

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor: Yves Behar
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For: PORTABLE COMPUTER WITH MULTIPLE
DISPLAY CONFIGURATIONS
Examiner: R. S. Desai
Art Unit: 3992

EXHIBIT B

**DECLARATION OF ERIC J. GOULD BEAR
IN SUPPORT OF PATENT OWNER RESPONSE TO
NON-FINAL OFFICE ACTION UNDER 37 CFR 1.111**

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APPENDIX A: Bear CV

APPENDIX B: *Funk & Wagnalls New Int’l Dict. Of the English Language*, 2000, “orientation”

APPENDIX C: Freescale semiconductor application note, “Tilt sensing using a three-axis accelerometer” (2007-2013)

I, Eric J. Gould Bear, declare as follows:

I. INTRODUCTION – PURPOSE OF THIS REPORT

1. I have been retained by counsel for LiTL LLC (“**LiTL**”), in this action. I have been asked to provide my independent analysis of how a person of ordinary skill in the art (a “**POSITA**”) at the time of the invention of U.S. Patent No. 10,289,154 (the “**’154 Patent**”) would have understood the claims of the ’154 Patent when viewed in light of its specification, figures and claims, the scope and content of the disclosures contained in International Pub. No. WO 95/24007 (“**Lane**”) and the other references cited by the examiner, and whether the claims of the ’154 Patent would have been obvious over Lane.

2. This report is limited to the specific issues stated above. I reserve the right to provide additional opinions at the appropriate time.

3. I am not, and never have been, an employee of LiTL. I am being compensated at the rate of \$520 per hour for time spent on this matter. My compensation is not related to the outcome of this matter, and I will not receive any additional compensation based on the outcome of any proceeding involving the LiTL’s Patent.

II. POINT OF VIEW & MATERIALS REVIEWED

4. My opinions, as explained below, are based on my years of education, experience, knowledge and background in human-computer interaction, as well as my study of relevant materials for this declaration.

5. In forming my opinions and preparing this declaration, I have considered and relied upon not only the materials listed below and any other documents cited in this declaration, but my own education, experience, knowledge and background in the relevant art. These materials are the types of materials that an expert would reasonably consider in forming opinions regarding the topics discussed herein. I reserve the right to rely on additional information that may be provided to me in this matter.

6. I reviewed the Request for *ex parte* Reexamination of the ’154 Patent under 35 U.S.C. § 302-307 and 37 CFR 1.510 submitted by Lenovo (United States) Inc. (“**Lenovo**”) (the “**Request**”), the Declaration of Christopher Schmandt (the “**Schmandt Decl.**”) which was Ex. 1004 to the Request, the ’154 Patent and its file history, Lane, Tonouchi, Fujinawa, and the other

references cited in the Request, the Office Action mailed December 12, 2022 (the “**OA**”), and the Response to Non-Final Office Action under 37 CFR 1.111 (“**Response**”) filed with this declaration. I also attended the interview held on January 25, 2023 with Examiner Desai and the conferees.

7. For consistency and ease of review, my column and line citations to the patent specification are in “(column:line)” format. It should also be understood that from time to time, while I may refer to a patent’s “specification” without mention of the patent’s figures, I use the term “specification” as a shorthand referring to all components of a patent filing, including the patent’s written specification, figures, tables, source code and such.

III. SUMMARY OF CONCLUSIONS

8. As a result of studying the materials outlined above in **Section II** and performing the analysis described herein and measured against the standards outlined below in **Section VI**, it is my opinion that Lane does not teach or suggest a display manager “configured” to detect a current display mode as required by all claims of the ’154 Patent.

9. My opinions are supported by the evidence in the patent specifications, figures and claims, as well as the other materials identified above in **Section II**; and contrary to the OA discussion regarding these issues, a person of skill in the art would find corroborating evidence in the materials identified above in **Section II** in support of my findings.

10. The opinions and conclusions expressed in this declaration represent my current opinions and conclusions, and the bases thereof, in this matter. Although I do not believe that my opinions and conclusions, and the bases thereof, are likely to change, they may be revised and/or supplemented should additional relevant information or insights become available to me.

IV. BACKGROUND AND QUALIFICATIONS

11. While I summarize my qualifications below as it relates to the analysis and opinions in this declaration, more detailed qualifications can be found in my curriculum vitae (“**CV**”), attached to this declaration as **Appendix A**, including a summary of my professional and educational background.

12. For over 35 years, I have been involved in the research, teaching, design, development and manufacturing of graphical user interface (“**GUI**”) and other hardware and

software user experience (“UX”) technologies. In this field, I have been named first inventor on 84 issued U.S. patents. I am also the first named inventor on a number of international patents and patent applications.

13. Inventions of mine for which patents have been issued relevant to the ’154 Patent include real-time communications architectures, auxiliary visual displays for personal computers, auxiliary processing by sleeping computing devices, methods for navigating content using media transport controls symbolic and schematic displays of protocol-specific information, user interfaces for visualizing data backup and recovery, and handheld multi-channel interactive environments.

14. These inventions have been licensed to a wide range of companies, among which are the largest consumer electronics and operating system companies in the world, all of the major motion picture studios in the United States, and other Fortune 500 industry players.

15. Of particular additional relevance to this matter is my work as manager of the user experience team that created and brought to market Microsoft’s Tablet PC SKU. I managed software interface designers, hardware industrial designers, user researchers, and user assistance experts, organizing separate disciplines into a unified practice. I also worked closely with third party hardware manufacturers experimenting with a variety of fixed and convertible form factors for tablet computing devices with and without keyboards.

16. Also relevant to this matter is the convergence of my work on consumer graphical user interfaces, the design of touch screen user interfaces of various form-factors, and the design of user interfaces for video and media control – from universal remote controls (Logitech; Microsoft) and mobile phones (Samsung) to car dashboards (Ford), blood analyzers (Luminex) and hospital handhelds (Novartis). In each case, I led a team of user interface and interaction designers in studying real-world usability challenges and writing functional and technical specifications for engineering teams to implement that addressed those usability challenges.

17. I have designed and written iOS applications to create virtual reality experiences that allow users to navigate virtual reality with a handheld or stereoscopic head-mounted display. One of my inventions in this field (entitled *Walk-in Theater*) has enabled stereoscopic viewing via Google Cardboard and other VR headsets, with a library of 3D experiences by world-famous media artists.

18. This invention family has been awarded at least eight U.S. patents, and research results were published in the MIT Press journal, *Leonardo*.

19. In 2017, I adapted the interaction technologies to the piloting of drones using head-mounted displays. A drone aviation app (entitled *Teleport*) and a tutorial game embodying the technology (entitled *BodyNav*) are both available in the iOS App Store. In 2018, to provide hands-free locomotion, smoother user interactions, a reduction in motion sickness and enhanced physical presence in 3rd party virtual worlds, I designed and led the development of a body-based extended reality (“XR”) developer kit for HTC Vive and Oculus Rift.

20. Since 2013, I have been a partner and angel investor at Austin’s Capital Factory start-up incubator, where I have served as an advisor to executives in intellectual property strategy and the design and development of new hardware, software and services.

21. From 2015 to 2020, I served as the Chief Experience Officer, Corporate Secretary, lead investor, and a board director of Curb, Inc., an energy technology start-up company that builds integrated hardware and software systems for visualizing and managing energy in residential and commercial settings. At Curb, I advised executives, mentored engineers and managed legal operations, including patent prosecution and intellectual property licensing. In August of 2020, Curb was acquired by Elevation Home Energy Solutions, Inc.

22. In addition to gaining relevant expertise through the academic training, professional experiences and research accomplishments described above, I stay abreast of the user experience field by reading technical literature and attending and presenting at conferences across the nation and internationally. I have also served as a director on the board of several non-profit organizations.

23. My experience designing and evaluating user interfaces over the last 35+ years, including the optimization of human performance through the use of computing technology and automated feedback of various forms and modalities, as well as my background hiring and managing teams of user experience professionals, all position me as an expert in the design and development of graphical user interfaces with a nuanced understanding of what people of skill in the art would have known at the times of invention of the ’154 Patent.

V. PERSON OF ORDINARY SKILL IN THE ART

24. All of the opinions I express herein have been made from the standpoint of a person of ordinary skill in the art at the time of the invention of the '154 Patent, which I may refer to as a **"POSITA."** I understand that a POSITA is a hypothetical person who is presumed to be aware of all pertinent prior art and the conventional wisdom in the art at that time, and is a person of ordinary creativity.

A. Time of Invention of the '154 Patent

25. The application which led to the issuance of the '154 Patent (US Application no. 15/896,201; the **"'201 Application"**) was filed on February 14, 2018. The '154 Patent claims the benefit of Provisional US Application No. 61/041,365 (the **"'365 Application"**), was filed on April 1, 2008, and two non-provisional applications filed on July 10, 2008. I have not analyzed which limitations benefit from any date other than April 1, 2008 and my reliance on that date should not be construed as an opinion on the issues of conception and reduction to practice of the claimed inventions in the '154 Patent. Therefore, in this declaration, I have evaluated the meaning that certain terms in the patent would have had to a POSITA as of April 1, 2008. But my opinions would not be materially different if the priority date was July 10, 2008.

26. I reserve the right to supplement my opinions as necessary.

B. Level of Ordinary Skill in the Art

27. I have considered the level of ordinary skill in the art at the time of invention of the '154 Patent using the following factors: (1) the types of problems encountered in the art; (2) the prior art solutions to those problems; (3) the rapidity with which innovations are made; (4) the sophistication of the technology; and (5) the education level of active workers in the field. In a given case, every factor may not be present, and one or more factors may predominate.

28. Considering these factors, I believe a POSITA in this matter would have had: (i) a Bachelor's degree with a focus on human-computer interaction (such as industrial design, user interface design, cognitive science or computer science), plus at least two years of work experience in designing hardware and/or software aspects of user interfaces for portable computing devices. Alternatively, the POSITA could have received a graduate degree such as a Master's degree in the same field with at least one year of work experience in designing hardware and/or software aspects of user interfaces for portable computing devices.

29. Though I have submitted a declaration associated with the '154 Patent in a co-pending litigation that articulated the level of skill in the art using slightly different terms, there is no substantive difference between the two articulations. My opinions in this declaration would not change if I had used the previous articulation of the level of skill in the art.

30. Based on my qualifications, I am and was at the relevant time a POSITA relevant to the '154 Patent. I am also an expert with an understanding of what a POSITA would know at the time of invention of the '154 Patent.

VI. LEGAL PRINCIPLES AND METHODS

31. Although I am not an attorney and offer no opinions of law, I have been informed by counsel of the legal standards that apply. In forming my analysis and conclusions expressed in this declaration, I have applied the legal principles described in the following paragraphs, with which I am familiar from my own extensive experience with the patenting process.

A. Interpretation at the Time of Invention

32. I interpreted the meaning of the claims as a POSITA would understand them at the time of invention of the '154 Patent.

B. Claim Construction

33. I have been informed by counsel of the legal standards that apply with respect to claim construction. I understand that claim construction is the process by which a fact finder determines the scope and meaning of terms used in the claims of a patent.

34. I have been advised by counsel that claim terms that do not have any special meaning to a POSITA should generally be given their “plain and ordinary” or “ordinary and customary” meaning. I have also been advised that claim terms should generally be construed as a whole, as meaning is often context dependent. In some cases, though, the patent specification may reveal a special definition given to a claim term by the patentee that differs from the meaning it would otherwise possess. In such cases, the inventor’s lexicography governs.

35. I understand that during a reexamination proceeding, claim terms are to be accorded their “broadest reasonable interpretation” (“BRI”), but that the best source for determining the meaning of a claim term under that standard is the claims themselves and the specification.

36. In all cases, even under the BRI standard, I understand that claims must be read in view of the specification and the record evidence, because they do not have meaning removed from the context from which they arose and with an interpretation that a POSITA would reach. Thus, I understand that the relevant inquiry in claim construction is the question of how a POSITA would have understood the claim terms at the time of the earliest priority date, in light of the patent specification, including the claims themselves and all text and figures, as well as the prosecution history, and any other relevant intrinsic and extrinsic evidence.

37. I understand that the prosecution history of a patent provides evidence of how the PTO and the inventor understood the patent. I understand that because the prosecution history represents an ongoing negotiation between the PTO and the applicant, rather than the final product of that negotiation, it often lacks the clarity of the specification and thus is less useful for claim construction purposes. I understand that post-grant proceedings (e.g. *inter partes* reviews and *ex parte* reexaminations) involving a patent are part of that patent's prosecution history.

38. I understand that if a disputed claim term lacks an accepted meaning in the art and thus has no plain or established meaning to a POSITA, then its meaning must be found elsewhere in the patent. Where that is the case, I understand that fact finders construe such a term only as broadly as provided for by the patent itself.

39. Extrinsic evidence, including dictionaries and learned treatises, may be considered only when the meaning of a term is unclear in view of the patent and its prosecution history.

40. I understand that claim terms should be construed consistently throughout a patent. In other words, each term should have the same meaning whenever it appears in the claims. I have also been advised that the prosecution history of a patent can be considered in the claim construction process, but that it is less useful than the specification of the patent. I have been advised that the prosecution history may reveal an interpretation that was disclaimed by the applicant, but that such a disclaimer must be unequivocal and unmistakable in order to be effective.

41. I have been advised that claim construction is intended to resolve disputed meanings and technical scope, to clarify, and when necessary to explain what the patentee covered by the claims, but that it is not an obligatory exercise in redundancy.

C. Validity: Obviousness under 35 U.S.C. §103

42. I have been informed that a patent claim is only invalid as "obvious" under 35 U.S.C. §103 in light of one or more prior art references if all of the claim elements and their

limitations would have been obvious to a person of ordinary skill in the art at the time of the alleged invention POSITA, 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, (4) any so called “secondary considerations” of non-obviousness, which include long-felt but unsolved needs for the claimed invention, commercial success attributable to the claimed invention, industry acceptance, praise, unexpected results of the claimed invention, skepticism of others, failure by others to achieve the claimed invention, and “copying” of the claimed invention by others, and (5) any other objective evidence of non-obviousness.

43. I understand that a claim of obviousness may be based on a single prior art reference or multiple prior art references, taken in combination, but that a patent claim comprised of several elements is not proved obvious merely by demonstrating that each of its elements was known in the prior art. 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 achieves the claimed invention. This showing may come from a teaching, suggestion, or motivation to combine in the prior art, or may come from the reference(s) themselves, the knowledge of a POSITA (including inferences and creative steps a POSITA would employ), 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 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 and impermissible, however, to rely on hindsight in making an obviousness determination. I understand that even when there is a motivation to modify or combine the prior art to achieve the claimed invention, a POSITA would also need a reasonable expectation of success in making the proposed modification or combination for the claimed invention to be obvious.

44. I understand that a claimed invention is not obvious when the prior art discourages or teaches away from the claimed invention. Further, I understand that “teaching away” does not require that the prior art foresaw the specific invention claimed in the patent and warned against taking that path; rather, the prior art design itself may teach away from the claimed invention.

45. I understand that in an obviousness analysis, only analogous art may be considered. Art is considered analogous if it is from the same field of endeavor as the patent. If it is not from the same field of endeavor, it may be considered analogous if it is reasonably pertinent to the

particular problem with which the patent is involved. A reference is reasonably pertinent if, though in a different field, it would have commended itself to an inventor's attention in considering the problem.

VII. FIELD OF THE INVENTION

A. Inventions Necessarily Rely on Existing Technologies

46. No new technology can exist in a vacuum wholly disconnected from the past. Whether built using metal, wood, plastic or pixels on a computer screen, all innovations must – to some extent – be made from a combination of known components. Pixels are building block materials used to construct software interfaces just like plastic is a building block material used to construct hardware controls.

47. There are myriad user interface visualization and interaction techniques known to be employable when creating new user experiences. The existence of these techniques, a.k.a. technologies, is akin to the existence of raw physical building materials. Just like building a house, certain technologies lend themselves to certain types of use. Similarly, certain technologies draw designers of software systems into using them in particular combinations. Simply knowing that various technologies exist that can be used for a variety of purposes is not enough to motivate, inspire or enable someone to combine such techniques in new ways. Nonetheless, I believe it important to establish that human-computer perception and/or human-computer interaction innovations should not be treated differently from innovations based on physical technologies not built using software toolkits. The field of innovations in the human-computer interaction space is one in which significant patentable advances can be, and have been, made. It is, indeed, the field to which I have devoted my career as an inventor.

B. The Science of Human-Computer Interaction

48. Understanding the inventiveness of the '154 Patent depends upon understanding the field of the invention – which is the science of human-computer interaction (“**HCI**”), also known as user experience (“**UX**”) design – as applied in contexts such as a portable computer that is configurable between a plurality of display modes including a laptop mode ... and an easel mode ('154 Patent, Abstract).

49. The discipline of user experience grew out of ergonomics and what was once called man-machine interface (“**MMI**”). It is generally concerned with how to make machines reliably

responsive to human expression while being easy to use and unobtrusive. The user interface (“UI”) or graphical user interface (“GUI”) is the boundary or bridge between a person and a machine. It includes the physical hardware and logical software, capturing concrete measurable human input and outputting processed information for human perception. To be clear, just as HCI is concerned with the science of interaction between humans and computers, the inventions of the ’154 Patent is concerned with functional hardware and software technologies for accomplishing speed in human interactions, accuracy of human interactions, and a minimum of human error in such interactions.

50. By the time of invention of the ’154 Patent, many corporations had established a track record of investing into user experience research and design to craft and improve the engineering of their own products and the industry’s technical competency. Among such companies are, Apple, IBM, Microsoft, Sony, AT&T, HP, and Intel. By the time of invention of the ’154 Patent, there were likewise many leading non-profit institutions and agencies with notable programs in one or more UX disciplines, including Stanford, M.I.T., Carnegie Mellon, UCSD, SFSU, and the National Science Foundation.

51. The user experience success metrics used today are the same as they were at the time of invention of the ’154 Patent. Great user experiences may come across to end-users as simple and easy to use, quick and efficient, seamless and effortless – but these are often the most difficult to formulate and the most requiring of inventive skill and insight.

52. To accomplish excellent results depends on the science of user experience design. There are three general domains of design involved in crafting user experiences: information design, interaction design, and interface design. Information design is about the specific techniques for organizing content. Interaction design is about what people functionally do with their bodies and their hands, such as hovering over a cell and clicking a mouse button. And interface design proper is about the sensory aspects of the experience: How are things technically changing on screen? How do people know what they can do? How do they know what they are doing and what they just did? The science of user experience design is at the core of the ’154 Patent as the claimed inventions involve the intersection of interaction and interface design, incorporating hardware and software to optimize the user experience.

