage of Artificial Intelligence and Patient Care," IEEE Transmitter Blog (<http://transmitter.ieee.org/marriage-artificial-intelligence-patient-care/>) (solicited by IEEE)

Invited Lectures and Seminars (Since 1999)

6-May-2022, Robotics Seminar, University of Wisconsin, Madison (via Zoom)
14-Oct-2020, Keynote Speaker, 2020 IEEE International Conference on Mechatronics and Automation, Beijing, China. (via Zoom)
Sept 30, 2020, Keynote Speaker, 10th Conference on New Technologies for Computer/Robot Assisted Surgery, Barcelona Spain (via Zoom)
July 23, 2020, Outreach event: Nationwide Slides and Q&A with tech interns, CodeLabs Online Expert Lunch, <https://labs.codeday.org/>.
July 2019, Plenary Speaker, Advances in Robotics (AIR 2019), 4th International Conference of The Robotics Society of India, IIT Madras, Chennai, India
October 2018, Invited Speaker, 1st International Forum on Engineering Education, Tsinghua University, "GIX: Global Innovation Exchange - Developing Leaders in Innovation", Beijing.
May 2018, Invited Keynote Speaker, "Modeling and Optimization for Mechanism Design in Robotic Surgery", SIMPAR 2018, Brisbane Australia.
Feb 2018, Invited panelist on Accountability for the Actions of Robots, Seattle University 2018 Law Review Symposium, "Singularity and The Law", Seattle Wa.
May 2017, Lead off speaker, Workshop on "Methods for Stability Analysis of Haptic Teleoperation Systems," International Automatic Control Conference (ACC), Seattle Wa.
April 2017, "Introducing Automation to Surgical Robotics: Where are we? and Who's in charge?", Mechanical Engineering Department Distinguished Lecture, Colorado School of Mines, Golden Co.
February 2017, "Introducing Automation to Surgical Robotics: Who's in charge?", Invited Keynote, Our Futures conference, Quest University Canada, Squamish BC.
Sept 2016, "The Essential Interface Between Haptics Science And Haptics Technology", Invited Talk, Oculus Research, Redmond, WA.
July 2016, "The Essential Interface Between Haptics Science And Haptics Technology", Invited Keynote, Eurohaptics 2016, London.
May 2016, "Debate: Resolved, The cost of health care innovation is too high.", Debator, Simnovate 2016, McGill University, Montreal.
October 2015, "Augmented Reality in Surgical Robotics: A research perspective", Uppsala University department of Medical Informatics, Uppsala Sweden.
September 2015, "Augmented Reality in Surgical Robotics: A research perspective", USC/ Childrens Hospital of Los Angeles planning retreat, Palos Verdes, CA
October 2014, "Raven II Platform for Collaborative Research in Surgical Robotics," Invited opening Talk, 7th KIST International Workshop on Micro Surgical Robotics, Korean Institute for Science and Technology, Seoul Korea.
August 2014, "Raven II Collaborative Research Platform for Surgical Robotics," Keynote, IEEE Intl. Conf. on Robots and Systems (IROS), Chicago, IL
August 2014, "Open source software framework for surgical robotics research," Summer School on Surgical Robotics, Carnegie Mellon University, Pittsburg, PA.
November 2013, "Raven II Research Surgical Robot Platform," IEEE Smart Tech: Metro Area Workshop Series, Seattle WA.
September 2013, "High stakes telerobotics: augmenting human skills in robotic surgery," Google X, Mountain View Ca.
April 2013, "History of Medical Robotics and Current UW Raven Research," Stanford Medical Robotics Seminar, Palo Alto, CA.
November 2012, "Raven II Research Surgical Robot Platform," Samsung Technology Forum, Suwon Korea.
March 2012, "Raven II Research Surgical Robot Platform," Qatar University Department of Mechanical Engineering Seminar, Doha Qatar.
January 2012, "Raven II Research Surgical Robot Platform," Yale University Department of Mechanical Engineering Seminar.
December 2011 "Raven II Research Surgical Robot Platform," National Cheng Kung University, Tainan, Taiwan.
November 2011 "Surgical Robotics and Teloperation" Psycholotron Theater Project, Seattle.

November 2011 “Teleoperation and Human Augmentation Technology,” Boeing Ergonomics Technology Forum, Boeing Research and Technology Division, Everett, Wa.

September 2011 “Telesurgery,” Summer School on Surgical Robotics, Montpellier France.

August 2011 “Raven-II Surgical Robot Research Platform,” Twente University of Technology, Twente, Netherlands.

June 2011, “Teleoperation Control in Surgical Robotics,” Dutch Institute of Systems and Control (DISC) Summer School on Dynamic Systems and Control, Leeuwenhorst, Netherlands.

August 2010, “Teleoperation Control in Surgical Robotics,” North American Summer School on Surgical Robotics, Seattle, WA (Organizer).

May 2010 “Surgical Robotics the last 20 years,” 50th Anniversary Keynote lecture, IEEE International Conference on Robotics and Automation, Anchorage, Ak,

Sept 09 “Haptics and Telesurgery,” Summer School on Surgical Robotics, Montpellier France.

May 09 “Telesurgery via the Internet,” Imperial College London.

April 09 “Biorobotics Research in Surgery,” Association of Health Care Journalists, UW Campus visit from Seattle National Meeting.

February 09, “When to stop? What is the limit of safe tissue manipulation in surgery?”, Bioengineering Department Seminar (BIOEN 509), University of Washington, Seattle.

January 09, “Telesurgery,” Johns Hopkins Winter School on Surgical Robotics, Baltimore Md.

September 08 “Markov Modeling of Errors,” American College of Surgeons (ACS) Postgraduate Course, “Exploring New Educational Opportunities Through the Consortium of ACS-accredited Education Institutes,” Seattle

August 08 “Surgery over the Internet,” National Taiwan University, Taiwan

August 08 “Surgery over the Internet,” National Central University, Taiwan

August 08 “Introduction to the Science and Technology of Haptics.” (40 contact hours). 1-Week Course for IT Faculty, Advanced Institute for Information Technology, Seoul, Korea.

April 08 “Surgery over the Internet,” Applied Physics Lab Seminar, Seattle WA.

March 08 “Surgery over the Internet,” GRASP lab seminar, University of Pennsylvania.

February 08 “Open Source Software in Engineering Education,” DaNang University of Technology, DaNang Vietnam (16 lecture and workshop hrs).

February 08 “Surgery over the Internet,” Robotics Institute Seminar, Carnegie Mellon University, Pittsburgh, PA.

November 07 “Mechanisms for Surgery via the Internet,” Invited Keynote Lecture, International Mechanical Engineering Conference and Exhibition, Seattle WA.

October 07 “Control of Tissue Damage,” Biomechanics Seminar, Dept of Mechanical Engineering, University of Washington.

Sept 07 “Surgery via the Internet,” Distinguished Lecture, Computer Science Department, Columbia University, New York.

Sept 07 “Surgical Telerobotics,” Summer School in Surgical Robotics, Montpellier France.

June 07 “Biorobotics: can robots restore the house call to the practice of medicine?”, Science on Tap, Seattle WA.

March 07 “Telesurgery Research Overview,” Intel Research, Seattle.

Jan. 07 “Telesurgery Research,” DOD (TATRC) sponsored panel, NextMed/MMVR 2007 Conference, Long Beach, CA.

Sept 06 “Multifinger Haptic Display Design I and II,” (3 hrs total) IEEE RAS Summer School in Haptics, Paris, France.

July 06 “Engineering Issues and Field Experience in Remote Surgery,” Dept. of Computing, Imperial College, London.