C. The '154 Patent is Concerned with Solving Technical Problems.

53. The claimed inventions solve technical problems of speed, precision, and usability with prior portable devices and GUI tools. These are classic technical problems. The problems of speed, accuracy, and usability and their solutions are necessarily rooted in computer technology and the operation of prior art GUIs.

54. Reducing task time is a technical challenge well established in the field of user interface and interaction design. It is also a well-established technical problem in the field of physical devices and man-machine interfaces.

55. Also, increasing task accuracy is a technical challenge core to the field of user interface and interaction design – in both hardware and software realms. As in the physical world, motivations to solve such technical challenges generally do not yield obvious solutions, and even the most intellectually logical solutions do not necessarily correlate with the most intuitive or efficacious solutions. For that reason, the science of user experience depends heavily on usability research and real-world validation testing to ascertain technical efficacy and to direct designers back to the drawing board to craft better-performing and frequently novel and non-obvious solutions.

56. It is my understanding that there is considerable evidence that the claimed combination was successful in the marketplace, copied by others, and received praise from many participants in the industry. This is evidence of careful, nuanced, technical design that created an improvement over prior GUIs.

57. Changing the makeup of known GUI elements (structures) on a computer screen often results in a dramatic change in the functionality of the GUI. And because the makeup of any set of user interface structures – whether involving numerical display regions, lists, cells, graphical buttons, or other elements – establishes the specific technical capabilities of that user interface, this cannot, by definition, avoid being deemed technology.

58. The claimed inventions thus improve the functioning of a computer because they provide new structure, makeup, and functionality that does not exist absent the claimed specialized GUI. By “**structure**,” I mean the individual hardware and software components of the invention, whether interactive elements or pure data display elements. By “**makeup**,” I mean the specific ordering and layout configuration of the various structures of the device and the GUI on screen. By “**functionality**,” I mean the ways in which the structures and the makeup of the structures: (i)

restrict and/or enable data to flow in and out of the system and (ii) restrict and/or enable a user to (a) perceive information presented by the device and (b) take action in relation to the system and its displayed information and interactive structures.

59. A POSITA would know that the '154 Patent clearly and unambiguously set forth technical usability challenges which a POSITA would be motivated to attempt to solve by using a specifically constructed UX using a combination of hardware and software user interface techniques not known to be employed prior to the time of the invention.

VIII. SUMMARY OF THE '154 PATENT

60. The '154 Patent relates generally to portable computers that are configurable into different functional and positional modes and solves the problem of requiring additional hardware, such as an arm assembly, to permit configuration into different modes. '154 Patent, 1:39-41, 2:26-30. In addition, the '154 Patent improves the user experience through its capability and flexibility, offering different functionality in the different physical configurations. '154 Patent, 2:30-34.

61. Before the LiTL Webbook commercialized an embodiment of the '154 Patent, home computers were essentially the same as office computers. LiTL worked for years to develop its Webbook, recruited leading user experience design ("UXD") experts and worked closely with some of the world's leading technology and UXD consultancies. The '154 Patent's inventions were groundbreaking in 2008 and have become industry standards that are ubiquitous today. I understand that the commercial embodiment of the inventions earned substantial contemporaneous praise. See, e.g., *The Litl webbook | Computer test and reviews - European Consumers Choice - Product Reviews and Tests* (<https://www.europeanconsumerschoice.org/hi-tech/litl-webbook-computer-test-and-reviews/> last accessed October 26, 2022); *Litl Webbook Beats ChromeOS, Becomes First Cloud Computer – Cool Things – November 16, 2009* (<https://www.coolthings.com/litl-webbook-beats-chromeos-becomes-first-cloud-computer/> last accessed October 26, 2022); *Noe, The Litl Webbook: A more social computing device – Core77 – November 5, 2009* (<https://www.core77.com/posts/15122/The-Litl-Webbook-A-more-social-computing-device/> last accessed October 26, 2022); *litl Webbook Review – August 31, 2010* (<https://littletechgirl.com/2010/08/31/litl-webbook-review/> last accessed October 26, 2022). These inventions were anything but ubiquitous at the time of invention of the '154 Patent.

A. “Display Modes” Are Particular Physical Configurations of the Portable Computer

62. The '154 Patent describes, and all claims require, a “portable computer configurable between a plurality of display modes.” '154 Patent, Claims 1, 11, 20. The '154 Patent’s different display modes correspond to different physical configurations of the computer. The '154 Patent discloses several different display modes, including “a closed mode, a laptop mode, an easel mode, a flat mode and a frame mode” (*id.*, 2:45-47). Some of these are illustrated in the figures reproduced below. The “portable computer has a conventional laptop appearance” in the “laptop mode,” whereas in the “easel mode” the “base of the computer and its display component stand upright forming an inverted ‘V.’” *Id.*, 2:16-21. The physical configuration of the computer is different in the different display modes as illustrated in the figures below.

Closed Mode

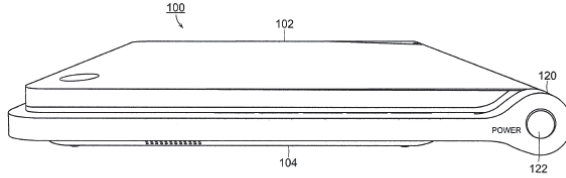


FIG. 2

Laptop Mode

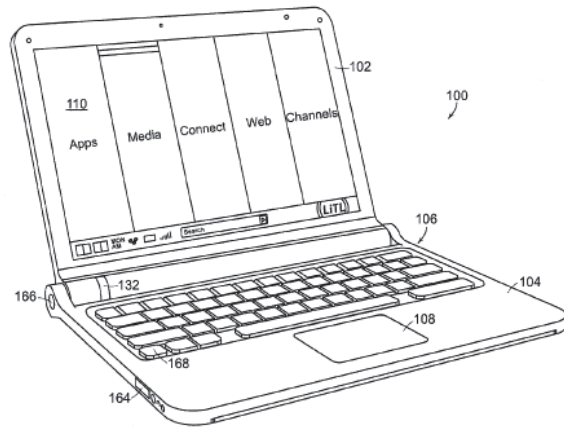


FIG. 17

Easel Mode

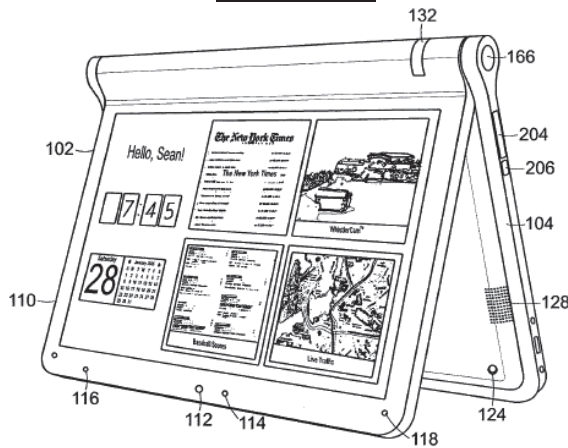


FIG. 4

Frame Mode

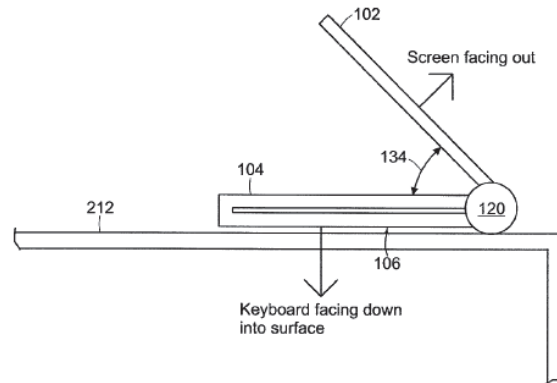


FIG. 26

Flat Mode

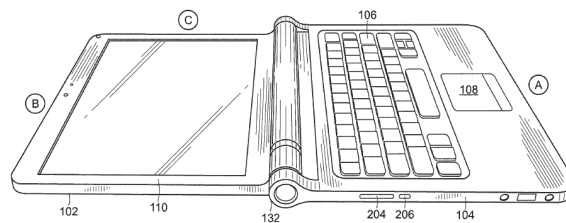


FIG. 27

63. Each claim requires either an “orientation sensor” or “accelerometer” “to generate orientation information indicative of an orientation of at least part of the portable computer.” Each claim also requires a “display manager configured to detect a current display mode from among the plurality of display modes based at least in part on the orientation information.” Different

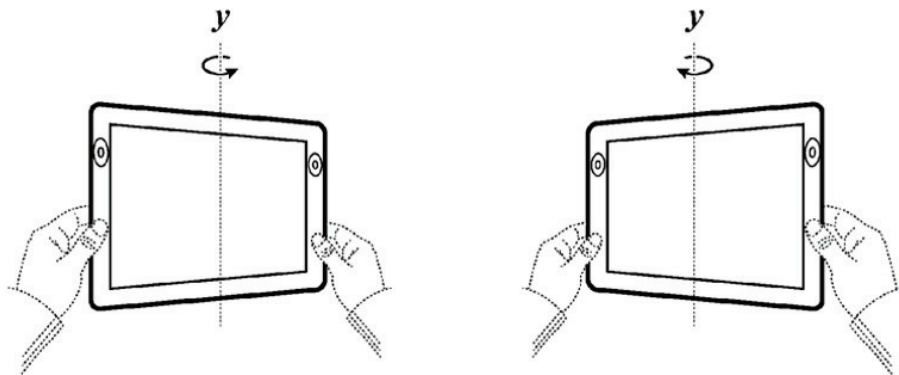
display formats and different functionality can be enabled in the different display modes because the embodiments of the '154 Patent (using electronic and/or mechanical sensors) can detect the current display mode.

B. The Term “Orientation” Appears in the Claims in Different Contexts and Means Different Things in Those Contexts

64. The term “orientation” is used in different contexts to mean different things. To make sure we’re comparing apples to apples, it is important to be clear on these distinctions.

1. Orientation as Heading

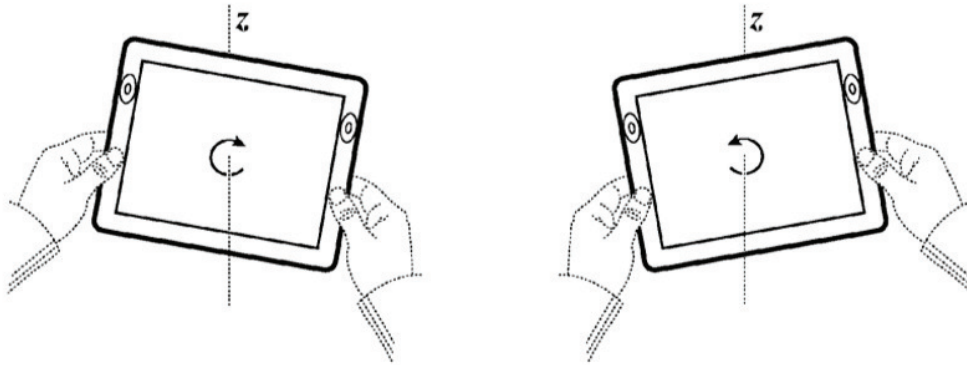
65. One ordinary use of the term, “orientation,” refers to the heading of an object, as in the direction a ship may be moving on a body of water. One dictionary defines it as: “Position, or the determining of position, with relation to the points of the compass.” **Appendix B**, *Funk & Wagnalls New Int’l Dict. Of the English Language*, 2000. Below are figures I drafted illustrating rotation of a device around its y-axis (*y*).



66. Magnetometers may be used by computing devices to determine such heading, but this is *not* a use of the term relevant to the '154 Patent.

2. “Display Content in a First Orientation [and] ... in a Second Orientation”

67. A second use of the term, “orientation,” refers to the rotation of a computing device around its own z-axis, like the left/right rotation of a steering wheel around the axis of its steering column. For tablet computing devices, it is helpful to detect this type of orientation in order to ensure that content is displayed properly (e.g. portrait or landscape; and right-side up). Below are figures I drafted illustrating rotation of a device around its z-axis (*z*).



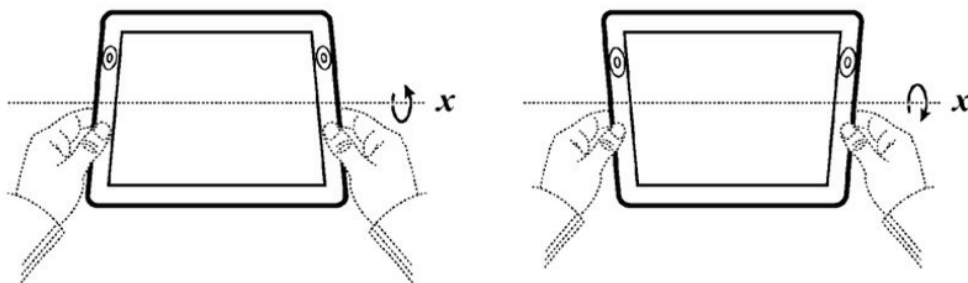
68. Accelerometers may be used by computing devices to detect which way is up, so the device can, as the '154 Patent describes, switch “the display between portrait or landscape mode.” (9:16-20).

69. Some of the claims (e.g., claims 3, 11 and 20) recite displaying content in different orientations when the computer is in different display modes.

3. “Orientation Information Indicative of an Orientation of at Least Part of the Portable Computer”

70. In the '154 Patent, we find a third use of the term, “orientation,” in the form of “orientation information” that is generated by an orientation sensor or accelerometer is indicative of the orientation of “at least part of the portable computer” and is used to detect the current display mode of the device (e.g. closed mode, easel mode, frame mode, flat mode or laptop mode).

71. Now, in order to successfully detect a current display mode, the device needs to know about rotation of two components of the device (i.e. its display component and base/keyboard component) around their respective x-axes. Below are figures I drafted illustrating rotation of a device around its x-axis (x).



72. The '154 Patent describes using this orientation information to determine the relative positioning or relationship between two parts (the base and the display) of the portable

computer. The device is capable of determining the rotation of each component around its own x-axis as a relationship with gravity. A POSITA would know that subtracting one component's reported angle from the other component's reported angle would result in a delta angle. This delta indicates, for example, the relative angle or angular distance between the posture of the display and the posture of the base, as described in more detail below.

4. Relationship Between the Two Types of Orientation

73. As described below, the “display manager” can determine some display modes solely by calculating the delta angle between the base and display parts of the computer. Other display mode distinctions (such as distinguishing between easel and frame mode) require the “display manager” to use both the delta angle between the base and display parts of the computer AND the orientation of at least one of the parts (display or base) in relation to the ground plane of the Earth (i.e. gravity). Not only will that allow the “display manager” to determine in which display mode the device is physically postured, but also to display content right side up. See '154 Patent, 9:9-20.

C. Detecting the Display Mode Allows Different Display Formats and Different Functionality To Be Enabled in Different Display Modes

74. The '154 Patent discloses a “portable computer is capable of different display formats and functionality in the different modes.” '154 Patent, 6:16-21; *see also, id.*, 14:51-15:8, 2:30-34, 1:39-41, 17:44-48. The specification provides several examples of different display formats and different functionality associated with different display modes, including:

- Enlarging content for more comfortable viewing in some display modes such as easel mode. *Id.*, 14:61-67.
- Functioning as a digital photo frame in some display modes if the device determines it is not being actively used. *Id.*, 15:1-17.
- Disabling the keyboard in certain display modes to avoid inadvertent keystrokes. *Id.*, 8:44-49; 16:50-17:8.
- Rotating content so that it is displayed right-side up. *Id.*, 14:55-60.

75. All claims require detecting the display mode as a distinct requirement from providing a particular format or functionality associated with the detected display mode.

D. Display Modes Are Detected by Detecting the Configuration of the Portable Computer

76. The '154 Patent discloses that the portable computer “detects a current display mode of the portable computer” by using electronic and mechanical sensors that detect the portable computer’s current display mode by detecting the computer’s physical configuration. '154 Patent, 3:4-8; *see also id.* at 8:54-9:34, 10:4-20. For example, accelerometers can be used to “detect a configuration of the portable computer 100 (e.g., laptop mode or easel mode).” *Id.*, 9:6-13; *see also id.*, 8:64-67.

77. In one example, an orientation sensor “may be used to detect, either approximately or precisely, the angle 134 and to provide the information to the computer operating system.” *Id.*, 9:30-34. Figure 5 depicts angle 134 as the angle between the display and base, shown below.

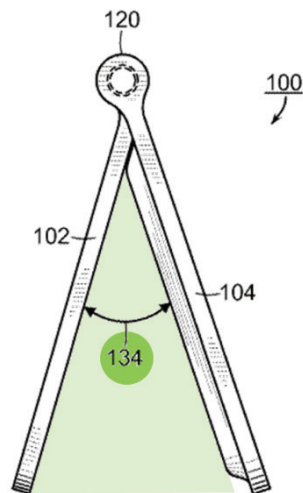


FIG. 5

78. The '154 Patent explains that “[a]ccelerometers have been used in portable devices such as cellular phones, media players or computers, as sudden motion sensors By contrast, however, the accelerometer in the portable computer according to an embodiment of the invention is not used to detect motion of the overall computer, but rather to detect a configuration of the portable computer 100.” *Id.*, 9:6-13.

79. Near the end of the specification, the '154 Patent explains:

[A]lthough the above discussion refers primarily to the portable computer 100 being in either the laptop mode or easel mode, other modes or configurations are also possible. For example, as discussed above, because the portable computer 100 can be configured from the closed position, through the laptop mode into the easel mode by rotating the display component 102, a number of configurations are

possible in between “true” laptop mode and “true” easel mode. In another example, the portable computer 100 may be configured into a “frame” mode, as illustrated in FIG. 26, in which the portable computer is placed on a surface 212 with the keyboard 106 “face down” on the surface 212 and the display 110 facing upward. In the frame mode, the display component 102 may be at a similar orientation, and angle 134, with respect to the base component 104 as in the easel mode. However, rather than the base component 104 and display component 102 being oriented vertically with respect to the surface 212, as in the easel mode (in which the portable computer forms an inverted “V” as discussed above), in the frame mode, the base component 104 may lie flat on the surface 212, as shown in FIG. 26. In one example, software and/or hardware protection may be provided for the keyboard to prevent keys from being pressed (or to prevent the portable computer from responding to pressed keys) when the portable computer is in the frame mode.

Id., 16:50-17:8.

80. An angle between two objects can be calculated using an accelerometer incorporated into each object. First, an accelerometer mounted to an object is used to determine the angle of the object with respect to the surface of the Earth (i.e., gravity).¹ A second accelerometer mounted to a second object is likewise used to determine the angle of the second object with respect to the surface of the Earth (i.e., gravity). Second, the two angles can be used to calculate the relative angle between the two objects. The ’154 Patent describes using an accelerometer “to detect a configuration of the portable computer 100 (e.g., laptop mode or easel mode), particularly, to detect an orientation of the display component 102 relative to the base component 104.” ’154 Patent, 9:10-16.

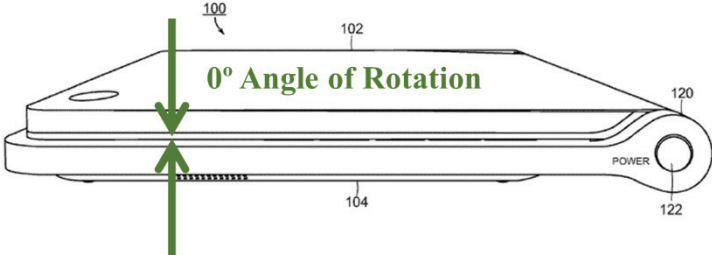
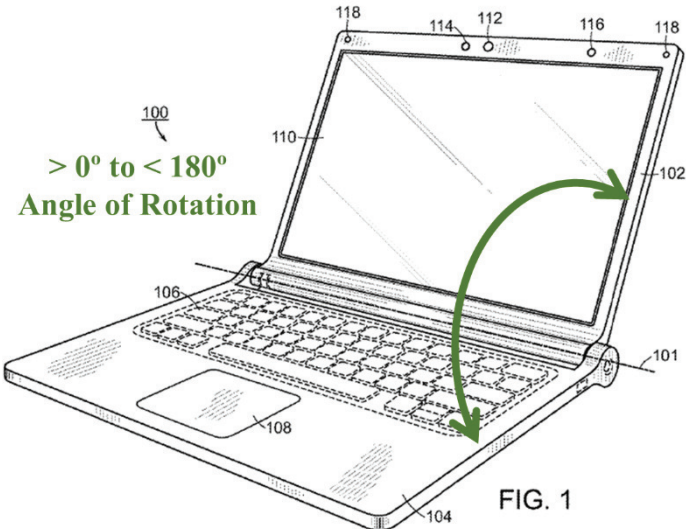
81. The ’154 Patent also describes other “electronic or mechanical components, or a combination thereof. For example, a hinge assembly may be provide[d] with detents that provide an indication of the mode of the portable computer,” and can thus be used to detect the display mode of the portable computer. *Id.*, 10:16-20. Detents are physical depressions or protrusions or magnetic markers that indicate when a certain degree of rotation has been reached.

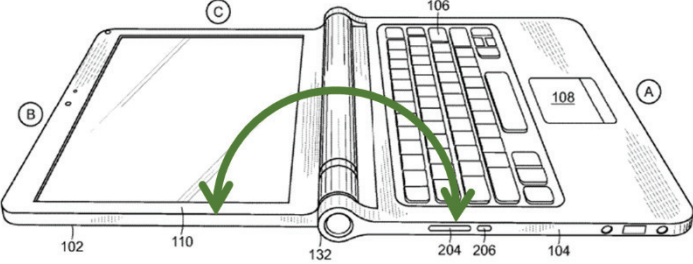
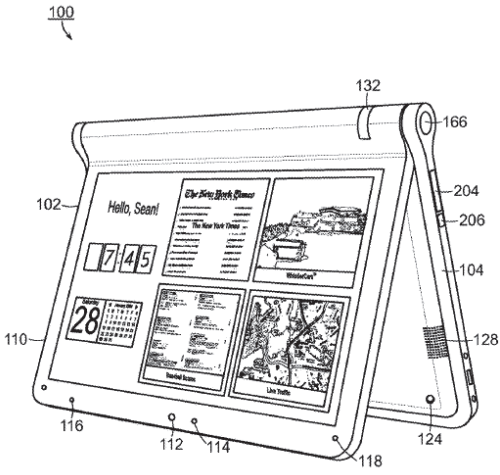
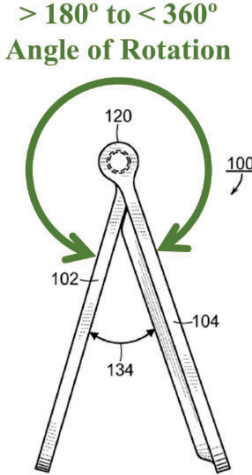
82. The ’154 Patent explains that these sensor components may be located in the display, the base, and/or the hinge to determine the display mode of the portable computer. *Id.*, 8:58-62, 10:10-20. A POSITA would have understood the ’154 Patent to disclose placing sensor components in the display, the base, the hinge, or any combination of these locations. While some

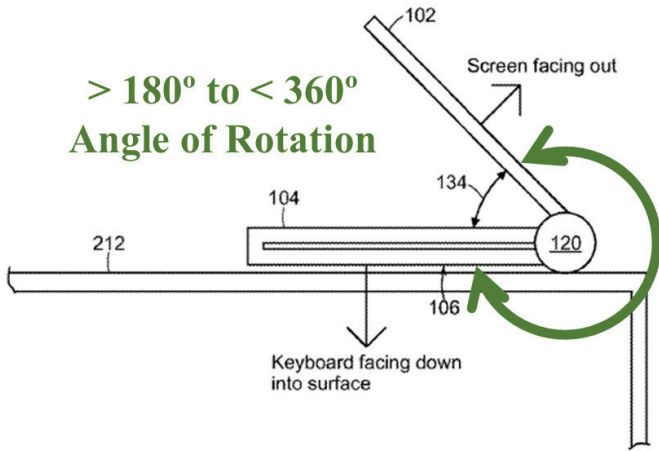
¹ See, e.g., “Tilt sensing using a three-axis accelerometer.” *Freescale semiconductor application note* (2007-2013) describing how to calculate tilt angle using an accelerometer and how to select between portrait and landscape screen orientations; attached herein as **Appendix C**.

of these embodiments refer to “an orientation sensor” in the singular (10:4-7), the ’154 Patent teaches that “elements ... referred to in the singular may also embrace embodiments including a plurality of these elements” (6:45-48).

83. The five display modes described in the patent (i.e., “a closed mode, a laptop mode, an easel mode, a flat mode and a frame mode” (2:45-47)) can be detected by using sensors such as accelerometers to “detect, either approximately, or precisely, the angle [between the display and base] and to provide the information to the computer operating system” (9:30-34).

Mode	Citation
Closed Mode (0° Angle of Rotation)  FIG. 2	Fig. 2, 5:4-5 (“FIG. 2 is a view of the portable computer of FIG. 1 in the closed position.”), 2:53-58 (“In the closed mode, the display screen may be disposed substantially against the base.”).
Laptop Mode (> 0° to < 180° Angle of Rotation)  FIG. 1	Fig. 1, 5:1-3 (“FIG. 1 is an illustration of one example of a portable computer, according to aspects of the invention, in a ‘laptop’ configuration.”), 2:53-58 (“rotating the display component about the longitudinal axis up to approximately 180 degrees from the closed mode may configure the portable computer into the laptop mode.”).

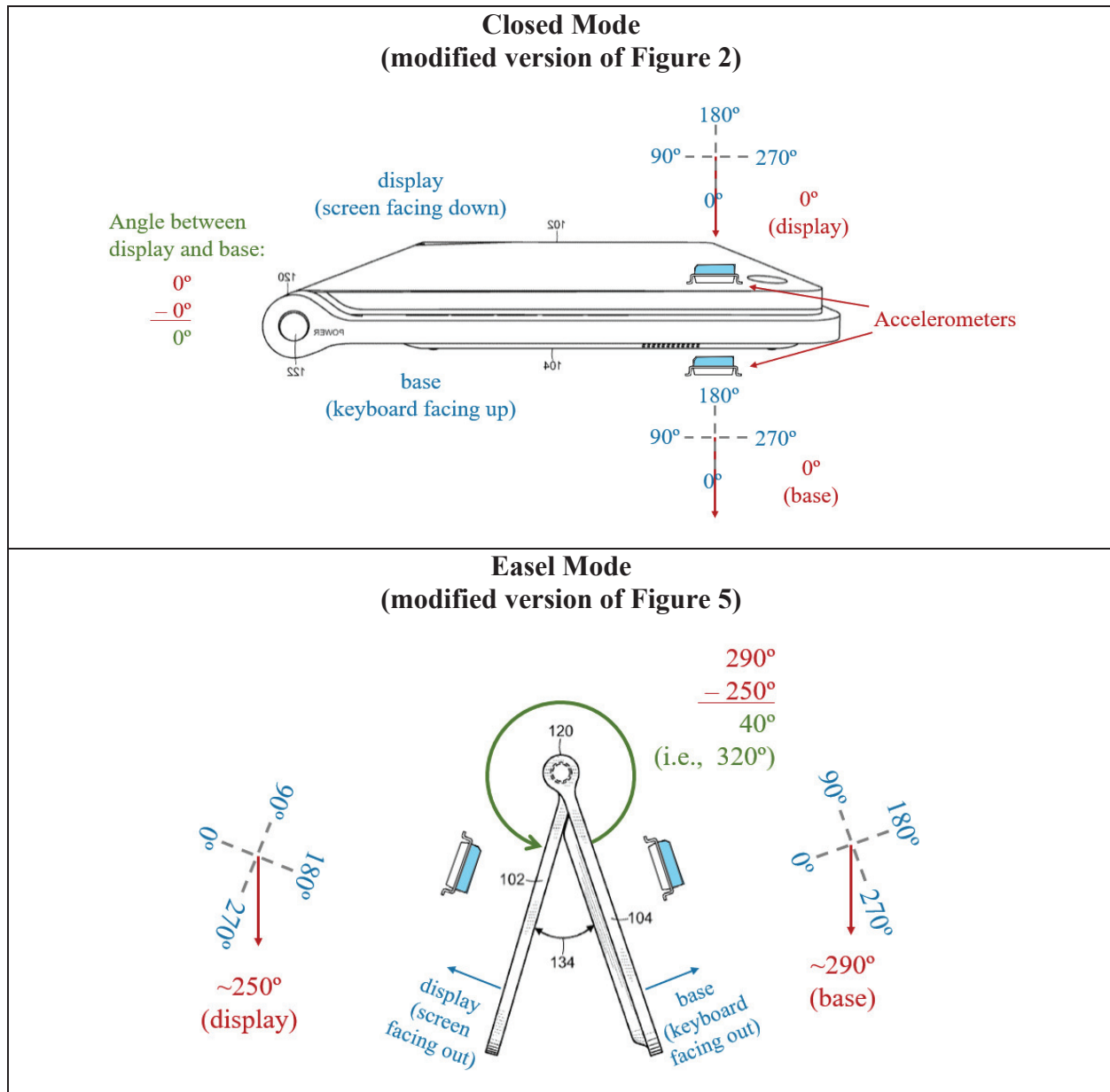
Mode	Citation
Flat Mode (180° Angle of Rotation)  180° Angle of Rotation FIG. 27	Fig. 27, 6:4-6 (“FIG. 27 is an illustration of the portable computer configured into a ‘flat’ mode, according to aspects of the invention.”), 17:11-16 (“In the flat mode, the display component 102 may be rotated (or opened) to approximately 180 degrees with respect to the base component 104, such that the base component and display component lay flat on a surface, with the keyboard 106 and display screen 110 exposed, as shown in FIG. 27.”).
Easel Mode (> 180° to < 360° Angle of Rotation)  FIG. 4 > 180° to < 360° Angle of Rotation  FIG. 5	Figs. 4 and 5, 5:8-12 (“FIG. 4 is a perspective view of the portable computer of FIG. 1 in the easel mode. FIG. 5 is a side view of the portable computer of FIG. 4.”), 2:19-21 (“an easel mode in which the base of the computer and its display component stand upright forming an inverted ‘V.’”), 6:14-16 (same), 8:18-31 (“To convert the portable computer 100 ... into the easel mode, the display component 102 may be folded away from the base 104, ... such that the base 104 and the display component 102 form an inverted “V” shape ..., as illustrated in FIG. 4.”).

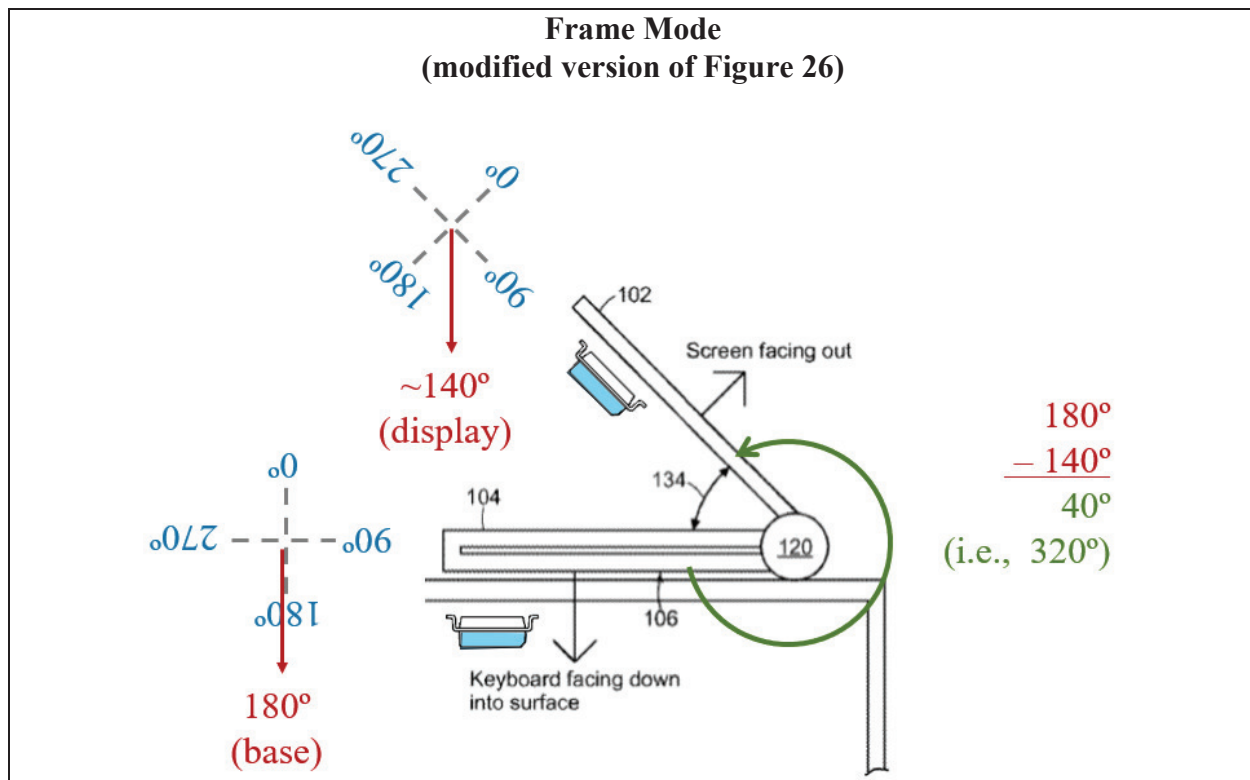
Mode	Citation
Frame Mode ($> 180^\circ$ to $< 360^\circ$ Angle of Rotation)  $> 180^\circ$ to $< 360^\circ$ Angle of Rotation FIG. 26	Fig. 26, 6:1-3 (“FIG. 26 is an illustration of the portable computer configured into a “frame” mode, according to aspects of the invention.”), 16:63-17:4 (“In the frame mode, the display component 102 may be at a similar orientation, and angle 134, with respect to the base component 104 as in the easel mode. However, ..., in the frame mode, the base component 104 may lie flat on the surface 212, as shown in FIG. 26.”).

84. The '154 Patent explains that in easel and frame modes “the display component 102 may be at a similar orientation, and angle 134, with respect to the base component 104.” 16:63-66. In 2008, a POSITA would have understood that the '154 Patent teaches placing sensors in both the base and the display to distinguish between frame mode (depicted in Figure 26) and easel mode (depicted in Figure 5), to properly orient the content on the screen for that display mode, and to disable the keyboard.

85. The '154 Patent does not depict orientation sensors in any of the figures. In the images below, I have modified Figure 2 (closed mode), Figure 5 (easel mode), and Figure 26 (frame mode) to illustrate how two accelerometers – one in the display and one in the base – could be used to determine the angle between the display 102 and the base 104. In 2008, a POSITA would have understood that the angle between the display and base could have been calculated by first determining the angle of each component with respect to the Earth’s surface (depicted in red font), and then calculating the difference between the two angles (depicted in green font), as shown below. When calculating angles between the display and the base that exceed 180° (i.e., for the easel and frame modes), I have expressed the angle in terms of the degrees of rotation of the display about the base. This outside angles shown below in modified Figures 5 and 26 are calculated by subtracting the 40° inside “angle 134” from 360° to arrive at the equivalent outside angle of 320°

in each. To help visualize how the display is rotated into the easel and frame modes, I flipped Figure 2 horizontally (which makes the original figure's numbers appear backwards).