July 06 “Assessment of Damage and Appearance in Abdominal Organs,” Dept. of BioSurgery and Surgical Technology, Imperial College, London.

Jan. 06 “Surgical Robotics: An Engineer’s Perspective,” DOD (TATRC) sponsored panel, NextMed/MMVR 2006 Conference, Long Beach, CA.

Nov. 05 “Saving Soldiers, Robots to the Rescue” (with Dr. Mika Sinanan). University of Washington College of Engineering/Alumni Association Lecture Series, ”Engineering the Unexpected”, covered by UWTV. 15-Nov-2005.

Oct. 05 “Science at the Movies,” University of Washington Department of Chemistry Outreach Lecture, “Actuator Technology in I-Robot”. 24-Oct-2005.

Mar. 05 Dept. of Surgery and Bioengineering, Imperial College London. 21-Mar-2005.

Mar. 05 IMT Lucca Institute for Advanced Studies, Lucca Italy. 18-Mar-2005.

Jan. 05 DOD (TATRC) sponsored panel “Are Haptics Really Necessary”, NextMed 2005 Conference, Long Beach, CA January 2005.

Nov 04 Industrial and Operations Engineering Departmental Seminar, University of Michigan

Oct. 04 Keynote Speaker, IEEE Industrial Applications Society 39th Annual Meeting, 5-Oct-2004, Seattle.

Sep. 04 Faculty Member. Society for Laparoscopic Surgeons 13th International Congress and Endo Expo SLS Annual Meeting, September 29-October 2, 2004. New York. Multidisciplinary Plenary Session and Future Technology Session.

Sep. 04 Invited Participant. US Army Medical Research Command (TATRC) workshop on Surgical Robotics, Marina del Rey, California.

Aug. 04 Invited Plenary Talk, International Conference on Control, Automation, and Systems, Bangkok, Thailand.

Aug. 04 Invited Seminar, Samsung Advanced Institute of Technology (SAIT), Seoul Korea.

Aug. 04 Invited Seminar, Korean Advanced Institute of Technology (KAIST), Daejeon Korea.

Feb. 04 Robotics, Controls and Mechatronics Colloquium, University of Washington College of Engineering.

Feb. 04 Departmental Seminar: Department of Electrical Engineering and Computer Science, Case Western Reserve University.

Jan. 04 Distinguished Lecture: Department of Computer Science, University of Southern California.

Dec. 03 Intuitive Surgical Inc. Sunnyvale, CA.

Sept. 03 Invited Instructor: European Summer School on Surgical Robotics, University of Montpellier, France.

May 03 Invited Participant: DARPA Workshop on the Operating Room of the Future, Arlington VA.

Apr. 03 Kendal Retirement Community Seminar, Oberlin OH.

Jan. 03 Puget Sound MENSA Society, Mercer Island, WA.

Nov. 02 Mechanical Engineering Department Seminar, Johns Hopkins University

Oct. 02 Biomechanics Seminar, University of Washington Dept. of Mechanical Engineering.

Sept 02 Control Seminar, University of Michigan, Dept. of Mechanical Engineering.

Sept 02 Graduate Research Seminar, Purdue University, Department of EECS.

Aug. 02 Computer Motion Inc., Goleta, CA.

July 02 International Symposium on Experimental Robotics, ISER-02, Isola-di-Ischia, Italy, July 8-12, 2002.

June 02 Invited Lecture, University of Pisa, Pisa Italy.

June 02 Invited Lecture, University of Verona, Verona Italy.

May. 02 University of Washington Academic Medical Center Development Council, “Institute for Advanced Surgical Technology”.

Apr. 02 Grand Rounds, University of Washington, Department of Surgery.

Sept. 01 Invited Visitor, Human-friendly Welfare Robot Systems Engineering Research Center, Korean Advanced Institute of Science and Technology, Daejeon, Korea.

Sept. 00 Distinguished Visitor, Samsung R&D Center, Seoul Korea.

Apr. 00 Workshop Speaker: ”Personal Robots in Education,” IEEE Intl. Conference on Robotics and Automation, San Francisco, CA.

Aug. 99 Invited participant, UW-Microsoft Research summer institute on Ubiquitous Computing. Blaine Washington.

Professional Society Memberships

IEEE Robotics and Automation Society (IEEE Life Fellow), AAAS.

Professional Society Service

Program Committee Member, Robotics Science and Systems (RSS) 2017
Plenary Speaker and Member, Best Demo Award Committee, World Haptics Congress, London 2016
Awards Committee, IEEE Robotics and Automation Society, 2012
Fellows Nomination Committee, IEEE Robotics and Automation Society, 2010, 2011
Program Committee, Associate Editor, 2010-2012 IEEE International Conference on Robotics and Automation.
Program Committee, 2010 North American Haptics Symposium, March 2010
Program Committee, Robotics Science and Systems (RSS) 2009, Seattle WA.
Conference Advisory Board, BioRob 2008, Phoenix, AZ.
Program Committee, 2008 Haptics Symposium, Reno.
co-Guest Editor: Special Issue on Biorobotics, IEEE Transactions on Robotics. 2007.
Steering Committee Member, World Haptics Congress, Pisa 2005, Tsukuba 2007, Salt Lake City, 2009
Co-Chair Technical Committee on Biorobotics, IEEE Robotics and Automation Society 2006.
Program Committee, Biorob 2006, Pisa February 2006.
General Chair, International Conference on Advanced Robotics (ICAR), Seattle 2005
Program Co-Chair, Annual Haptics Symposium. 3 year term May 2002-April 2005., 1yr extension through 2006. (<http://www.hapticssymposium.org>). Los Angeles, March 2003, Chicago, March 2004, Arlington, VA March 2006. The Haptics Symposium is held in conjunction with the IEEE Virtual Reality Conference (VR2003, <http://www.vr2003.org>).
Founding Editor of “Haptics-e”, the first peer-reviewed journal devoted to the interdisciplinary field of Haptics and also, one of the first electronic refereed journals in any of the fields of Engineering that I am involved in. The journal is technically co-sponsored by the IEEE Robotics and Automation Society.
Associate Editor, IEEE Transactions on Robotics and Automation, 8/92 - 9/97,
Associate Editor Annals of Biomedical Engineering, 6/92 - 6/97.

Refereeing and other activity.

Numerous journal and conference paper reviews averaging about 10-20 per year.

Graduate Students

Chaired Doctoral Degrees

Completed

(Career total 31 Ph.D. students: 22 Electrical Engineering, 6 Bioengineering, 3 Mechanical Engineering. 10 Female Ph.D. advises completed.)

- Shan Lin, “Vision-based Surgical Instrument Segmentation and Endoscopic Sinus Surgery Skill Assessment,” Spring 2021, PostDoc with Prof. Michael Yip, UCSD.
- Dianmu Zhang, “Building Modular, Human-Interpretable AI Systems with Behavior Trees,” Spring 2020, Microsoft AI.
- Yun Hsuan (‘Melodie’) Su, “Vision Based Surgical Tool Tracking and Force Estimation with Robot Kinematics Prior,” Spring 2020, Accepted position: Assistant Professor of Computer Science, Mount Holyoke College.
- Kyle Lindgren, “Robust Vision-Aided Self-Localization of Mobile Robots,” Spring 2020, US Army Research Lab.
- Miyasaka, Mune, “Mechanical and Lifetime Properties of Wire Rope Cables in Surgical Robotics,” Mechanical Engineering, June 2017, Riverfield.com (Japan).