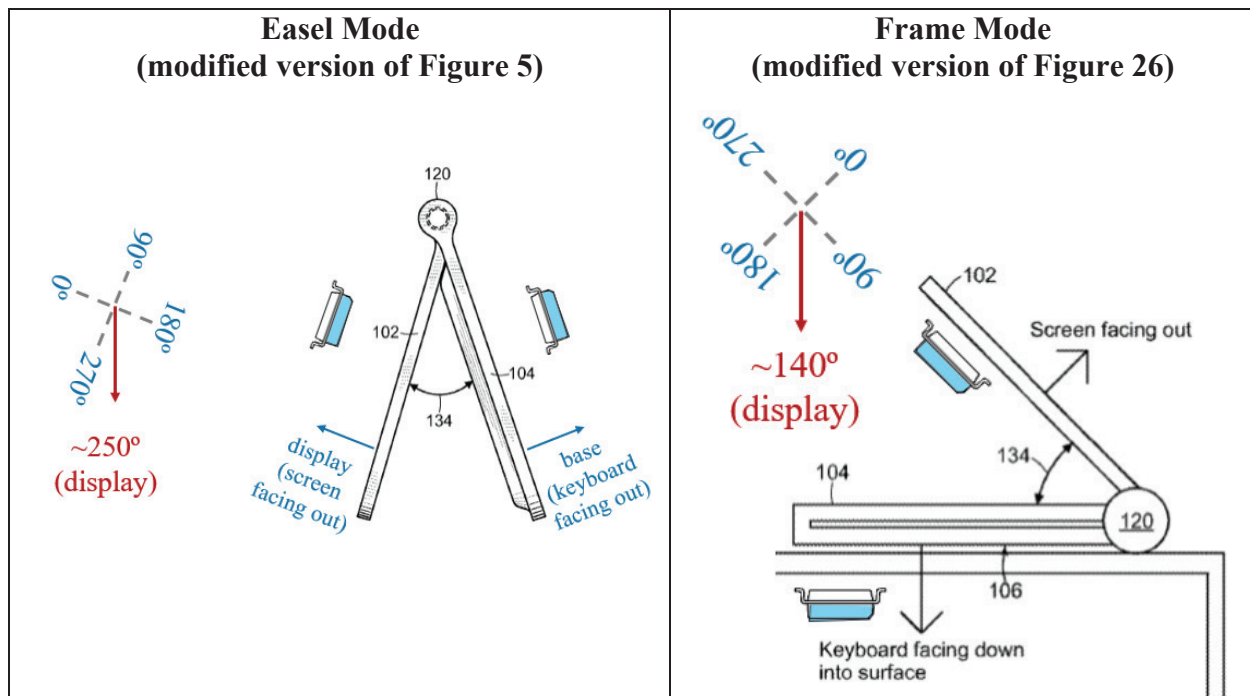


86. The accelerometers in the display and base can “detect, either approximately, or precisely, the angle [between the display and base] and to provide the information to the computer operating system.” ’154 Patent, 9:30-34. If the detected angle is greater than 180° and less than 360° the possible display modes are either easel mode or frame mode. *Id.*, 8:18-31; 16:63-17:4.

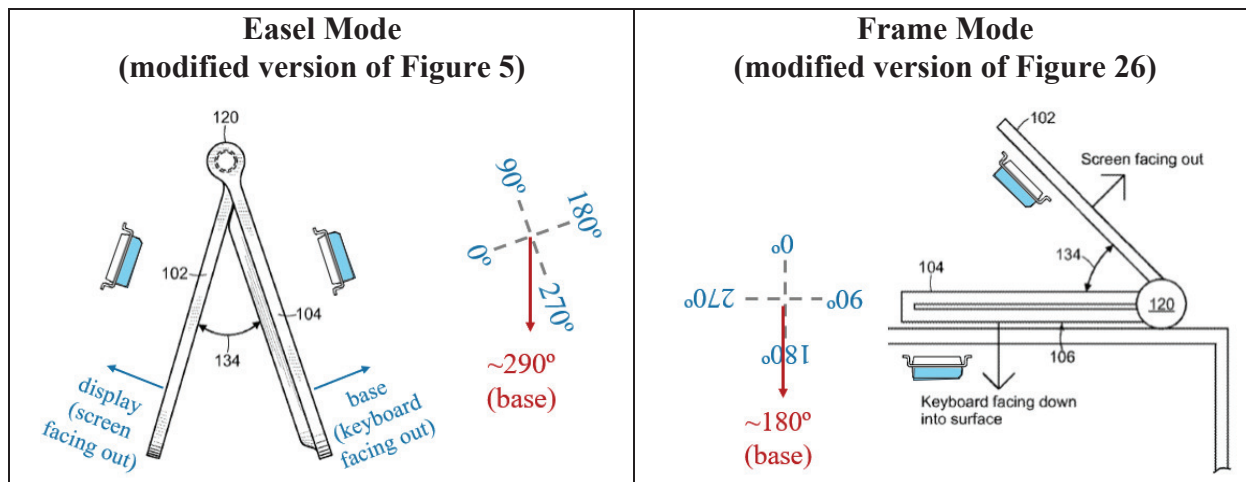
87. The display-to-base angle, on its own, is insufficient to distinguish between easel mode and frame mode because the delta angle can be exactly the same for these two modes, as illustrated above (e.g. both having a 320° spread between display and keyboard) and as described in the ’154 Patent. *Id.*, 16:63-17:4 (“In the frame mode, the display component 102 may be at a similar orientation, and angle 134, with respect to the base component 104 as in the easel mode. However, ..., in the frame mode, the base component 104 may lie flat on the surface 212, as shown in FIG. 26.”).

88. Accelerometers, however, provide information that can be used to distinguish easel and frame modes. The orientation of the base (104) and of the display (102) relative to the Earth’s surface are different between easel and frame modes. In easel mode, the display edge that is adjacent to the rounded portion 120 that houses the hinge is “up” and the opposite edge is “down.” By contrast, in frame mode, the display edge that is adjacent to the rounded portion 120 that houses

the hinge is “down” and the opposite edge is “up.” In the example depicted below, the display (102) is oriented about 250° with respect to the Earth’s surface in easel mode but is oriented about 140° to the Earth’s surface in frame mode. ’154 Patent, 16:63-17:4.



89. Information from an accelerometer mounted on the base (104) can also be used to distinguish between frame and easel modes. As between frame and easel mode, there is a difference in the orientation of the base (104) relative to a surface (212) upon which the computer rests. *Id.*, 16:50-17:8 (in easel mode the “the base component 104 and display component [are] oriented vertically with respect to the surface 212 ... [I]n the frame mode, the base component 104 may lie flat on the surface 212, as shown in Fig. 26.”). In the example depicted below, the base 104 is oriented about 290° with respect to the Earth’s surface in easel mode but is oriented 180° to the Earth’s surface in frame mode. *Id.*, 16:50-17:8; *see also id.* at 3:34-44, 2:62-3:13.



IX. OVERVIEW OF PRIOR ART LANE

90. Lane is a publication of a PCT international patent application entitled “Modular, Reconfigurable Devices.” Lane discloses “[a] modular, reconfigurable system designed to permit coupling and decoupling of devices or components (14, 18) of varying types, including portable computers or other electrical devices ... The system also is adapted to rotate about two adjacent parallel axes (58, 62) permitting components to be positioned throughout approximately 0-360 degrees.” Lane, Abstract.

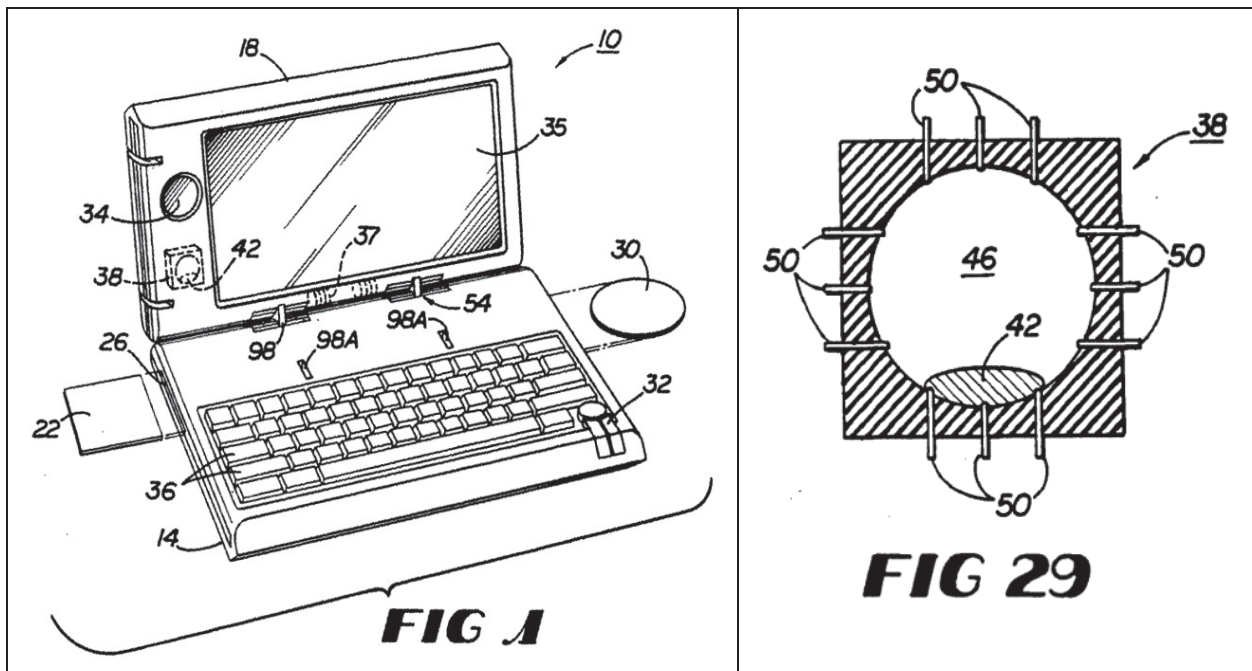
91. Lane describes “rapid improvements to components of an overall device have contributed to consumers desiring periodically to upgrade their systems merely by purchasing the improved components.” *Id.*, 1:21-24. Lane states that “the invention permits a user to ‘mix and match’ electronic or other devices and components as needed.” *Id.*, 3:1-4.

92. Lane explains that consumers desire “reconfigurable components to meet the requirements of the varied locations and situations in which the components operate” and contends that “existing electronic systems have components which can neither be decoupled nor reconfigured ... and thus fail to address these and other consumer needs.” *Id.*, 1:25-31. According to Lane, “the present invention permits components to be repositioned about each other throughout approximately 0-360°, allowing use of a visual display not only in a standard laptop computer format but also in formats facilitating use of the display as, for example, a television or telecommunications monitor or a pen-based computing tablet.” *Id.*, 3:5-14.

93. Lane includes 29 figures that emphasize the reconfigurable and modular nature of the electronic device.

- Figures 1 and 2 depict “an exemplary modular device” that includes “a first module 14 (e.g. a keyboard) and second module 18 (e.g. a display).” *Id.*, 5:2-6. Figures 3 and 4 detail a connector that connects first and second modules 14 and 18 of the exemplary device. *Id.*, 6:25-36.
- Figures 5-9 depict five configurations of the first and second modules rotated from 0° to 360°. *Id.*, 7:30-8:23.
- Figures 10, 12, and 13 depict a support 122 that either brace the second module or elevate the first module. *Id.*, 8:24-30.
- Figures 15-18 depict devices that include three modules connected in various ways. *Id.*, 9:13-10:5.
- Figures 19-28 depict various couplings of the first and second modules. *Id.*, 10:10-11:16.

94. The exemplary device depicted in Figure 1 includes as part of second module 18 (display) a “position-indicating mechanism 38” that is detailed in Figure 29.



95. Lane’s entire description of the position-indicating mechanism and its associated software is contained in the following passage:

Also shown in FIG. 1 (and FIG. 29) as part of second module 18 is position-indicating mechanism 38. Mechanism 38 includes a moveable conductor 42 (such

as liquid mercury) in a spherical cavity 46 having contacts 50 spaced about its periphery. Conductor 42 responds via gravitational forces to spatial reorientation of mechanism 38 by moving relative to contacts 50 (to contact at least one contact 50 to close its respective circuit). Including mechanism 38 as a component of *either* first or second modules 14 *or* 18 would thus permit it to indicate the spatial orientation of that module. Doing so would also allow mechanism 38 to assist device 10 (and its associated software) in determining, for example, whether the information to appear on visual display 35 should be in “**landscape**” or “**portrait**” position as the visual display 35 is spatially configured, the **direction in which to move a curser** of second module 18 when a visual display, **or whether to render keys 36 of first module 14 inoperable** when unused.

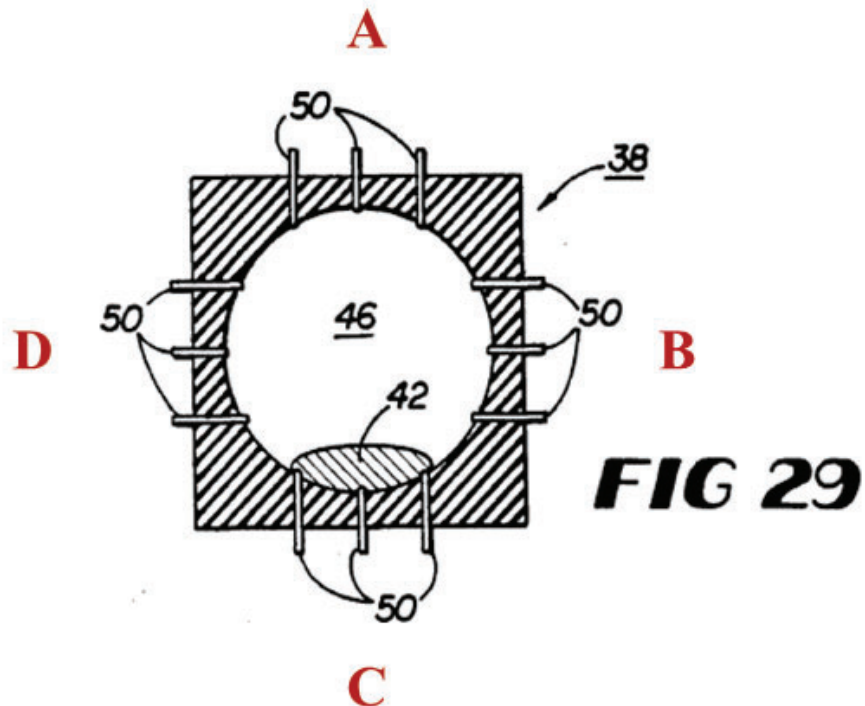
Id., 5:23-6:6 (emphasis added).

96. As indicated in the portions of Lane emphasized above, Lane discloses that the position-indicating mechanism can be included in “**either**” the first module 14 (with the keyboard) “**or**” the second module 18 (with the display), to assist the computer in determining three things:

- (1) whether displayed information should be in landscape or portrait orientation,
- (2) the direction the cursor should move, **or**
- (3) whether the keyboard should be inactivated.

Id., 5:35-6:6.

97. Mechanism 38 indicates the spatial orientation of the module to which it is mounted via a movable conductor 42 that moves relative to contacts 50 located around the periphery of a spherical cavity 46. *Id.*, 5:24-28. Figure 29 depicts four sets of contacts 50, which I have labeled A, B, C, and D below.

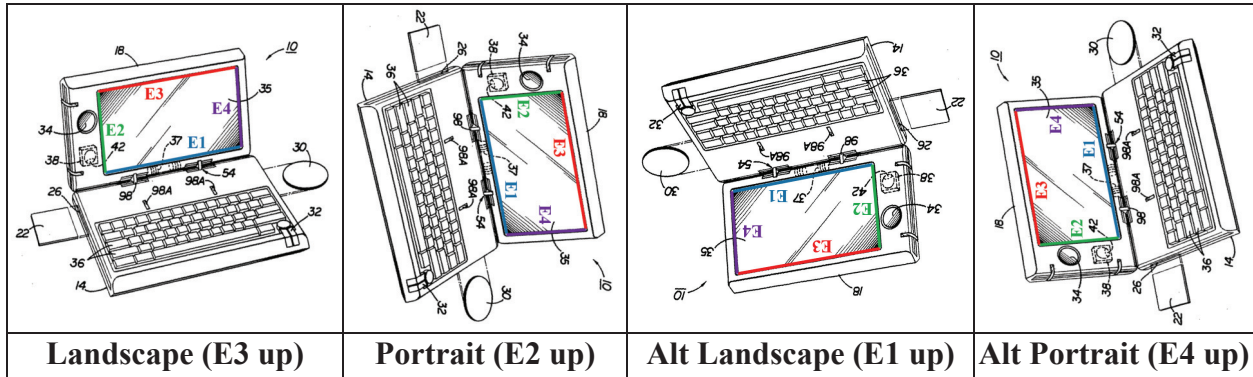


98. When movable conductor 42 comes into contact with the different contacts 50 it closes the respective circuit of each contact 50 (i.e., A, B, C, D above). *Id.*, 5:28-31. A POSITA would have understood that electrical signals from the various contacts 50 A, B, C, D (based on whether their circuit is closed by conductor 42 or not) provides an indication of the orientation of the computer's component. A POSITA would also have understood that Lane's mechanism 38 is illustrated in Figure 1 to be mounted parallel to the plane of the display component in order to be able to detect rotation around the display's z-axis, regardless of the orientation of the base component of the computer.

99. Mechanism 38 would therefore be understood by a POSITA to assist the device in performing the three determinations identified in Lane, 5:35-6:6.

100. First, output from mechanism 38 can be used to determine whether the information shown on visual display 35 should be in landscape or portrait orientation. *Id.*, 5:35-6:6. This determination involves detecting rotation about the display's "z-axis" that is perpendicular to the plane of visual display 35 (shaded light red below), as depicted with a red arrow in Figure 1 below.

101. Visual display 35 has four possible positions for which portrait and landscape positions can be determined. I have annotated the four edges (E1-E4) of visual display 35 to illustrate the four possible positions:



102. As conductor 42 of mechanism 38 contacts the contacts 50 around the periphery in response to rotation about the z-axis, mechanism 38 assists the device to determine which of the four possible portrait/landscape positions to display on visual display 35. Mechanism 38 assists in making the portrait/landscape determination by detecting which of the four edges is “up” (i.e., determining rotation about the z-axis of visual display 35). In making this determination, Lane never discloses mechanism 38 detecting in which of the 17 configurations depicted in Figures 5-9, 12, 13, and 19-28 the device is configured. Detecting the device configuration is simply not necessary to accomplish Lane’s goal of keeping the display’s content upright, and is unrelated to determining the device’s portrait or landscape position. In fact, all of Lane’s 17 configurations are in landscape orientation, and a POSITA would understand that the portrait/landscape rotation determination would not apply to transitions between any of those configurations; and that Lane’s 17 configurations are entirely unrelated to Lane’s use of information about rotations of the screen around its z-axis.

103. Second, mechanism 38 can determine which direction to move the cursor shown on visual display 35. When the cursor control device (5:10-14) is moved left, right, away from the user (up), and toward the user (down), the direction in which the cursor moves on the display depends on which edge of the display (i.e., E1-E4) is oriented up. Similar to the portrait/landscape determination, mechanism 38 can assist in making the cursor-direction determination by detecting which of the four edges is “up” (i.e., determining rotation about the z-axis of visual display 35). Again, Lane does not disclose mechanism 38 detecting the any of the 17 device configurations

when determining cursor-direction, and there would be no need to do so. Determining which of the four edges is “up” is sufficient. Again, all of Lane’s 17 configurations are in landscape orientation, and a POSITA would understand that the cursor rotation determination would not apply to transitions between any those configurations; and that Lane’s 17 configurations are entirely unrelated to Lane’s use of information about rotations of the screen around its z-axis.

104. Third, while Lane briefly mentions a motivation to “render keys 36 of first module 14 inoperable when unused,” (*Id.*, 6:5-6), Lane never discloses how mechanism 38 would assist in determining whether the keyboard is unused. A POSITA could guess at what Lane means by “unused,” but a POSITA would not *know* what Lane means. As an expert witness, I can only attest to what a POSITA would reasonably know to be true; and there is no basis here for any such analysis. Is a keyboard unused when it is rotated along with the screen into portrait mode? Perhaps. But, we just don’t know.

105. Lane illustrates 17 configurations of a portable computer, but never describes (i) any component or software as detecting the display mode of the portable computer nor (ii) doing anything as a result of detecting the display mode of the portable computer. In Lane’s discussion of mechanism 38, it is simply never used to detect which of the display modes Lane’s computer can be in – e.g., Lane’s laptop, easel, frame or tablet modes. Lane, Fig. 6 (laptop), Fig. 28 (easel mode), Fig. 25 (frame mode), Fig. 27 (tablet mode) – and a POSITA would not be motivated by any of Lane’s disclosures to use mechanism 38 to do so.

X. LANE DOES NOT DISCLOSE DETECTING A DISPLAY MODE

106. I understand that for each prior art combination in the Office Action (“OA”), the examiner concluded that the claimed requirement of a “display manager configured to detect a current display mode from among the plurality of display modes” is disclosed by Lane’s position-indicating mechanism 38 and Lane’s software. OA, 6, 15.

A. Lane’s disclosure that a portable computer can be placed into different physical configurations is not a disclosure of a display manager configured to detect the computer’s display mode.

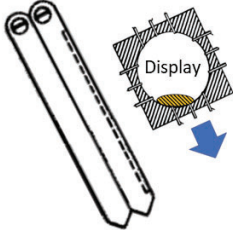
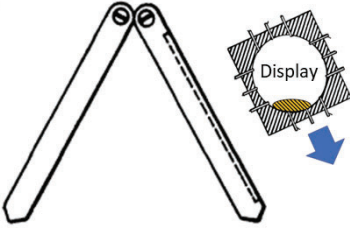
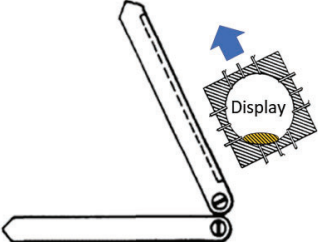
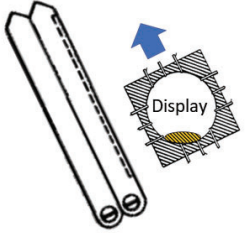
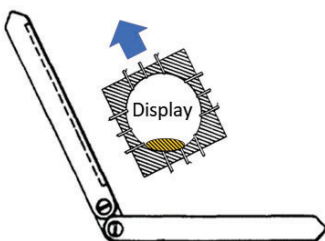
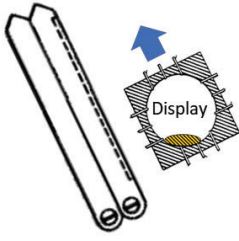
107. As I explained in Paragraphs 76-89 above, detecting a computer’s display mode requires (1) sensors that can collect the information necessary to differentiate between each of the

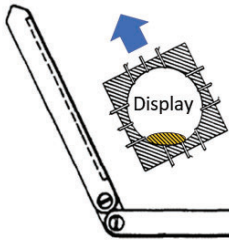
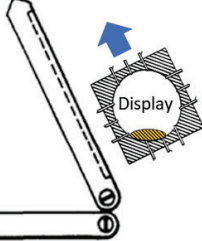
computer's display modes and (2) the ability to process the sensor information to make the display mode determination. Lane does not disclose either of these.

108. Although Lane's mechanism 38 can generate some information about the orientation of a component of the computer, such as the computer's display, mechanism 38 is not capable of generating the orientation information necessary to detect the computer's display mode. As will be described in detail below, mechanism 38 can only determine the spatial orientation of the component into which it is incorporated; but it cannot distinguish between display modes in which the spatial orientation of the display or the base can be the same in each of those modes. Accordingly, even if mechanism 38 were incorporated into the display, into the base, or into both of Lane's computer's base and display, the mechanism(s) 38 would *not* generate sufficient information necessary to detect a computer's display mode.

109. First, a POSITA would have understood that even if mechanism 38 were incorporated into the display, it would not be capable of generating the information necessary to distinguish between certain of Lane's display modes.

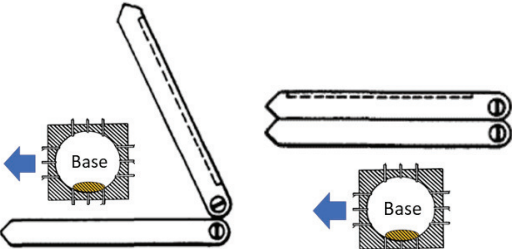
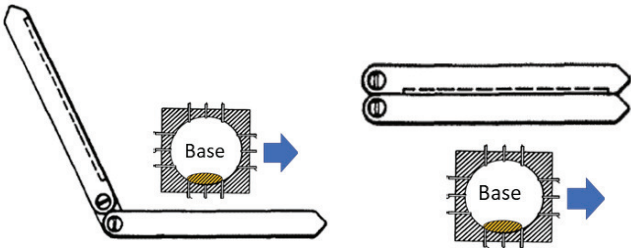
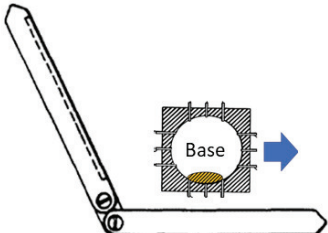
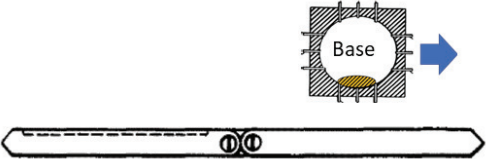
110. In the table below, I have modified Figures 20, 25, 27, and 28 by adding an annotated version of mechanism 38 along with a blue arrow, which indicates the edge of the display opposite the hinge. Note, however, that the mechanism 38 in my below hypothetical exploration is not mounted in a plane parallel to the display as taught by Lane in Figure 1; and would therefore no longer be capable of determining rotation of the display around its z-axis to handle either Lane's portrait/landscape corrections, for example, or Lane's cursor direction mapping. The display module 18 is oriented in the same direction in the four pairs of display modes depicted below: (1) tablet mode and easel mode, (2) frame mode and tablet mode, (3) laptop mode and tablet mode; or (4) laptop mode and frame mode. Lane's position-indicating mechanism 38 can be in precisely the same orientation when the computer is in each pair of display modes depicted below. As a result, the movable conductor 42 will close the circuit for the exact same group of contacts, and provide exactly the same output. Given that Lane's mechanism 38 can provide the same output for different display modes, mechanism 38 does not provide sufficient information that would allow Lane's computer to use mechanism 38 to detect the computer's display mode.

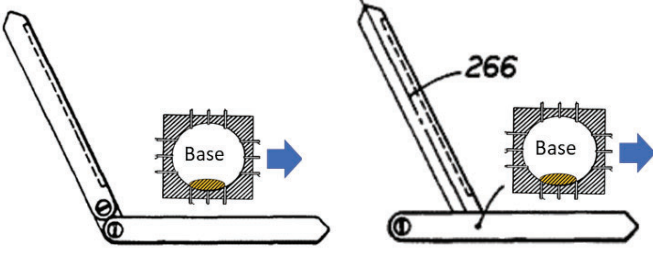
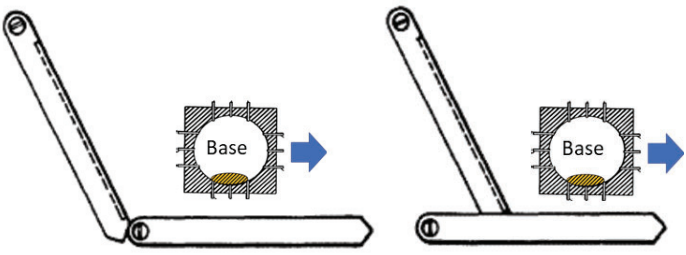
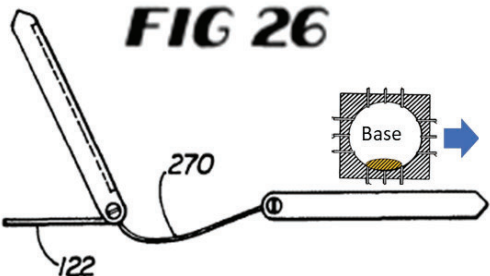
Row	Modes
1	FIG 27  FIG 28  Tablet mode and easel mode
2	FIG 25  FIG 27  Frame mode and tablet mode
3	FIG 20  FIG 27  Laptop mode and tablet mode

Row	Modes
4	FIG 20  FIG 25  Laptop mode and frame mode

111. Second, even if incorporated into the base, mechanism 38 would not be capable of generating the information necessary to distinguish between certain of Lane’s display modes.

112. In the table below, I have modified Figures 19-27 by adding an annotated version of mechanism 38 along with a blue arrow, which indicates the edge of the base opposite the hinge. Again, however, note that the mechanism 38 in my below hypothetical exploration is not mounted in a plane parallel to the display as taught by Lane in Figure 1; and would therefore no longer be capable of determining rotation of the display around its z-axis to handle either Lane’s portrait/landscape corrections, for example, or Lane’s cursor direction mapping. The base module 14 is oriented in the same direction in the four combinations of modes depicted below: (1) frame mode and tablet mode, (2) laptop mode and closed mode, (3) laptop mode and flat mode, or (4) the various laptop-like configurations Lane discloses. As a result, Lane’s position-indicating mechanism 38 can be in precisely the same orientation when the computer is in the two or more display modes shown in each row. Mechanism 38 does not output information sufficient to differentiate among the display modes shown on each row, and therefore does not provide sufficient information to identify the computer’s current display mode.

Row	Modes
1	FIG 25 FIG 27  Frame mode and tablet mode
2	FIG 20 FIG 19  Laptop mode and closed mode
3	FIG 20  FIG 21  Laptop mode and flat mode

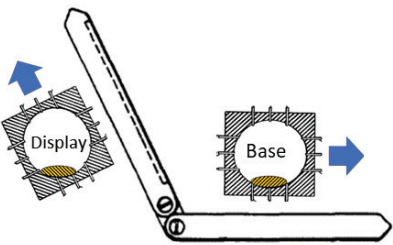
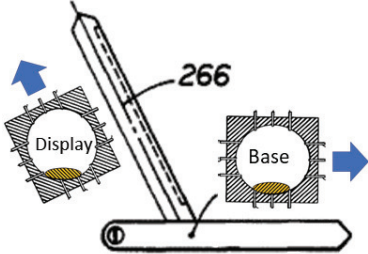
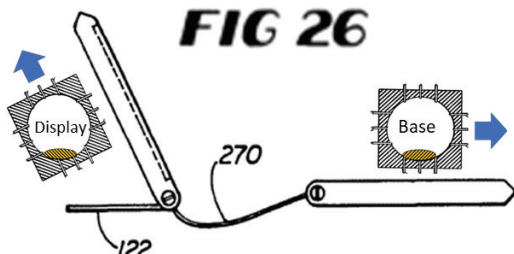
Row	Modes
4	FIG 20 FIG 22  FIG 23 FIG 24  FIG 26  Various laptop-like configurations

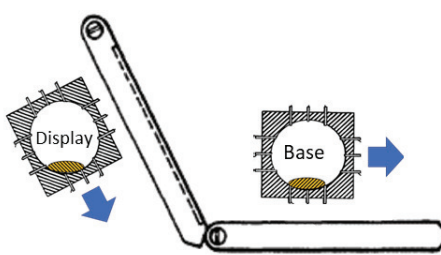
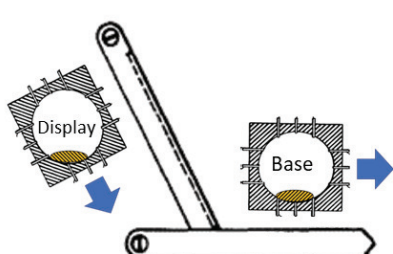
113. Third, Lane only discloses including mechanism 38 in “*either* first [base] *or* second [display] modules 14 or 18,” not both. But even if mechanism 38 were incorporated into both the display and the base, it would not be capable of generating the information necessary to distinguish between certain of Lane’s display modes.

114. In the table below, I have modified Figures 20, 22, 23, 24, and 26 by adding an annotated version of mechanism 38 along with a blue arrow, which indicates the edges of the display and the base opposite the hinge. Once again, however, note that both mechanisms 38 in my below hypothetical exploration are not mounted in a plane parallel to the display as taught by Lane in Figure 1; and would therefore no longer be capable of determining rotation of the display around its z-axis to handle either Lane’s portrait/landscape corrections, for example, or Lane’s

cursor direction mapping. For example, the angular orientations of both the display and base modules are the same in the display modes depicted in Figures 20, 22, and 26 in the first row below. The only difference is that the display module is displaced along the plane of the base in the two configurations in ways that mechanism 38 simply cannot detect through any manipulation of any combination of output from those devices. Lane at 4:29-32, 7:24-29, 10:10-11:16 (describing these configurations).

115. Similarly, as shown in the second row of the table below, the angular orientations of both the display and base modules are the same in Figures 23 and 24 below. The only difference is that the display module is displaced along the plane of the base in the two configurations in ways that mechanism 38 simply cannot detect through any manipulation of any combination of output from those devices. Lane neither motivates nor discloses that its position-indicating mechanisms should or could determine displacement of the second module relative to the first.

Row	Modes
1	FIG 20  FIG 22  FIG 26 

Row	Modes
2	FIG 23  FIG 24 

B. The Determinations Lane Makes Do Not Determine the Display Mode.

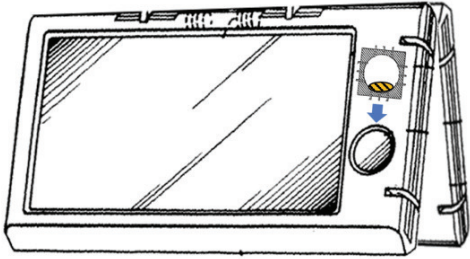
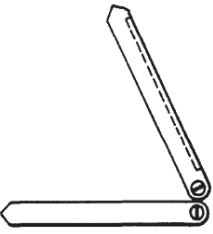
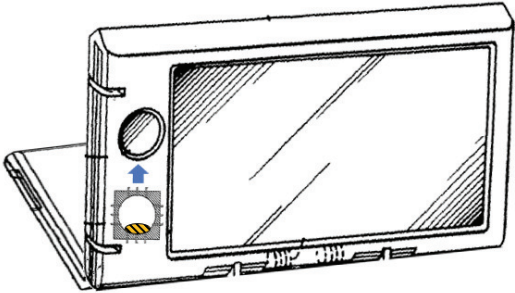
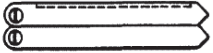
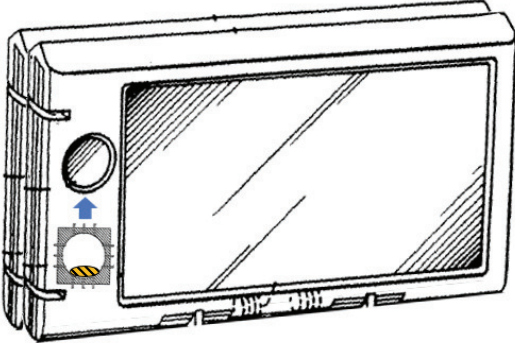
116. Lane does not disclose a “display manager” that is “configured” to use the output of the position-indicating mechanism 38 to “detect a current display mode from among the plurality of display modes” as each of the claims require. Lane discloses that mechanism 38 can perform three determinations: (1) whether the display is in landscape or portrait orientation; (2) which direction to move the cursor; or (3) whether the keyboard is operable. Lane at 5:23-6:6. None of these three determinations provide the information necessary to distinguish amongst each display mode disclosed in Lane. Lane simply neither motivates nor discloses that mechanism 38 (or any other elements in Lane) should or can make this determination.

117. **First**, determining whether the device is in portrait or landscape orientation does not require knowing the computer’s display mode and is not sufficient to distinguish among each display mode disclosed in Lane.