- Aghdasi, Nava, “Optimal Planning of Surgical Approaches in the Skull Base,” Electrical Engineering June 2017, Meta Reality Labs Research, Redmond).
- Hu, Danying, “Semi-Automation in Image Guided Surgery,” Electrical Engineering, June 2017, Magic Leap Inc.
- Haghighipناه, Mohammad, “Estimation of Position and External Force for a Cable Driven Surgical Robot,” Electrical Engineering, June 2017, Machine Learning Engineer, Intel Corporation
- Lei (‘Levi’) Cheng, “Evaluation of liver tissue damage and grasp stability using finite element analysis,” Mechanical Engineering, 6/2015, Echodyne Corp.
- Jiang, Iris, “Localization of Tactile Information in the Lower Limb,” Bioengineering, 6/2015, SRI International.
- H. Hawkeye King, “Human-Machine Collaborative Telerobotics: Computer Assistance for Manually Controlled Telesurgery and Teleoperation”, 3/2014, Sairdronc Inc.
- Sina Nia Kosari (Joint with Howard Chizeck), “Haptic Virtual Fixtures for Robotic Surgery,” Manager, Control Systems Group, Cruise Automation. 8/2013
- Lee White, “Quantitative Objective Assessment of Preoperative Warm-up for Robotic Surgery,” (Bioengineering). Currently medical resident (Urology) at Stanford University. 6/2013
- Tim Kowalewski, “Real-time Quantitative Assessment of Surgical Skill,” Assistant Professor, University of Minnesota Dept. of Mechanical Engineering. 5/2012. **NSF CAREER Award, July 2019**
- Diana W. Friedman, “Scaling Laws and Size Thresholds for Minimally Invasive Surgical Instruments,” Intuitive Surgical, Sunnyvale CA. 6/2011.
- Phillip Roan “An Instrumented Surgical Tool for Local Ischemia Detection,” 3/2011. Robert Bosch Research and Technology Center, Palo Alto, CA.
- Jonathan Lester (joint supervision with Gaetano Boriello), “Personal Sensing from Mobile Devices: The Feasibility of Mobile Devices for Diverse Applications,” 2/2010, Senior Scientist, Microsoft.
- Mitchell Lum, “Quantitative Performance Assessment of Surgical Robot Systems: Telerobotic FLS” 8/2008. Intel Healthcare Division. (Co-Advised with Jacob Rosen).
- Smita De (Bio-E MD/PhD) “Acute Indicators of Injury at the Grasper-Tissue Interface in Minimally Invasive Surgery.” 5/2008, Attending Urologist, The Cleveland Clinic.
- Ganesh Sankaranarayanan, Collaborative Haptic Environments over the Internet. 12/2007. Associate Professor, Department of Surgery, The University of Texas Southwestern Medical Center
- G. Lee, Low Power Haptic Effects. 6/2004. Assistant Professor, Electrical Engineering & Computer Science. Case Western University, Cleveland, Oh.
- J.D. Brown (Bioengineering, Whitaker Fellowship) - Biomechanics of surgery 10/03
Now with Intuitive Surgical, Sunnyvale, CA.
- K. Jaax (Bioengineering, Whitaker Fellowship, Paul Allen Fellowship, MSTP MD/Ph.D. program) - Biorobotic Position Sensor based on the Artificial Muscle Spindle, 6/2001
Vice President, Boston Scientific, Sylmar, CA.
- T. Maneewarn (Thai Gov’t Fellowship) - Force Feedback of Kinematic Information in Teleoperation and Remote Control 1/2000
Deputy Director of Research, Institute of Field Robotics, King Mongkut’s University of Technology Thonburi
Bangkok 10140 Thailand

- R. Adams - (Air Force Palace Knight Fellow) Optimal Design of Coupling Networks for Haptic Simulations, 6/1999
Faculty Member, US Airforce Academy 2008-2010,
Researcher, Barron Associates, President and CEO, Virtual Therapy Solutions, LLC 2010–
- G. Klute (Bioengineering) - Gaylord McKibben Artificial Muscle Actuators. 9/1999
VA Rehab Engineering Research Center, Seattle.
- S.C. Venema - Haptic display and perception of surface discontinuities, 5/1999
Associate Technical Fellow Boeing Phantom Works, Bellevue.
- C.P. Chou - Anthroform biorobotic arm. 5/1996
Avanti Inc., San Jose California
- P. Buttolo- Force Displays for Virtual Env. 5/96
Ford Research Labs, Dearborn MI.
- Dal Yeon Hwang (LG Corp. Fellowship) - Force Reflecting Teleoperation with Kinematic Redundancy. 12/95
Full Professor, Korea Polytechnic University, Seoul Korea 12/95
- P.H. Marbot - Artificial Muscle Spindle 4/95
MBA 1997, Director of Production Planning, Tosco Inc. Brussels Belgium.

Ph.D. Students in Progress (estimated completion)

- Nive Kalavakonda⁺*, Summer 2024
 - Yana Sosnokova⁺*, Spring 2024
 - Andrew Lewis (ME)⁺*, Summer 2024
 - Haonan Peng (ECE)⁺*, Autumn 2024
- * = passed General Exam + = passed qualifying exam

Chaired Masters Degrees (23 career completed)

Completed (Thesis Option)

- Joel Hwee, “Modeling and Applications of Everting Vine Robots,” (ME), June 2021.
- Andrew Lewis, “Dynamic Gravity Compensation for the Raven Surgical Robot,” (ME), August 2013
- Jack Lindsay, “A Mechanical Amplifier for Haptic Feedback,” (ME) June 2013
- Srikrishnan Ramdurai. “Non Linear State Estimation of a Multi Axis Surgical Robot” (ME), 2011
- Diana Friedman, “Kinematic and Dynamic Analysis of a Surgical Robot Positioning Arm,” (ME thesis, Co-Advised with Jacob Rosen) 2008.
- Jonathan Lester, “Using Accelerometers to Determine if Two Devices are Carried by the Same Person”. (co-advised with Gaetano Borriello) 6/04,
UWEE Ph.D. program.
- Mitch Lum, “Kinematic Optimization of a 2-DOF Spherical Mechanism,” Ph.D. Candidate in UWEE Ph.D. program.
- Bill Anderson, “Haptic Device Interface Design and Testing for Manipulations in Real and Virtual Environments,” 12/2004. Founder, Novint Inc. Albuquerque, NM (Haptic Interface Startup Company).