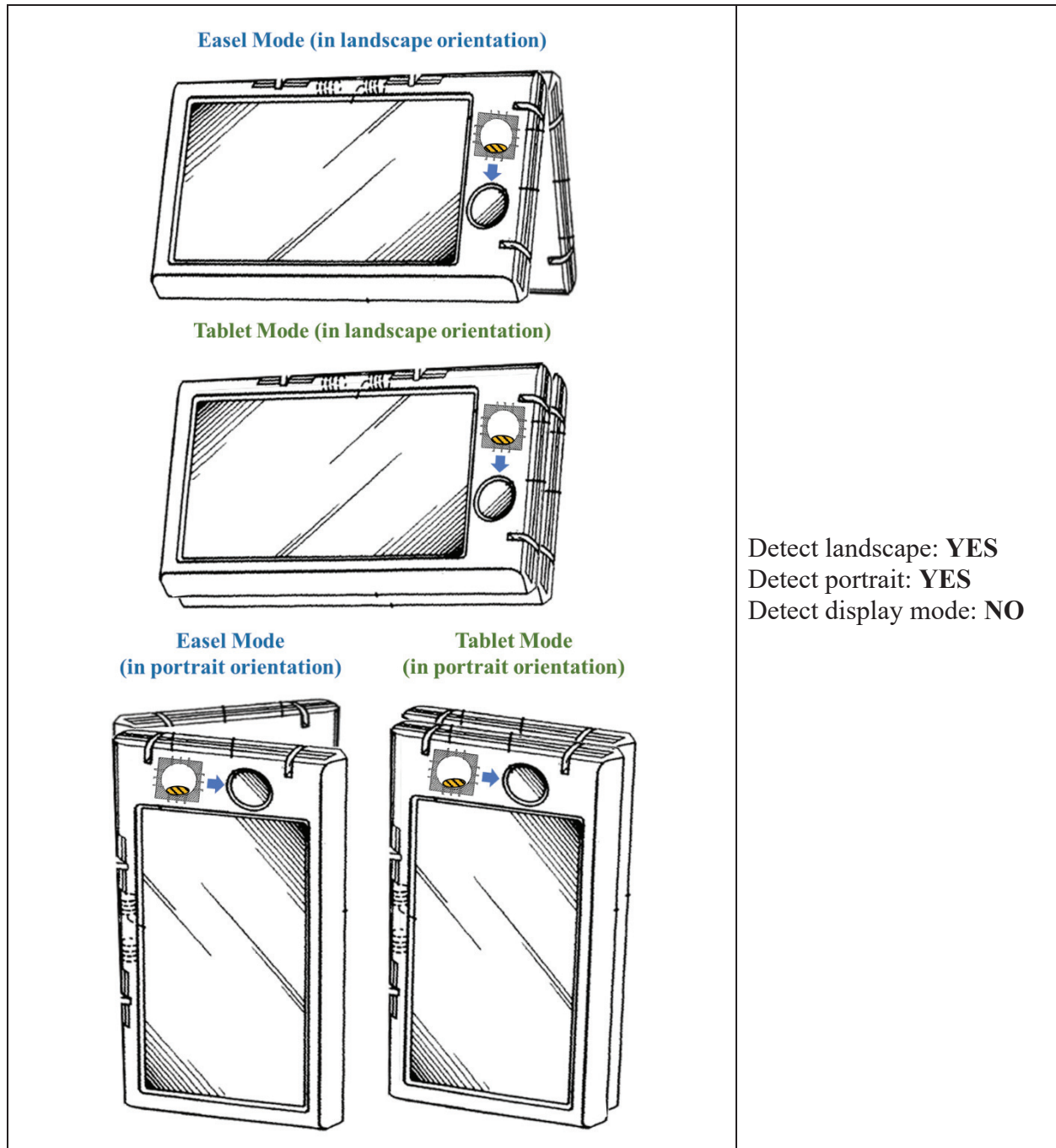
118. Lane discloses using mechanism 38 to “determine[e] whether the information to appear on visual display 35 should be in ‘landscape’ or ‘portrait’ position as the visual display 35 is spatially configured.” *Id.*, 5:35-6:3. Lane does not identify which display modes have the display 35 “spatially configured” such that the information should be in a portrait orientation. In fact, Lane’s Figures only ever demonstrate landscape orientation; never does Lane show any

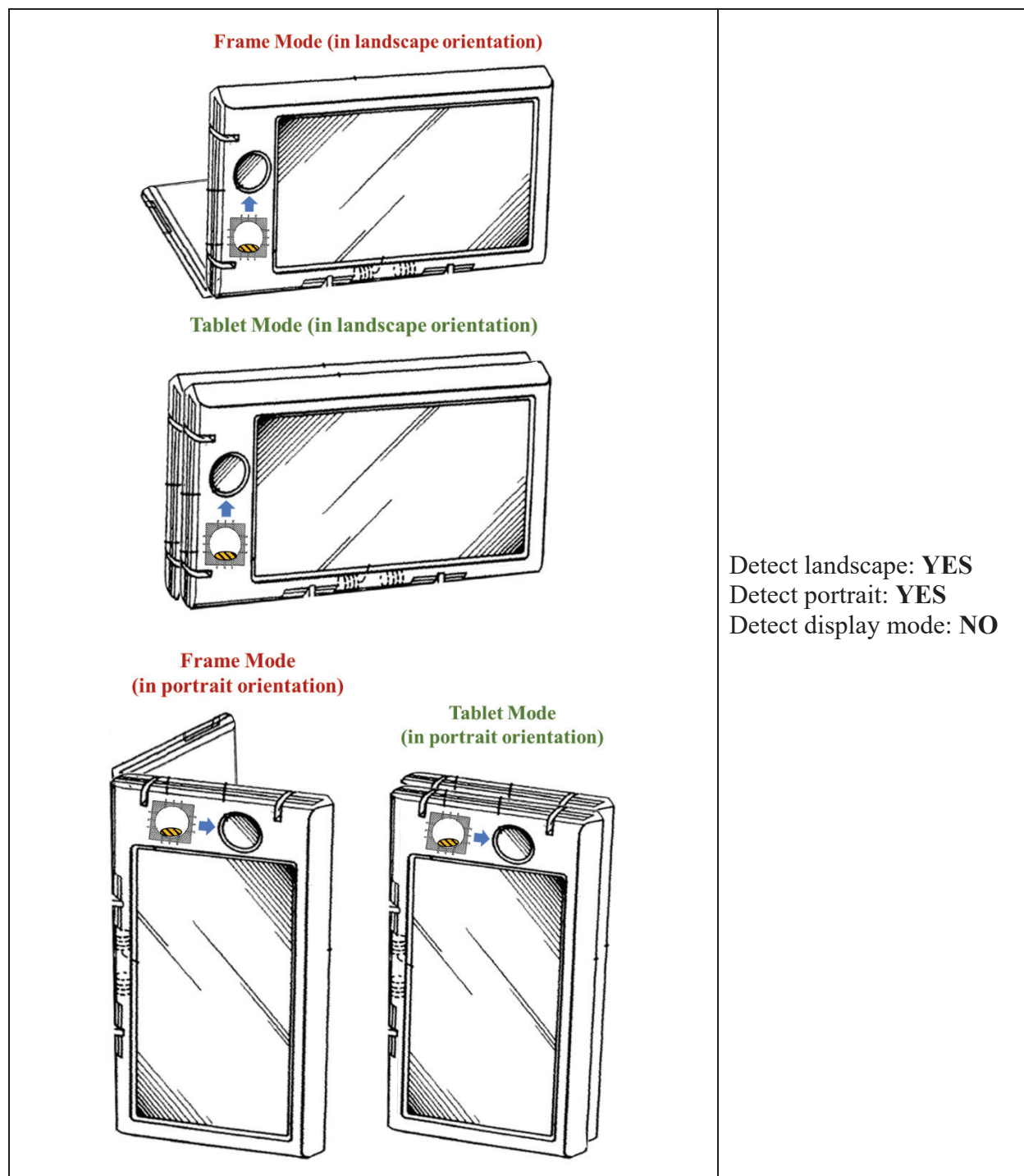
component in portrait orientation. Portrait orientation might be appropriate in Lane's tablet mode, easel mode, or frame mode. For example, when a user holds Lane's computer in tablet mode (Figure 27) in certain spatial configurations, a portrait orientation might be appropriate. Likewise, portrait mode might be appropriate in easel mode (Fig. 28) and frame mode (Fig. 25) when Lane's computer is rotated and set on a table. But these orientations are not actually disclosed.

119. In the righthand column of the illustration table below, I have created hypothetical perspective images of easel, frame, and tablet modes corresponding with the display modes that are depicted in Lane's Figures 28, 25, and 27, respectively. I have added to each display module a modified version of mechanism 38 (mounted properly according to Lane's Figure 1, so that landscape/portrait orientation information would not be lost) to illustrate the position information that mechanism 38 would provide. As with the illustrations above, I have added a blue arrow next to mechanism 38 to indicate the direction of the device edge that is opposite the "hinge" that connects the display and base modules.

 FIG 28 Easel Mode	
 FIG 25 Frame mode	
 FIG 27 Tablet mode	

120. As illustrated below, mechanism 38's ability to detect whether Lane's display is in the landscape or portrait orientation would not distinguish between tablet and easel modes, or between tablet and frame modes.

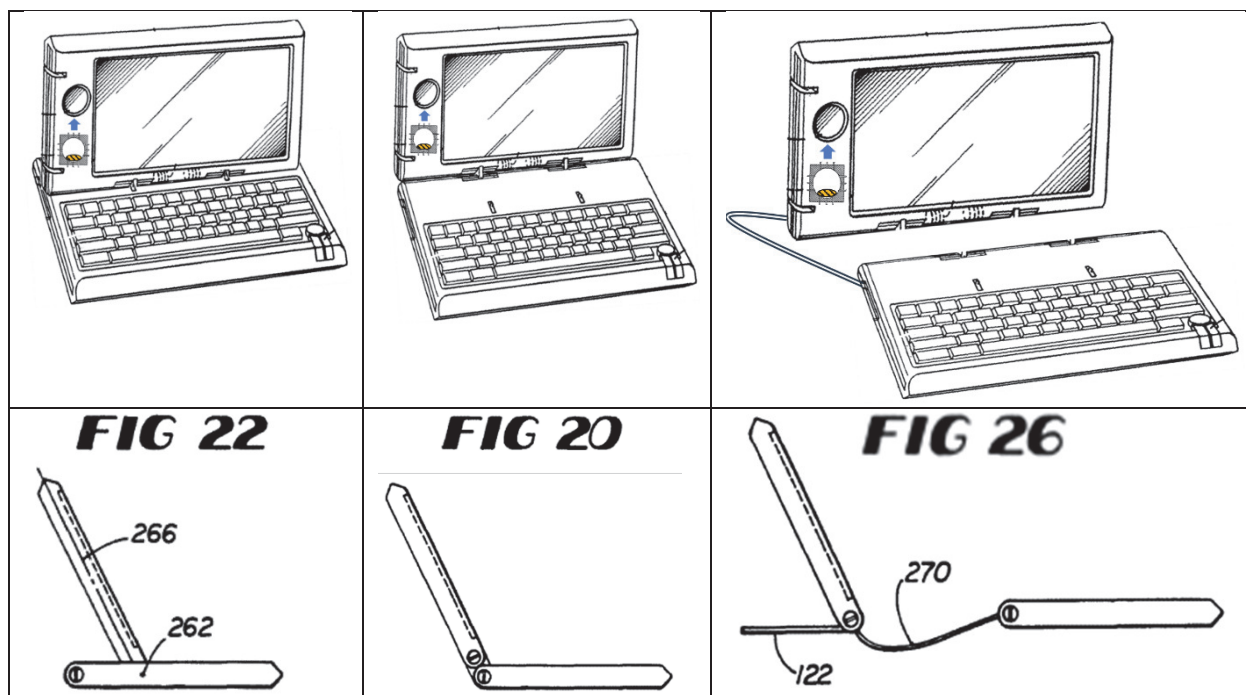


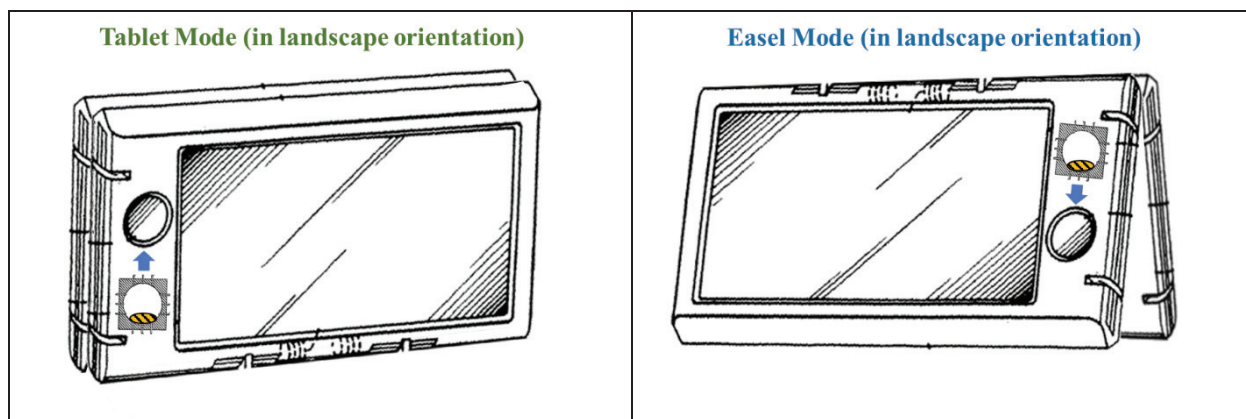


121. By using Lane's mechanism in the display module as shown in the figures annotated above, it is possible to detect whether the display is spatially configured so that its longer dimension extends vertically (suitable for portrait orientation) or whether its longer dimension extends horizontally (suitable for landscape orientation). The computer need not know which

display mode the computer is in (e.g., tablet, easel, frame, laptop) to make that determination of whether to display content in portrait or landscape mode. Knowing the orientation of the display module suffices to make that determination.

122. Further, detecting that Lane's display is in a landscape orientation would not distinguish between the display modes illustrated in Figures 20, 22, 23, 24, 25, 26, 27, and 28 because Lane depicts all of them in the landscape orientation. For example, the display modes depicted in a profile view in Figures 20, 22, and 26, are all in landscape orientation. In the illustrations below, I have created perspective views of the display modes shown in Figures 20, 22, and 26. As with the illustrations above, I have added a blue arrow next to mechanism 38 to indicate the direction of the device edge that is opposite the "hinge" that connects the display and base modules. I have also provided an illustration of Lane's computer in easel and tablet modes in which content would be displayed in landscape orientation.

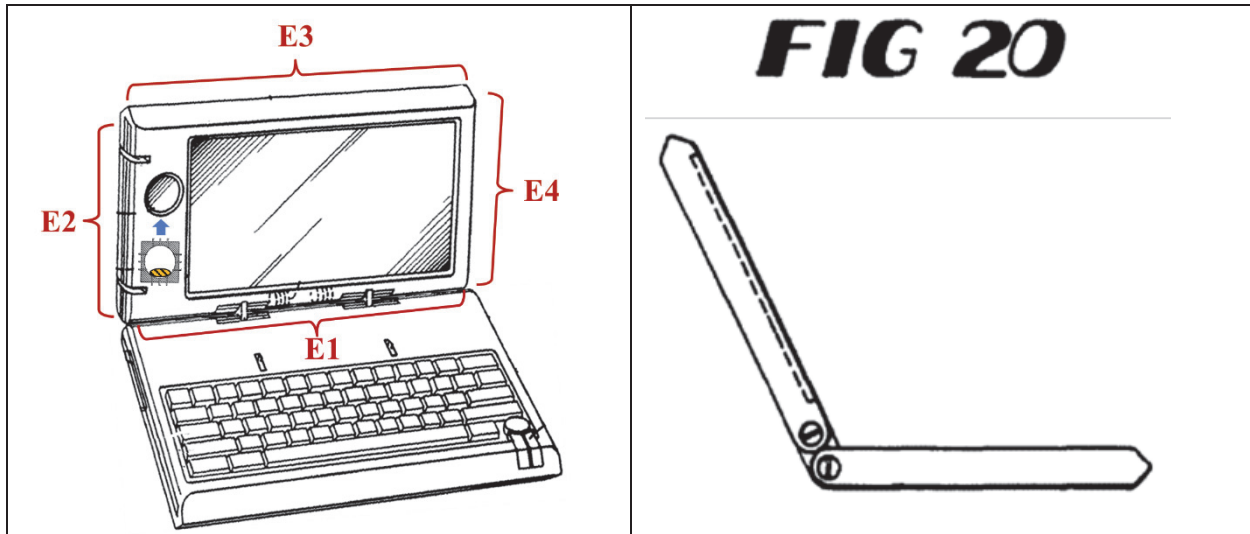




123. *Second*, determining which direction to move the cursor does not require knowing the computer’s display mode and is not sufficient to distinguish Lane’s display modes.

124. Lane discloses using position-indicating mechanism 38 to “determine[e] the direction in which to move a curser of second module 18 [*i.e.*, the module with the display].” *Id.*, 5:35-6:6. When a user moves the cursor control device (32) left, right, up, or down in relation to the user, the direction in which the cursor moves depends on the spatial orientation of the display. *Id.*, 5:10-14. For example, in the easel mode, “up” is towards the hinge, but the same could also be true in the tablet mode, as shown below. Although Lane describes “[a]n electronic mouse or other pointer 32,” which is depicted on the lower-right corner of the keyboard in Figure 1, an external mouse could also be used to control the cursor. An external mouse could be available in display modes in which the keyboard might be inoperable (e.g., easel mode, frame mode, and tablet mode).

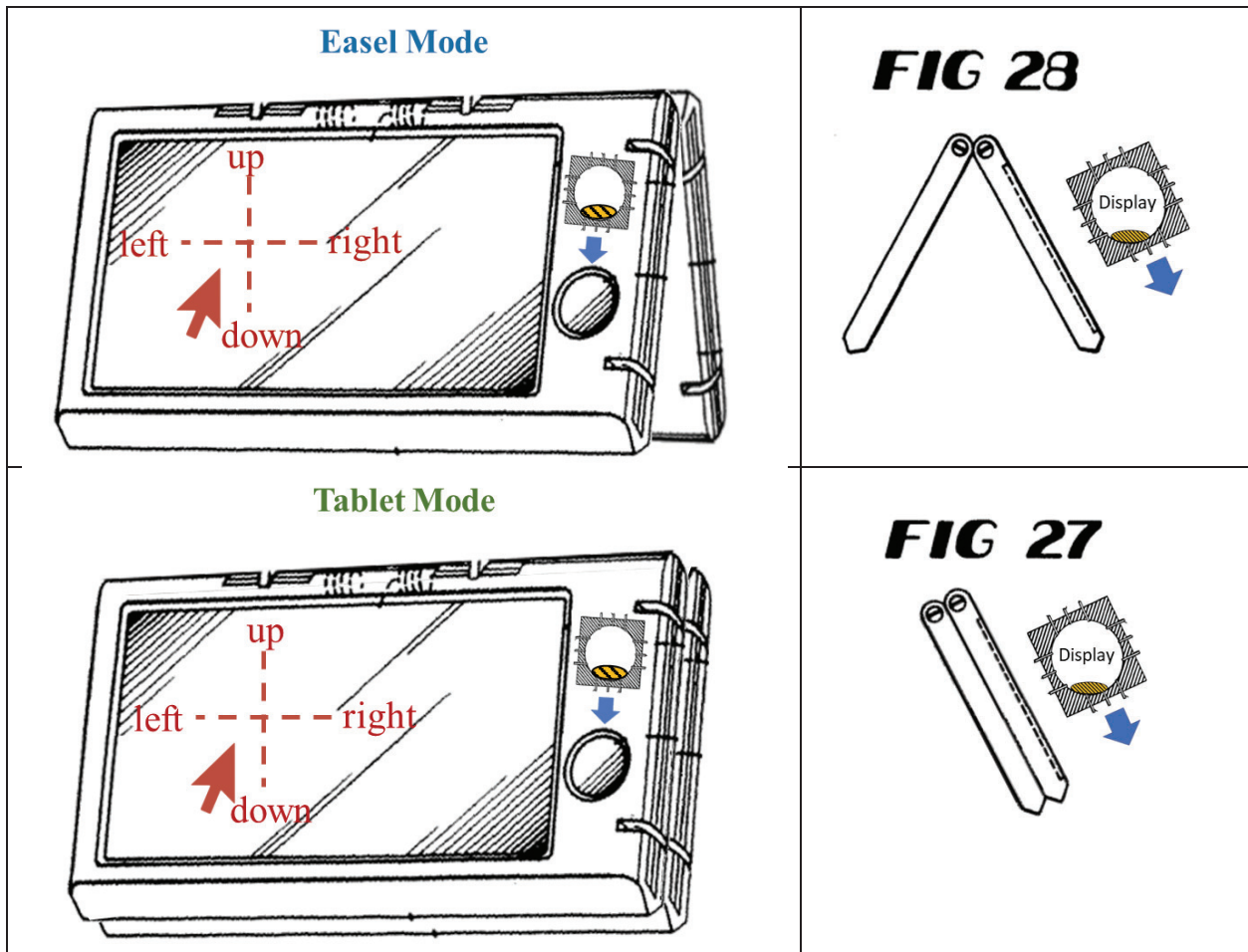
125. In the figure below, I have used a simplified version of Figure 1 and assigned labels E1 to E4 to the four edges of the display. Edge E1 and E3 are longer than edges E2 and E4. E1 is the edge that connects to the base component via a hinge.



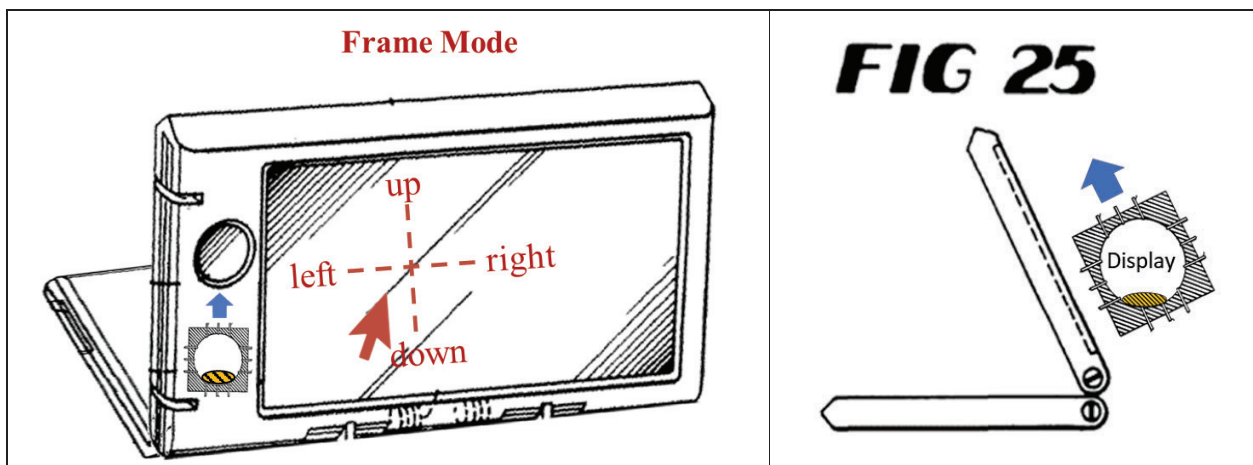
126. Lane's computer can be configured and/or held by the user in various ways so that any one of the four edges can be "up." The direction the cursor moves depends on which edge is up. When the user moves the cursor left to right, the cursor could move across the display in any of the following four directions depending on which edge of the display is up:

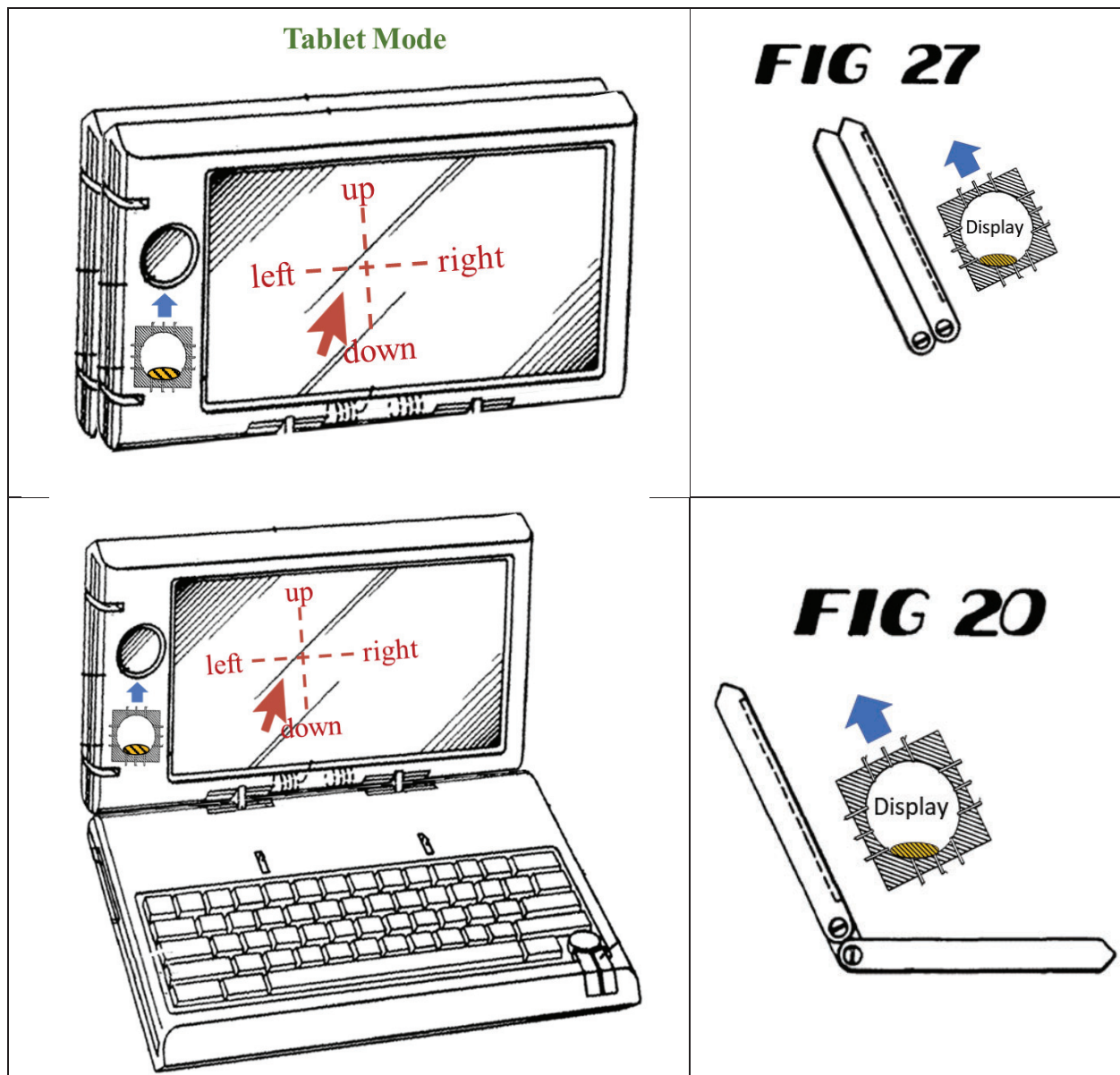
- from edge 1 → edge 3 (if edge 2 is up)
- from edge 3 → edge 1 (if edge 4 is up)
- from edge 2 → edge 4 (if edge 3 is up)
- from edge 4 → edge 2 (if edge 1 is up)

127. Determining which edge of the display is up does not require knowing what display mode the computer is configured in. When mechanism 38 is mounted in the display module it indicates which edge of the display is up but does not indicate the computer's display mode. Additionally, identifying a particular edge as up does not identify the computer's display mode, because the same edge can be up (and thus the cursor movement direction can be the same) for different display modes. For example, edge 1 (with the hinge) can be "up" in the easel mode or tablet mode as shown below.

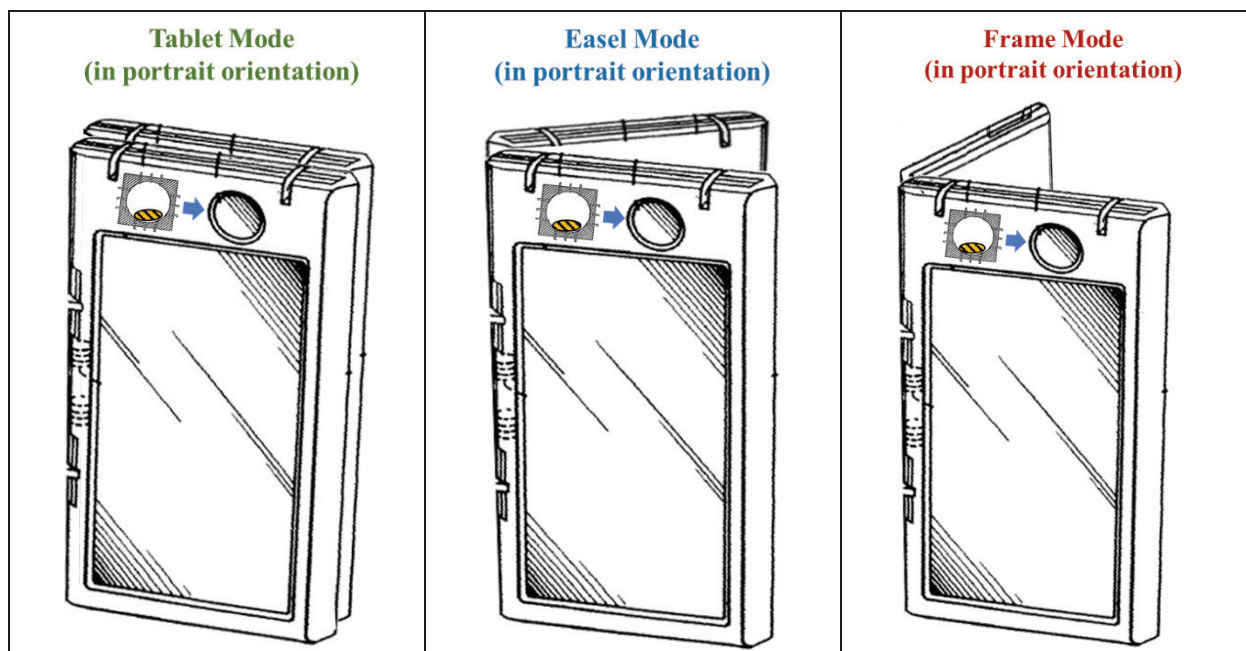


128. Edge 3 (opposite the hinge) can be up in tablet mode, frame mode, and laptop mode, as shown below. The frame, tablet, and laptop modes are exemplified below, but the principle applies to each display mode depicted in Figures 20, 22, 25, and 26 and Fig. 27 (with the tablet oriented in that same way).

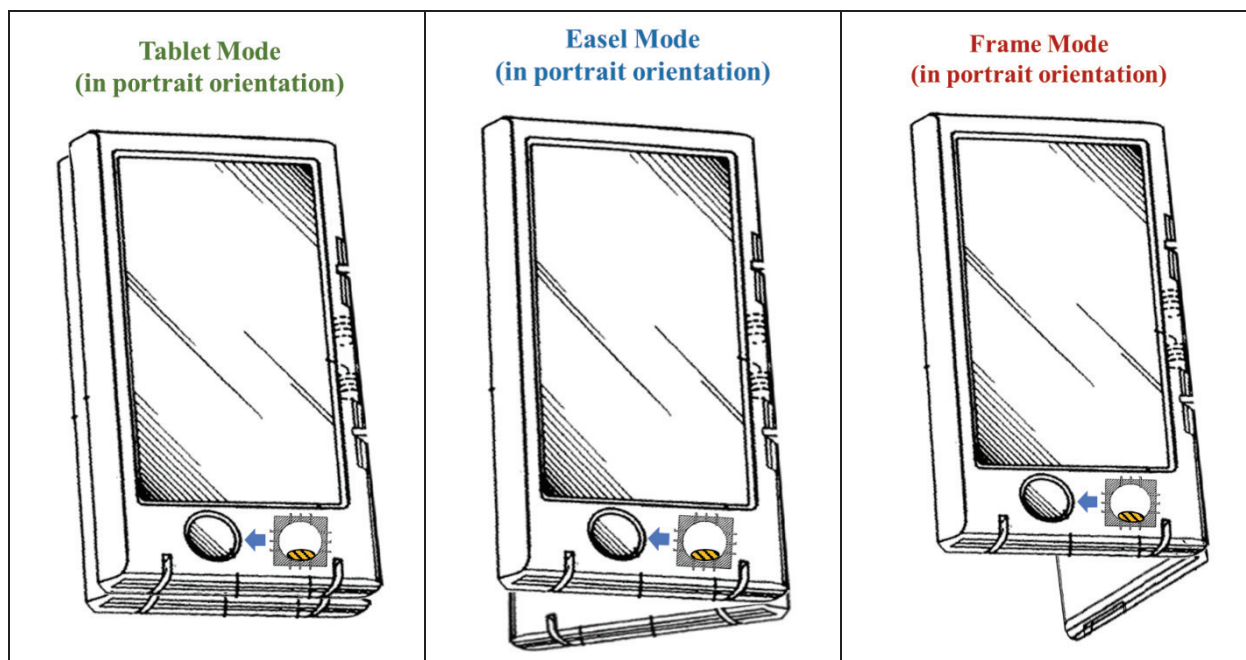




129. Edge 2 (shorter edge) can be “up” in the tablet mode, easel mode, and frame mode as illustrated below.

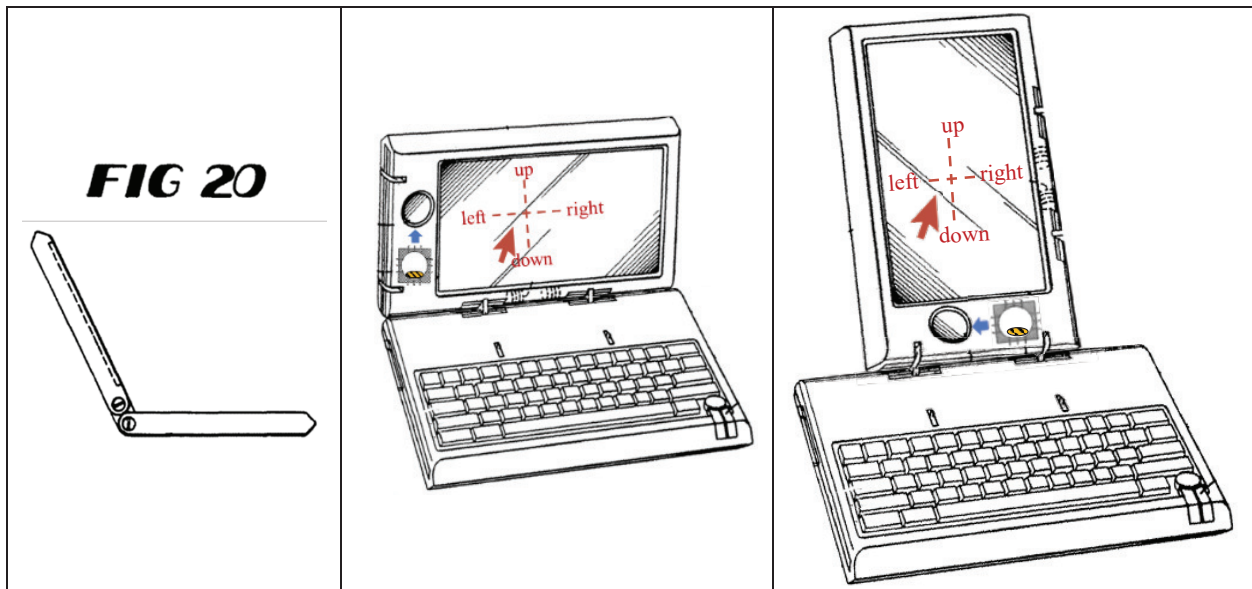


130. Edge 4 (the other shorter edge) can be “up” in the tablet mode, easel mode, and frame mode as illustrated below.

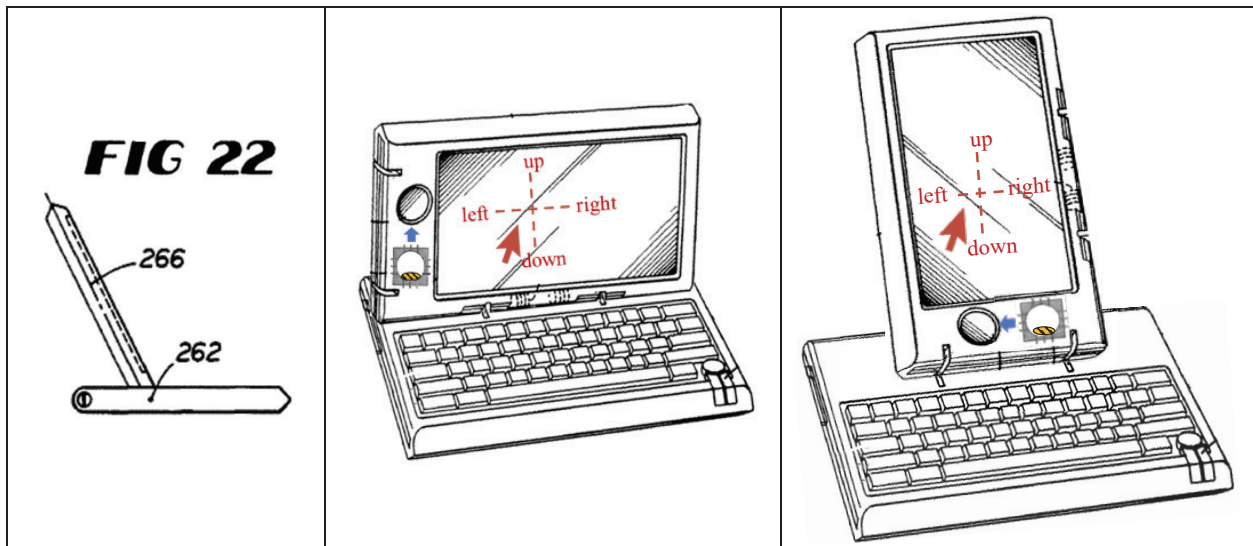


131. Lane contemplates cursor control in different physical configurations of its computer. *See e.g.*, Lane 5:35-6:6. But Lane only expressly discloses cursor control device 32. Lane, 5:10-15. The cursor control device 32 depicted in Figure 1 is only available in certain modes; those when the keyboard is also readily available to be used. But a POSITA would

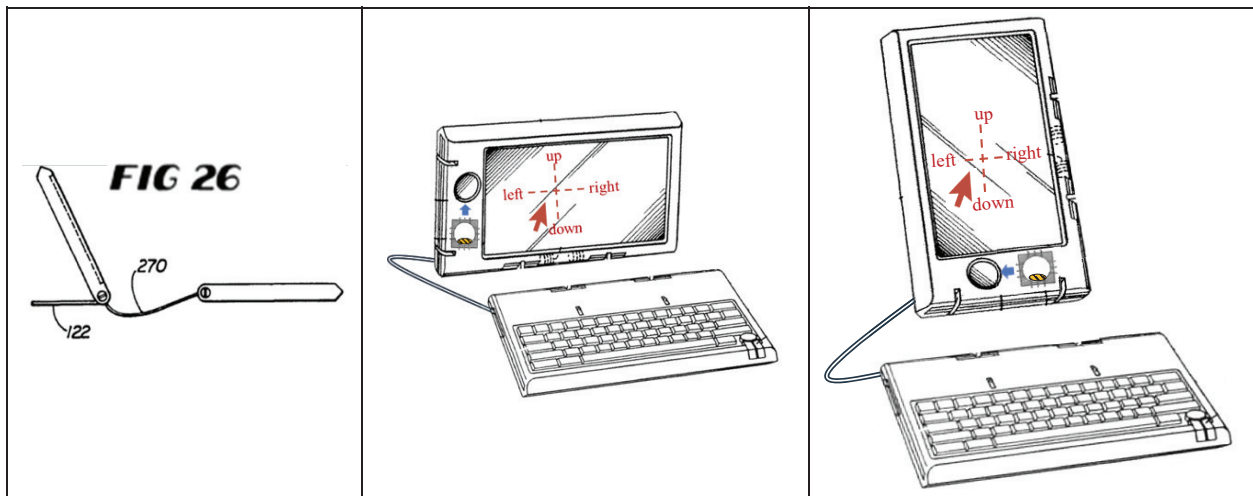
understand that other means for cursor movement, like an external mouse, could be used in modes where the keyboard is not operable or is inaccessible. Now, Lane also never shows us what portrait modes are available for his device. Tablet mode certainly is a reasonable guess. Thus, we could guess that Lane might position a display in portrait mode in laptop mode. See Lane's Figure 20 below accompanied by a pair of orthographic reconstructions that are NOT present in Lane.