- Jesse Doshier - Detection Thresholds and Performance Gains for Small Haptic Effects, 2/02 Research Engineer II, Biorobotics Lab.
- Jason Trujillo - Control of a Surgical Grasper with Force Feedback, 6/97
Intel Corp., Albuquerque, NM.
- M. Moreyra (MSEE) - Advanced Force Sensor for Haptic Display, 8/96
Founder and President of Haptic Technologies Inc.
- Hisato Takenaka - Hidden Markov Modeling of Violin Bowing, 12/95
BDM Technologies, Tacoma WA.
- Nancy Greivell - Ferrofluidic Based Micro-Pump, 6/95
Agilent Heartstream Division, Seattle.
- Frederik Boe - An Iterative Trajectory Shaping Algorithm based on Run-Time Results
ABB Robotics & Arthur Anderson Consulting, Nice France. 12/94
- Darwei Kung - Hidden Markov Model with Explicit Duration and its Application to Robotic Task Segmentation 12/94
USWest, Denver, Co.
- Steven Venema - Kalman Filter Based Calibration of Analog Encoder Signals 6/94
UWEE Ph.D., Associate Technical Fellow, Boeing Phantom Works
- Manuel Moreyra (MSME) - Design of a Five Degree of Freedom Direct Drive Minirobot Using Disk Drive Actuators, 6/94
- D. Smith - A New Kinematic Index for Manipulator Motion 3/94
Applied Physics Lab, Seattle.
- P. Bhatti - Single chip velocity processor for optical encoders. 9/93
Assistant Professor, Georgia Tech, Jan-2007 —.
- M. Shoemaker - Neural control of the Anthroform Arm. 5/93
Ph.D. UWEE 2000, Assistant Professor, Seattle Pacific University
- P. Braathen - "Sliding mode control for force-reflecting teleoperation," 3/93
Norwegian Military
- A. Lawn (UW M.E.) - "Control methods for bi-lateral telemanipulation" 10/92
- Wei-Chi Wang, "A New Optical Microsensor for Mechanical Detection Using Scattering from a Micro-Pipette," 12/91
Ph.D. UWEE (Sinclair Yee, Adviser), Research Assistant Professor, Dept of Mech. Engineering UW.
- Ching Ping Chou, "Dual Stable Point Model of Muscle Activation and Deactivation" 11/91
(see Ph.D. Students)
- P.H. Marbot, "Mini Direct Drive Robot for Biomedical Applications"
(see Ph.D. Students) 8/91

MS In Progress

- Vidur Vij, ME, 9/20 (Currently full time at Unity).

MS Non-Thesis Option Completed

- Lisa Oh, Bioelectronic Tissue Impedance Measurement integrated in the surgical tool. 6/09
- Andrew Redmond, Embedded Software for Multifinger Haptics. 3/08
- Ken Fodero, Embedded software for surgical robotics. 3/06
- Arash Aminpoor, Embedded System Design, 4/05
- Greg Darlington, “ ‘LilHelper Rehabilitation Positioning Device,” (project report) 6/04
Liposonix Inc.

Post Doctoral Students and Surgical Fellows

5 Engineering PostDocs completed. 6 surgical fellows jointly supervised with M. Sinanan MD and Thomas Lendvay, MD.

Completed

- Yangming Li
Assistant Professor, Rochester Institute of Technology starting August 2018.
- Omar Aljanaideh, January 2017-December 2017. Control and modeling of non-linear friction dynamics.
Now at Facebook.
- Randy Bly MD (Surgical Fellow on 12 month research grant to work in BRL) 2012-13 Now faculty member at UW in ENT / Childrens Hospital.
- Joel Perry (with Jacob Rosen) Powered exoskeleton for rehabilitation. 6/06 - 5/08. Now Project Manager at Tecnalia Research and Innovation, San Sebastian Spain.
- Rainer Leuschke, Sensors for high resolution multifinger haptics. 4/04 - 1/08. Now with University of Washington CREST Lab.
- Yoonsang Kim Ph.D., Stable Control and Novel applications of Haptic Interfaces.
3/01 - 9/03. Associate Professor, School of Internet Media Engineering, Korea University of Technology and Education (KUT) Cheonan, Korea.
- Jee-Hwan Ryu Ph.D. (KAIST), Stable Control of Haptic Interfaces
3/02-4/03. Associate Professor, Korea University of Technology.
- Dan Ferris, Ph.D. (U.C. Berkeley), Artificial Muscle actuators for rehabilitation.
7/01-6/02. Associate Professor, Department of Movement Science, Division of Kinesiology, University of Michigan.
- Marco Solazzo MD, Marco Barecca MD, Lilly Chang MD, (joint with Mika Sinanan, Surgery) working on Surgical Robotics Project 7/98-6/02
Lily Chang now Assistant Professor of Surgery, UW School of Medicine.
Marco Solazzo and Marco Barecca, Private Surgical Practice.
- Jacob Rosen, Ph.D. (Tel Aviv University) working on DARPA-funded Surgical Force/Torque Signatures Project 7/97 - 9/02
Professor, Dept. of Mechanical Engineering, U.C.L.A.
- Dmitry Oleynikov, MD, Surgical Robotics Project 00-01
University of Nebraska Medical Center.

- Christina Richards, MD. (joint with Mika Sinanan, Surgery) DARPA-funded Surgical Force/Torque Signatures Project 7/97 - 9/99
Private Surgical Practice.
- Mark MacFarlane, MD. (joint with Mika Sinanan, Surgery) DARPA-funded Surgical Force/Torque Signatures Project 7/97 - 6/98
Private Surgical Practice, Tacoma Washington.

Undergraduate Research Mentoring

Roughly 10-20 Student credit hours per year.

Student Credit Hours

Quarter	SCH
W14	15
Au13	19
Su13	8
Sp13	19
W13	14
A12	23
Su12	3
Sp10	41
W10	18
A09	24
Sp09	36
W09	34

Selected Recent and Current Students

Name	qtrs	Project Title
Rachel Aina ^{*,**,x}	Su09	Haptics of Activities of Daily Living
Brittany Redmond ^{*+**,x}	Sp08-	Haptics of Activities of Daily Living
Kathy Lee ^x	Sp08-W09	High Definition 3D display system
Mohammed Logman ^x	A08-W09	Thermal modeling of motor coils
Radivoje Jovanovic ⁺	A06-S08	C-Arm Control Electronics
Lauren Potter ^{**,x}	W06-Su06	Network testing for collaborative haptics
Clint Bland ^{**}	Sp05-Sp06	Safety Processor for Surgical Robot
Gyung Sun (Lisa) Oh ^{++,x}	Su05-Sp06	Electronics for Haptic and Robotic Systems
Gina Donlin ^{++**,x}	Sp05-Sp08	Electronics for Haptic and Robotic Systems
Liz Kurihara ^{+**,x}	Sp04-A04	Thermal Actuator Measurements for Haptics
Ken Fodero ^{**}	Sp04	Embedded Systems for Haptic Control
Aaron Midkiff ^{*x}	Sp03-Sp04	Surgical Telerobot Operations and Technology
Tim Kowalewski ^{++*†}	Su02-Sp03	Hidden Markov Models for Surgical Performance
Jacques Le	W03	"
Fumihiko Nagahisa	W03-Sp03	"
Travis Morgan	W03-Sp03	USB-linked embedded microcontroller for surgical robotics.

* NSF REU; ** Co-author; + Mary Gates Award; † Current Ph.D. Student; x Woman or member of an underrepresented minority group.

Selected Success Stories

Gina Donlin (05-07) Gina started as a sophomore with little engineering knowledge. However she quietly became a key lab member by starting with the basics like soldering and board assembly. She made

key technical contributions to our surgical robot and was deemed an essential person to travel with us down to California for the HapSMRT wireless surgical teleoperation experiment in spring 2006. She designed her own experiments to evaluate methods of attaching the fingers to a haptic device and wrote up a paper on her own for the World Haptics Congress in Tsukuba, Japan (March 2007). She traveled to that conference and made excellent use of the experience making many contacts there. I heard many positive comments on her work from leading people in the field.

In Feb 2008, she presented a paper to about 200 international attendees at the highly selective, single track conference the North American Haptics Symposium, in Reno NV. She also supported a demonstration booth of her technology in which we performed over 100 demos. She spent 3 months in Spring 2009 at Scuola Superiore Santa Anna, Pisa/Pontadera Italy doing research.

Jeff Longnion (99-00) Starting with a loosely described idea, Jeff built an experimental apparatus that measured for the first time the effects of motor inertia and gearing friction on perception of stiffness through a haptic device. He then wrote and presented a conference paper ¹ and presented it himself at the Medicine Meets Virtual Reality Conference. While all the UG researchers mentioned in this section have published papers, Jeff was exceptional in his autonomy in doing so. One colleague from Berkeley claimed it was the best paper he heard at the conference. This research was recognized by a Mary Gates award and Jeff will enroll in UW's highly selective Medical Scientist Training Program (MD/Ph.D.) in fall 2003.

Dan Klowden (97-99) Starting with a basic software demonstration in which users manipulate a haptic device and interact with simulated Lego blocks on the screen (while feeling the interaction forces between blocks), Dan totally revised the collision detection algorithms incorporating knowledge of the Lego block geometry and a linked list structure to dramatically speed the computation. While the original code could only display up to 4 blocks on the screen at a time Dan's code expanded this to hundreds (and still completed the calculations in the required 1 millisecond time interval). (Mary Gates Winner)

Mitch Lum (99-02) When Mitch began in the lab doing basic tasks such as cleaning and organizing our electronics benches and fabricating mockups from PVC pipe, he was often torn between his interest in the lab and his hobbies like RC-car racing. As his imagination increasingly caught fire, he began to make important engineering contributions in his senior year (he also won a Mary Gates stipend). Now he is a Ph.D. student on an Army-funded surgical robot design project and after just three quarters, he has completed material for a Master's Thesis and journal paper which breaks new ground in the theory of spherical mechanisms as well as producing a tool for kinematic optimization of both parallel and serial spherical mechanisms.

He won the Outstanding Graduate Research Assistant Award from the EE Department in Spring 2007. He is expected to complete his Ph.D.

Tim Kowalewski (01-03) Tim graduated in Spring 2003 after performing two simultaneous UG research projects at both ends of the theoretical/applied scale. In 2001 he began to work at Washingtons Human Interface Technology Lab with Suzanne Weghorst and Urologist Rob Sweet. Together they have created a simulator for the Trans Urethral Prostate Resection procedure which has garnered national attention and and industrial licensee. At the same time, he worked with Prof. Hannaford studying Hidden Markov Model - based software for tracking surgical progress and skill monitoring. Recently he graduated and is working about 80% time on HMM's in the JHU/ITR project. He visited JHU and presented his research in June of 2003. Tim was also a Mary Gates winner. In early 2006 we hired him as a staff engineer, and since September 2007 he has been a Ph.D. student in our lab.

¹J. Longnion, J. Rosen, M. Sinanan, and B. Hannaford. *Effects of geared motor characteristics on tactile perception of tissue stiffness*, Studies in Health Technology and Informatics - Medicine Meets Virtual Reality, 81:286–292, Newport Beach, CA. January 2001.

Other Research Activities

Sponsored Research

**Awards: (PI unless otherwise noted)
Completed**

UW Graduate School Fund \$7.5k 5/91-4/92
UW Graduate School Research Fund \$10k 1/90-12/90
NSF Presidential Young Investigator \$350k 9/90-9/95
ONR: "Anthroform Biorobotic Arm" \$37k 5/91-4/92
ONR "Anthroform Biorobotic Arm" \$255k 3/92 - 4/96
UW Royalty Research Fund \$22k 2/93 - 1/94
Washington Technology Center, "High Bandwidth Force Display" \$100k 7/93 - 12/94
Washington Technology Center, "Advanced Genome Automation" (D. Meldrum PI) \$140k 7/93 - 6/95
NASA "Micro Telerobotics Experiment, Micro-Trex: Phase A" \$60k 3/94 - 12/94
NSF: "Consumer Electronics Design Course" \$100k 9/94 - 8/97
NASA Johnson Space Center, "Force Display for EVA Training" \$45k 5/95 - 9/95
UW Libraries Allen Innovation Award \$7.5k 9/95-6/96 "Haptic Interface to Databases"
Boeing Defense and Space Company \$68k 10/95 - 4/96 "Protein Crystal Growth Cell"
Boeing Information and Support Services \$16k 1/96 - 6/96 "Advanced Force Sensor for Haptic Display"
ONR / United Research Inc. STTR: "Improved Dynamic Response of McKibben Artificial Muscle Actuators," \$50k 9/96 - 4/97
Boeing Information and Support Services \$86k 8/96 - 12/96 "3-D Haptic Display Device Design and Test"
Boeing Defense and Space Company, "Telerobotic Protein Crystal Mounting System" \$20K 8/96 - 12/96
DARPA, "Force/Torque Signatures in Minimally Invasive Surgery," \$500k 7/97 - 6/98
Ford Research Labs (gift), "Haptic Interfaces for Body Panel Shape Perception," \$135k 1/97 - 12/99
VA Rehab Engineering Center (w/ Seattle VA), "Technologies for Powered Above-Knee Prostheses," \$375k 10/97 - 9/01
Boeing Defense and Space Company, "Telescience User Interfaces" \$100k 4/97 - 12/97
Washington Tech. Center, "Intelligent Control of cooking appliances" (J. Vagners PI, w/ Lang Manufacturing) \$60k 7/97 - 6/99
National Science Foundation, "Computing Appliances, A Context for Integrating Research and Education," Gaetano Borriello, P.I. \$490k 10/98-9/01
National Science Foundation, "Low Power Haptic Interfaces", Dissertation Enhancement project for Jesse Doshier, (3 month research visit to PERCRO lab, Scuola Superiore Santa Anna, Pisa Italy) \$23k 8/01 - 7/02.
National Science Foundation, "MEMS Technology for Low Power Haptic Interfaces," Dissertation Enhancement project for Greg Lee, (3 month research visit to ARTS lab, Scuola Superiore Santa Anna, Pisa Italy) \$23k 8/01 - 7/02.
Ford Motor Company, "Education and Research in Transportation Infotronics," \$750k 6/98 - 5/04

Rockefeller Brothers Fund, Charles E. Culpepper Biomedical Pilot Initiative Grant, "Exploration of Opportunities in Telemedicine for Surgery: Access for Rural Areas,"
\$24.8k 1/03 - 12/03.

Washington Research Foundation, "Advanced Surgical Technology,"
\$200k 7/01 - 12/03

Intel Seattle Research Lab, "Embedded Computing, Sensing, and Pattern Recognition in Health Care and Rehabilitation,"
\$29k, 1/03 - 3/05.

Boeing Company Phantom Works, "Collaborative Haptics,"
\$60k, 1/04 - 12/04,

National Science Foundation, "Hidden Markov Models of Surgical Procedures," (Subcontract on NSF ITR
award to Johns Hopkins University).
\$85k 4/01 - 9/05.

Boeing Company Phantom Works, "Collaborative Haptics,"
\$60k. 1/05 - 12/05,

Samsung Advanced Institute of Technology, "Human Performance for Low Power Hand Held Haptic De-
vices," 12/03 - 11/05, \$130k direct costs (gift).

National Science Foundation, " IIS-0303750 Exploratory Procedures in Multi-Finger Haptic Display,"
\$200k 5/01 - 5/05 (extended to 5/06).

TATRC via U. of Cincinnati "HAPSMRT Telerobotic Surgery Demo"
\$60k 2/06-7/06

US Army Medical Research Acquisition and Materiel Command, "Robotic Mechanism for Military Telesurgery
in the Battlefield,"
\$1.2M 5/02-4/06 (extended to 3/15/07)

DARPA (via TATRC/U.S. Army) "Traumapod Phase I" **J. Rosen P.I.**
\$600k 3/05 - 9/07 (\$350k Supplement, 6/06)

US Army TATRC "Hidden Markov Model evaluation of simulator data" **J. Rosen P.I.**
\$200k 10/05-9/07(?)

US Army TATRC via U. of Cincinnati "NEEMO-12 Telerobotic Surgery Demo"
\$35k 3/07-5/07

US Army TATRC, "Control of Teleoperated Surgery with Time Delay", Howard Chizeck, Co-I.
\$150k 8/06-10/07.

NSF, "Research Experience for Undergraduates Supplement,"
\$18k, 6/1/2008–5/31/2009.

NSF, "Research Experience for Undergraduates Supplement,"
\$12k, 6/1/2009–5/31/2010.

NSF, "IIS-0713028 HCC: Multi-Finger Haptics for Learning, Visualization, and the Arts,"
\$450k 6/07-5/10.

US Army TATRC (STTR via SPI surgical) "Surgical Cockpit for advanced surgical technologies," (**J. Rosen P.I.**)
\$30k (UW Portion) 9/2009-10/2010

Coulter Foundation (via UW Bioengineering), "Animal Testing of a multisensing surgical tool,"
\$50k, 6/1/2009 – 10/1/2009

Washington Technology Center & Simulab Inc., “Improved Machine Learning Methods for Surgical Performance Measurement,”

\$120k 7/1/09-6/31/10

US Army TATRC (STTR via SPI surgical) “Roboscope - Minimally invasive surgical system for neurosurgery through natural orifices,”

\$30k (UW Portion) 9/2009-2/2010 No Cost Extension to June 2010

UW Technology Gap Innovation Fund (TGIF), “Engineering robustness of the multisensing surgical tool,”

\$50k, 7/1/2009– 6/31/2010

NSF, “CPS Small: Control of Surgical Robots, Network Layer to Tissue Contact,”

\$550k 10/2009-9/2012

NSF, “II-NEW: A Network of Open Testbeds for Surgical Robotics Research,”

\$880k (\$550k UW Portion) 4/1/2010—3/31/2012.

Washington Technology Center & Simulab Inc., “Improved Machine Learning Methods for Surgical Performance Measurement, Phase II,”

\$135k 7/1/10—6/31/11

US Army TATRC (STTR via SPI surgical), “Surgome Surgical Skill Database” **Thomas Lendvay, P.I.**

\$32.6k (UW Portion) 9/1/2010 — 8/31/2011

NSF (REU) ”HCC: Multi-Finger High Fidelity Haptic Exploration.”

\$9.9k 5/10 — 7/31/10

US Army TATRC (STTR via SPI surgical) “Surgical Cockpit for advanced surgical technologies Phase II,” **J. Rosen, P.I.**

\$155k (UW Portion) 9/2010 — 4/2013

NASA (SBIR) via Barron Associates, “Vibrotactile Feedback for Space Suit Gloves. Phase II”

\$150k (UW Portion) 10/11 — 6/13

Qatar National Research Foundation, “Flexible Imaging Probe for Surgical Robotics,” **Wong Jong Yoon, Qatar University, P.I.**

\$250k (UW Portion) 10/1/2010 — 9/31/2013

University of Central Florida/University of Western Ontario/University of Montpellier (France), “Raven Surgical Robot Research Platform,”

\$950,000, 9/12-7/13, 5/22/12-5/21/15, 10/12-7/21/13

NSF ERC, via University of Washington, Computer Science

Hannaford CSNE 2014

\$66,566 (UWEE portion), 12/16/13 – 12/15/15

Qatar University (QNRF)

Demonstration of Tactile Sensing System and Imaging Probe for Smart MIS Tool

\$109,133, 4/2012 – 3/2015

University of Washington, Coulter Foundation

Computer Model for Advanced Pre-Operative Planning in Skull Base

\$99,176, 11/2013 – 11/2014

National Institutes of Health

R21: Computer Modeled Multiportal Approaches to the Skull Base

\$215,894, 9/2013 – 8/31/2015

American Academy of Otolaryngology

Computer Modeled Multiportal Approaches to the Skull Base

\$9,735, 7/2013 – 6/2014

National Institutes of Health (R01), “Robotic Assisted Surgery with Tumor Paint”, Eric Seibel, PI

\$391,000 (UWEE portion), 9/2012 – 8/2016 (No cost extension through 9/17)

Korean Institute of Science and Technology (KIST)

Dr. Hujoon

\$163,200 (year 1), 11/2013 – 10/2014 (total for 5 years \$681,045, 11/2013-10/2018)

National Science Foundation, “NRI Large: Collaborative Research: Multilateral Manipulation by Human robot Collaborative Teams,” Allison Okamura, Stanford, PI

\$219,000 (UW portion), 12/2012 – 12/2016

Amazon Catalyst Program

Intelligent Robotic Assistant for Neurosurgery

\$100,000, 3/2017 – 3/15/2018

Army Research Office

Tissue Characterization Cooperative Agreement

Robert M. Sweet, PI

\$150,000 (approx UWBRP portion) 1/2017–12/2016 (renewal pending)

National Science Foundation, Award: 2025814

FW-HTF-P: Planning for the future of rural telerobotic surgical healthcare

PI: Stephen Seslar; Co-Principal Investigator: Blake Hannaford, Tadayoshi Kohno

\$149,999, 10/2020 – 9/2021

National Science Foundation, National Robotics Initiative

NRI: Collaborative Research: Software Framework for Research in Semi-Autonomous Teleoperation

Peter Kazanzides JHU, PI.

\$479,998 (UWEE portion), 10/2016– 9/2020 **Active:**

1. National Science Foundation, Award: 2036255

SenSE: Smart Grasper for Intelligent Surgical Manipulation

PI, Profs. Eli Schlizerman and Mika Sinanan, Co-PI's

\$743,168, 9/2020 – 8/2023. (on a no-cost extension until 9/24).

2. Co-Motion Innovation Fund

TPT-Finder: smart surgical instrument for Thyroid - Parathyroid discrimination

PI.

\$50,000 1/1/24 – 10/1/24.

Pending:

TPT-Finder: smart surgical instrument for Thyroid - Parathyroid discrimination
 NSF PFI-TT program
 Submitted 2-Jan-2024
 \$ 550,000, 10/1/24 – 9/30/26

Un-sponsored Research and projects with Fellowship Students**Current****Completed**

“Low cost cricothyroidotomy simulator for developing countries,” Team of undergraduates, graduates, and MD’s. Seed funding from UWEE and Dept. of Global Health (\$10k).
 “Soft Tissue Biomechanics of Internal Organs Relevant to Abdominal Surgery,” Ph.D. work of Jeff Brown (Bioengineering). Supported by a Whitaker Fellowship. 9/99-8/03.
 “Force Feedback of Kinematic Information in Teleoperation and Remote Control,” Ph.D. work of Thavida Maneewarn, supported by a Thai Government Fellowship. 6/96 - 12/98.
 “Optimal Design of Coupling Networks for Haptic Simulations,” Ph.D. work of Rick Adams, supported by an Air Force Fellowship. 9/96 - 6/99.
 “Biorobotic Artificial Muscle Spindle,” Ph.D. work of Kristen Jaax, supported by a Whitaker Foundation Fellowship, 6/96 - 6/99.

Documentation of Teaching Effectiveness**Courses Taught**

(average of first 4 items) ECE 543 (PMP) Au21 Models of Robot Manipulation 4.3/4.2 (N=6/14)
 ECE 474 Sp 21 Introduction to Embedded Systems 3.0/3.1 (N=10/62)
 ECE 398 Sp21 Professional Issues in ECE 3.7/4.0 (N=17/69)
 ECE 398 W21 Professional Issues in ECE 4.8/4.4 (N=9/46)
 ECE 398 A20 Professional Issues in ECE 4.1/4.2 (N=11/40)
 Re-factored course for asynchronous online delivery. Developed first material in the course on Diversity, Equity, Inclusion in Engineering.

EE 543B W 17 Models of Robot Manipulation 4.3/4.2 (N=22/39)
 EE 543A (PMP) W 17 Models of Robot Manipulation 4.5/4.5 (N=10/23)
 EE 447 A 17 Control Systems Analysis I 4.4/4.4 (N=35/80)
 EE 398A Sp 17 Professional Issues in EE 4.8/4.7 (N=23/73)
 EE 589A W 17 Haptic Enabled Systems 3.8/5.0 (N=12/16)
 EE 447 A 16 Control Systems Analysis I 4.2/5.0 (N=63/67)
 EE 543(PMP) Sp 16 Models of Robot Manipulation N=7
 EE 543 W 16 Models of Robot Manipulation 4.1/5 (N=16/26)
 EE 589 W 14 Haptic Enabled Systems 4.7/5 (N=11/12)
 EE 447 A 13 Control Systems Analysis I 4.4/5 (N=35/79)
 EE 546 Sp13 Models in Control and Robotics (PMP) 3.8/5 (N=17/27)
 EE 543 W13 Models of Robot Manipulation 4.3/5 (N=21/28)
 EE 447 Au12 Control System Analysis I 4.3/5 (N=41/78)
 EE 546 Sp12 Models in Control and Robotics (PMP)
 EE 447 Au11 Control System Analysis I 4.9/5 (N=21/63)
 EE 546 Sp11 Models in Control and Robotics (PMP) 4.4/5 (N=24/28)
 EE 543 W11 Models of Robot Manipulation 4.4/5 (N=24/28)
 EE 447 A10 Control System Analysis I 4.7/5 (N=33/62)
 EE 546 Sp10 Models in Control and Robotics (PMP) 4.5/5 (N=27/31)

EE 589 W10 Haptic Enabled Systems 3.9/5 (N=11/12)
 EE 447 A09 Control Systems Analysis I 4.0/5 (N=36/59)
 EE 332 S09 Devices and Circuits II 3.7/5 (N=13/34)
 EE 543 W09 Models of Robot Manipulation 3.8/5 (N=8/11).
 EE 472 A08 Embedded Microcomputer Systems 3.8/5 (N=20/31)
 EE 472 A07 Embedded Microcomputer Systems 3.8/5 (N=22/30)
 EE 472 W07 Embedded Microcomputer Systems 3.7/5 (N=33/40)
 EE 472 A06 Embedded Microcomputer Systems 3.4/5 (n=21/30)
 EE 449 S06 Control Systems Design 3.9/5 (n=10/27)
 EE 543 W06 Models of Robot Manipulation 4.0/5 (n=11/16)
 EE 472 A05 Embedded Microcomputer Systems 4.2/5 (n=24/25)
 EE 332 S05 Devices and Circuits II 3.6/5 (n=40/67)
 EE 589A W05 Haptic Enabled Systems 3.5/5 (n=7/15)
 EE 472 A04 Embedded Microcomputer Systems 3.8/5 (n=21/31)
 EE 332 S04 Devices and Circuits II 4.1/5 (n=29/65)
 EE 472 A03 Embedded Microcomputer Systems 4.1/5 (n=27/30)
 EE 544 S03 Advanced Robot Manipulation 4.1/5 (n=7/7)
 EE 543 W03 Models of Robot Manipulation 3.9/5 (n=13/18)
 EE 472 A02 Embedded Microcomputer Systems 3.7/5 (n=30/38)
 EE/AA449 S02 Control Systems Design 1.8/5 (n=10/13)
 EE299b W02 The Secret Life of the Electron (coordinated a team of faculty) 4.1/5
 EE472 A01 Embedded Microcomputer Systems 3.42/5 (n=32/38)
 EE498 S01 Consumer Electronics Design (with D. Wilson) 3.75/5 (n=12/12)
 EE400c W01 Consumer Electronics Design (with D. Wilson)
 EE299b A00 The Secret Life of the Electron (coordinated a team of faculty) 3.69/5 (n=23/32)
 EE498 S00 Consumer Electronics Design 2.89
 release W00
 EE498 A99 Consumer Electronics Design 3.625
 EE498 S99 Consumer Electronics Des. N/A
 release W99
 EE498 A98 Consumer Electronics Des. 3.25/5 (n=17/24)
 EE449 S97 Control Systems Design 4.17/5 (n=10/13)
 EE546 W97 Industrial Automation Lab 3.4/5 (n=9/12)
 EE498 A96 Consumer Electronics 4.0/5 (n=16/20)
 EE544 S96 Adv. Robot Manip. 4.0/5 (n=9/15)
 EE543 W96 Intro. Robot Manip. 4.5/5 (n=15/24)
 EE498 A95 Consumer Electronics 3.3/5 (n=22/27)
 EE544 S95 Adv. Robot Manip. 4.0/5.0(n=7/9)
 EE543 W95 Intro. Robot Manip. 3.98/5.0 (n=13/23)
 EE 498 A94 Consumer Electr. Des. 3.46/5.0 (n=12/15)
 EE 544 S94 Advanced Robot Manip. 4.0/5.0 (n=14/15)
 EE 543 W94 Intro. Robotic Manip. 4.0/5.0
 - A94 Course Development: Consumer Electronics
 EE 544 S93 Adv. Robotic Manipulation (unrated)
 EE 235 W93 Linear Systems and Signals 2.9/5.0 (n=22/36)
 EE 446 W93 Classical Control 3.41/5.0 (n=29/45)
 EE 546 S92 Adv. Robotic Manipulation 4.31/5.0 (n=9/9)
 EE 231 S92 Electric Circuits 3.99/5.0 (n= 37/70)
 EE 546 W92 Intro. Robotic Manipulation 3.92/5.0 (n = 12/16)
 EE 231 A91 Electric Circuits Unrated (n = 50)
 EE546 S91 Adv. Robotic Manipulation 8th decile CofE
 EE333 W91 Circuits & Systems 3.88/5.0 (n=100/120)

EE400a W91 Intro. Robotic Manipulation 4.27/5.0 (n=13/13)

EE333 A90 Circuits & Systems 3.93/5.0 (n=40/70)

EE446 W90 Control Systems unrated

Curriculum Innovation

Redesigned EE 472 embedded and development computing environment (Spring/Summer 2008). New embedded platform now allows TCP/IP networking, web services, and power management to be integrated into EE472.

Revised Control Engineering Capstone to increase design orientation (EE449) (Spring 2006).

Revised labs for EE448 (with Eric Klavins) (Sum 2005).

Revised (with J. Peckol and G. Zick) EE472, Embedded Computer Programming.

Developed “Industrial Automation Laboratory,” (course number pending) a new course for Winter 97. This course exposed Engineering students to automation technologies widely practiced in industry but little studied in universities: PLC, CNC, and Robotic Assembly technologies.

EE498, “Consumer Electronics Design” (with Kelin Kuhn). Developed curricular materials and laboratory exercises. Wrote NSF grant application to ILI-LLD Program (Nov 93). NSF Grant funded 4/94 for \$100k. Proposal received 6 reviews all of which checked “Excellent”.

EE 543 and 544, “Introduction to Robot Manipulation,” and “Advanced Robot Manipulation”. These courses were developed and are now listed in the catalog. Typical enrollment in EE543 is 23 students. Received \$100k ECSEL TRP funding to create a lab component to EE543 this lab component was later merged into the Industrial Automation Lab. Developed 3 robotics lab exercises for EE543, W96.

Service

Departmental Service

- Systems, Robotics, and Control Group Chair, AY20-21
- Chair EE Faculty Search Committee, 9/12-6/13
- Chair EE Computing Committee, 9/09 – 9/10
- EE Space Committee, 9/08 – 9/09
- Excel Search Committee 12/07 – 6/08
- EE Executive Committee 1/06 – 8/07
- EE Faculty Search Committee 3/05 – 5/05
- EE Development Committee. 9/04 – 8/05
- EE Promotion and Tenure Committee. 9/04 – 8/07
- Faculty Senator representing EE dept. 9/03 – 6/07
- Coordinator for Undergraduate Research, 9/02 –
- Chair, Faculty Search Committee, 9/01 - 6/02
- Associate Chair for Education, 7/99 - 6/01
- Chair, Faculty Search Committee, 9/98 - 6/99
- Member, Dept Research Committee, 9/98 - 6/99

- Chair, Instructional Resources Committee, 9/95 - 6/97
- Member of Departmental Advisory Committee, 9/93 - 8/96
- Chair of Controls & Robotics Group, 3/93 - 8/96
- Teaching Laboratory Strategic Planning Committee, 1/95 - 9/95
- Organized first quarter of Robotics Colloquium, 8/93 and Spring Quarter 1995
- EE Chair Search Committee. 3/93-5/93
- Core Curriculum Development Com. AY 89-90
- Dept. Strategic Planning Com. AY 90-91
- Dept. Resource Allocation Com. Sp. 91
- Sun Micro-systems gift coordinating committee. 3/92
- Extensive participation in recruitment of Deirdre Meldrum to the faculty. AY 91-92

College Service

- College of Engineering Strategic Planning Subcommittee on Technology Transfer and Innovation, AY 20-21.
- ECE representative to College Council AY20-21.
- Electrical Engineering Department Chair Search Committee, 3/07-6/07

University Service

- Faculty “FPLC” participant and leader. Coordinated faculty learning group on “flipping the classroom”. Au & W 2013
- Testbed Leader, Center for Sensorimotor Neural Engineering (NSF ERC), 9/11 — 9/13
- Search Committee, Digital Arts program Faculty Position, 1/07-6/07.
- Ad hoc Committee supporting Mary Lidstrom in negotiating with Alfred E. Mann foundation for major gift to UW. 11/06 –
- Search Committee, Battelle Endowed Chair and Director of the Center for Technology Entrepreneurship, Business School. 4/03 – 7/03
- Review Committee, Center for Technology Entrepreneurship, Business School 1/03 – 3/03
- Leading ad-hoc strategic planning group of about 15 faculty. Result is a strategic plan for research in advanced surgical technologies which is being presented to donors in the Medical School’s capital campaign. 5/02 –
- Royalty Research Fund Grant Review Committee 3/95 – 12/96

Community Service

- Panelist, Start-Up Pitch Event. Korean Ministry of SMEs and Startups (KSC) Seattle and Intuitive-X, online, 16-Aug-2021
- Judge, Seattle Innovation Startup Competition, hosted by Seattle Entrepreneurship Club. Nov, 2019
- Judge, Tsinghua Univ. / GIX Innovation competition, Aug 2018.
- Science Teaching in K-12 classroom, TOPS elementary/ (2 hrs per year) 98-2002

National Service

- NIH Study Section, SBIR/STTR Surgical Sciences, Biomedical Imaging and Bioengineering IRG, 2020-21 (3 times)
- NIH Study Section, SBIR/STTR Surgical Sciences, Biomedical Imaging and Bioengineering IRG, 2018, 2020 (2 times)
- Department of Energy, Visiting delegation member, reviewing robotics opportunities in Nuclear Waste Cleanup at Hanford Site, August 2015.
- NSF National Robotics Roadmapping sub-panel in Medical Robotics, 2012
- FDA Device Certification Panel Consultant - November 2002.
- FDA Device Certification Panel Consultant - October 2000.
- FDA Device Certification Panel Consultant - June 1999.
- NSF panels: 2007, May 2010

Other Service

- Conference Program Committee and Steering Committee, North American Haptics Symposium (even years), World Haptics Congress (odd years). 2007–
- Conference General Chair, organizing committee for International Conference on Advanced Robotics. ICAR-2005, Seattle WA. (about 200 attendees).
- Program Co-Chair, Haptics Symposium 2003-2006, currently affiliated with IEEE Virtual Reality Conference IEEE-VR2003.
- Conference Program Committee: ICAR-2003, Portugal, IEEE Intl. Conf. on Robotics and Automation, Alexandria VA, 2002, Leuven Belgium, May98. ICAR-97, Monterey, ASME Haptics Symposium, 11/97, First International Symposium on Medical Robotics and Computer Assisted Surgery, Pittsburgh, Sept. 1994.
- Conference Steering Committee: IEEE Workshop on Human Robot Communication, RO-MAN-94, 95, 96, Nagoya, July 94, etc.
- Video Proceedings Chair: Vrais-95, Raleigh NC, March 95.
- Advisory Committee: NSF Research Planning Workshop on Computer Assisted Surgery, March, 1993
- Video Proceedings and Tutorials Chair: VRAIS-93, First IEEE Conference on Virtual Reality Technology, Seattle, 1993.

- Invited Panelist: NSF workshop on Biosystems Analysis and Control Expansion, October 95, Japan Science Foundation 11th Science and Technology Forum, Kawasaki, 1/92, support from JSF. Talk: Kinesthetic Interface to Virtual Environments
- Invited Speaker and Panelist: IROS'91 (Intelligent Robots and Systems), Osaka, 11/91, Support from NSF and Toshiba. Talk: Hidden Markov Models for Manufacturing
- Conference Program Committee: ICAR 91 "International Conference on Advanced Robotics," Pisa Italy, June 1991. Track Chair: "Bio-robotics"
- Track Chair: "Biorobotics," IEEE EMBS Annual Intl. Conference, Nov., 1989, Seattle, Nov., 1990, Philadelphia, Nov 1993, San Diego.

Consulting

- DLA Piper, Expert witness in Patent litigation before the International Trade Commission, IMMR vs Apple. (2016-2017)
- Dorsey & Whitney, LLP. Expert witness on behalf of IEEE in copyright case, Kumar vs. IEEE. (2014-2016)
- Google-X. Advice on robotic surgery proof of concept project. (2013)
- Steptoe & Johnson, expert witness in International Trade Commission Investigation 337-TA-834, Immersion vs. Motorola Mobility, (2012)
- Orrick Herrington and Sutcliffe, LLC, expert witness in International Trade Commission Investigation 337-TA-743, Motiva vs. Nintendo. (2011)
- Intellectual Ventures, Inventing in selected technology areas different from my research. 2009,10
- Fogarty LLC (Law Firm) Advising on Patent Prosecution (2009/10)
- Howrey LLC (Law Firm) Advising on intellectual property. (Nov 2008)
- International Advisory Board, The Hamlyn Centre of Robotic Surgery, Imperial College London 4/2008 -
- McKool Smith LLC, expert Witness in patent case related to bioelectronics, 2005-2006
- Accor Technology Corp, Wenatchee WA. Automation. 2004
- Advisory Board, In-Touch Health Inc., Goleta, CA. 2002-2004
- Expert consultant to Patent Case involving haptic technology, Spring 2002.
- Interface Displays and Controls, Oceanside CA. Touch Screen Design, Spring 2002.
- Immersion Human Interface Corp., San Jose, CA. Consultation on haptic interface product design., 1997
- Expert witness in trade secrets case related to industrial automation, Autumn 96