The same principle could theoretically apply to Lane's Figure 22 mode, extrapolated below, where the screen is placed closer to the keyboard. Again, the two images to the right of Figure 22 are NOT present in Lane.



Likewise, the same principle could theoretically apply to Lane's Figure 26 mode, extrapolated below, where the screen is detached from keyboard. Again, the two images to the right of Figure 26 are NOT present in Lane.

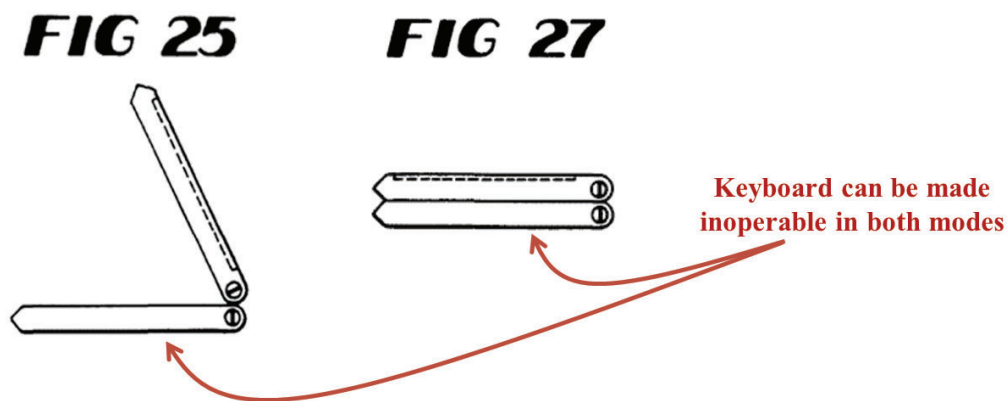


132. As depicted above, detecting the direction in which to move the cursor across the display does not require detecting the computer's display mode and does not distinguish between multiple display modes regardless of which end of the display module is up.

133. *Third*, determining "whether to render keys 36 of first module [i.e., the base] inoperable when unused" (Lane, 5:35-6:5) does not require knowing the computer's display mode and is not sufficient to distinguish among each display mode disclosed in Lane.

134. Lane does not identify the display modes in which the keyboard is unused. Lane also does not state that the display mode is determined to then determine whether to render the keyboard inoperable.

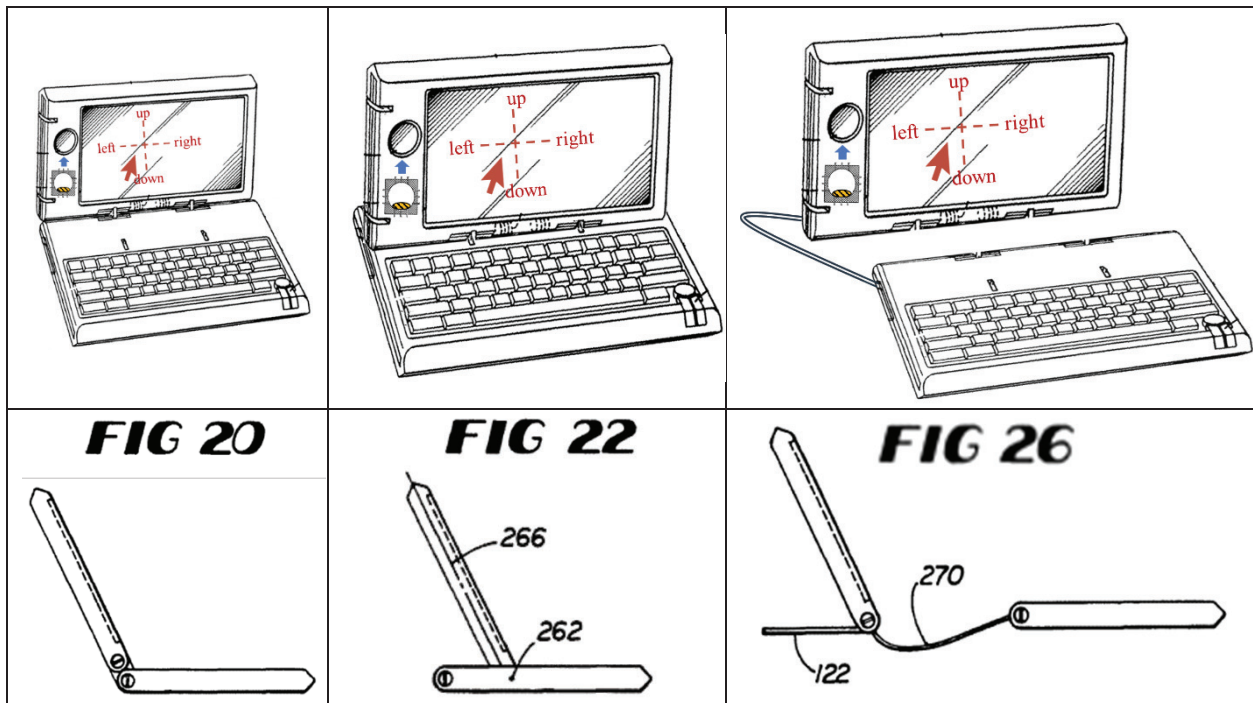
135. It might make sense to render the keys inoperable when the keyboard is facing down on a surface, which could increase the likelihood of inadvertent keystrokes. Lane identifies two display modes in which the keyboard is facing down on a surface: tablet mode (Fig. 27) and frame mode (Fig. 25). As depicted above, even if Lane taught that the keyboard should be made inoperable when the keyboard is facing down, determining whether the keys are unused would not distinguish among Lane's display modes as illustrated below.



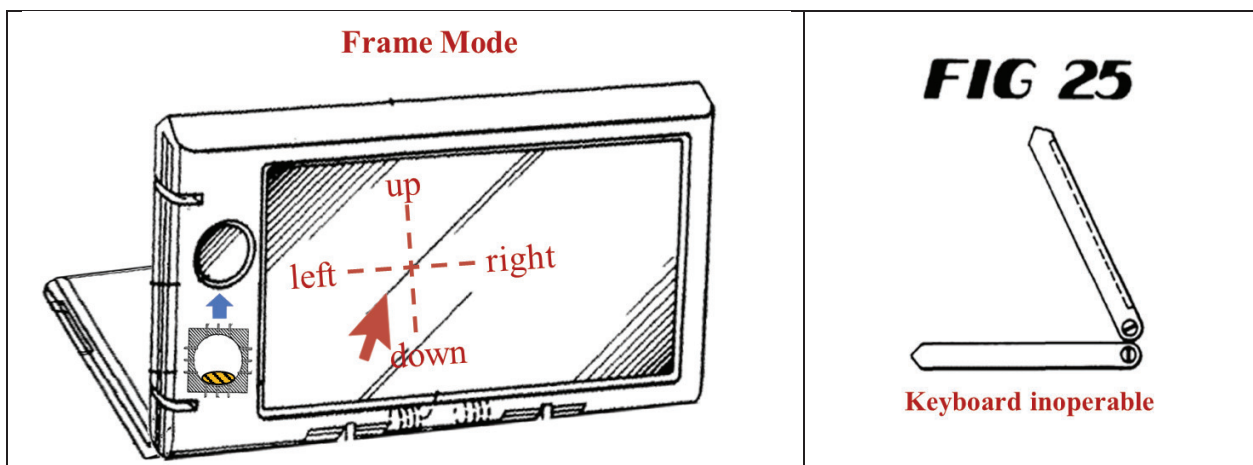
136. *Fourth*, Lane neither motivates nor discloses simultaneously performing all three of the mechanism 38 determinations (i.e., portrait-versus-landscape, cursor direction, and inoperable keyboard). But even if Lane did disclose performing the three determinations simultaneously, doing so would not require knowing the computer's display mode and would not provide sufficient information to distinguish between Lane's different display modes.

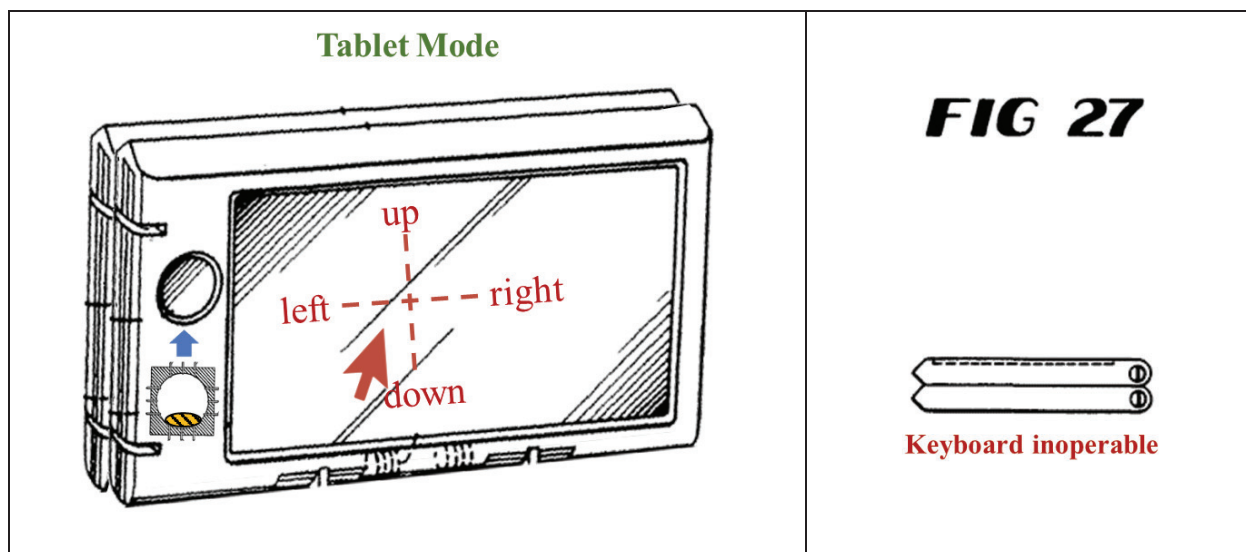
137. As detailed above, none of the three determinations described in Lane requires determining the computer's display mode and it is simply not possible to determine the computer's display mode using mechanism 38.

138. Making Lane's three determinations would not provide sufficient information to distinguish between Lane's display modes. For example, in Figures 20, 22, and 26, the display is in a spatial orientation in which landscape orientation is appropriate. As illustrated below, when moving the cursor from left to right, the cursor moves in the same direction across the display (from edge 2 to edge 4), and the keys on the keyboard are enabled. Thus, making all three of these determinations would still not provide sufficient information to distinguish Lane's display modes.



139. Similarly, in Figures 25 and 27, the display is in a spatial orientation in which landscape orientation is appropriate. The cursor moves in the same direction left to right across the display from edge 2 to edge 4 (with the hinge below the cursor), and the keys are disabled. Making all three of Lane's determinations would still not provide sufficient information to distinguish Lane's display modes.





The same is true for all the transformations between landscape and hypothetically extrapolated portrait modes I created for paragraph 131 above. The cursor would move in the correct directions left to right across the display without determining or even being able to distinguish between Lane's display modes. Thus, making all three of Lane's determinations would still not provide sufficient information to distinguish Lane's display modes.

140. For all of the reasons detailed above, Lane does not teach or suggest – expressly or inherently – a display manager “configured” to detect a current display mode as required by all claims of the '154 Patent.

141. I declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, 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 18 U.S.C. §1001.

Signed on February 9, 2023 in Austin, Texas.


Eric Justin Gould Bear

APPENDIX A

BEAR CV

ERIC GOULD BEAR

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Corporate Leadership in User Experience Strategy

Communication Arts has described Eric Bear as “one of the most thoughtful and provocative interface and interaction designers working in the field.” He has been leading the design of award-winning human-computer interfaces since 1984, has published numerous articles on the subject, and has been granted a variety of patents for cutting-edge techniques. An enthusiastic and inspirational leader, Bear invites everyone to join in the work of creating easier-to-use technology and more engaging digital media. Key management outcomes have included:

- Competitive customer experience strategy
- Integrated vision for products, services & brand
- Prioritized product requirements & specifications
- Maximized usability & customer satisfaction
- Confidence in solutions prior to public release
- Proven design management methodology
- Leadership of cross-functional collaboration
(*technology, strategy, marketing, content, design, usability*)
- Engineering resource, schedule & cost optimization
- Protection of proprietary interaction technology

CONSULTING

Chief Experience Officer, Inc. – Austin, Texas

2005 to Present

Executive consulting in corporate user experience strategy and design innovation – Performed “Virtual CXO” role to build in-house competencies, methods and teams. Advised business leaders in design management and intellectual property strategy. Guided entrepreneurs and designers through concept ideation and creative development. Representative projects include:

Capital Factory (2013 to Present) – *Partner & Angel Investor*

Aceable, Inc. – mobile education start-up; *Advisor*

Kenguru / KLD Energy, Inc. – electric wheelchair-accessible vehicle division; *Advisor*

SubjectMatter, Inc. – expert network platform start-up; *Advisor*

Weeva, Inc. – collaborative storytelling start-up; *Advisor*

FloSports, Inc. (2014 to 2015) – sports media network; *Advisor / Acting CXO*

Logitech International (2005 to 2009) – award-winning *MX Revolution* and *VX Revolution* mice and award-winning *Harmony One*, *Harmony 900* and *Harmony 1000* touch-screen universal remote controls

Tektronix, Inc. (2005 to 2009) – schematic and symbolic systems for protocol-based data analysis

projekt202, LLC (2005 to 2009) – *Chief Experience Officer & Strategic Innovation Advisor*

Charles Schwab – *StreetSmart Edge* active trader desktop software suite

e-MDs – electronic medical record and clinic management software suite

Motorola – mobile phone user interfaces

On-Q / Legrand – home automation LCD control panel interfaces

Samsung – next generation mobile phone user experience strategy

Thomson Reuters – *WestlawNext* legal research system

Testifying expert witness in patent litigation matters:

Alston & Bird LLP – *Testifying Expert Witness*

8:18-cv-01580 **Universal Electronics Inc. v. ROKU, Inc.**

Inter Partes Review 2019-01595 & 2019-01608 **ROKU, Inc. v. Universal Electronics Inc.**

ITC Investigation 337-TA-1200 **Universal Electronics Inc. v. ROKU, Hisense, Funai, TCL, et al.**

Dickinson Wright LLP – *Testifying Expert Witness*

Inter Partes Review 2018-00059 **Unified Patents, Inc. v. MONKEYmedia, Inc.**

Etheridge Law Group – Testifying Expert Witness

2:18-cv-00491; 2:18-cv-00502; 2:18-cv-00504; 2:18-cv-00550 **Uniloc 2017 LLC v. Google LLC**
Inter Partes Review 2019-01187 **Microsoft Corporation v. Uniloc 2017 LLC**
Inter Partes Review 2020-00115 **Google LLC v. Uniloc 2017 LLC**
Inter Partes Review 2020-00041 **Netflix, Inc. v. Uniloc 2017 LLC**
Inter Partes Review 2019-01367 **Sling TV LLC v. Uniloc 2017 LLC**
Inter Partes Review 2020-00441 **Google LLC v. Uniloc 2017 LLC**

Farney Daniels PC – Testifying Expert Witness

ITC 337-TA-994 **Creative Tech. v. ZTE, Sony, Samsung, LG, Lenovo, Motorola, HTC, Blackberry, et al.**
Inter Partes Review 2016-01407 **Sony Corp, et al. v. Creative Technology Ltd.**

Finnegan, Henderson, Farabow, Garrett & Dunner, LLP – Testifying Expert Witness

CBM2015-00161; CBM2015-00172; CBM2015-00179; CBM2015-00181; CBM2015-00182; CBM2016-00031; CBM2016-00051; CBM2016-00054; CBM2016-00087; CBM2016-00090 **Trading Technologies**

G2 Technology Law – Testifying Expert Witness

90/011,365 **MONKEYmedia, Inc. Ex Parte** Reexamination
 95/001,504; 95/001,506; 95/001,630; 95/002,256 **MONKEYmedia, Inc. Inter Partes** Reexaminations

Graves Dougherty Hearon & Moody – Testifying Expert Witness

1:10-cv-00319 **MONKEYmedia, Inc. v. Apple, Inc.**
 1:10-cv-00533 **MONKEYmedia, Inc. v. Buena Vista Home Entertainment, Inc. d/b/a Walt Disney Studios Home Entertainment; Twentieth Century Fox Home Entertainment, LLC; Lions Gate Entertainment Corp.; Paramount Pictures Corporation; Sony Pictures Home Entertainment; Sony Electronics, Inc.; Sony Computer Entertainment America, LLC; Warner Home Video, Inc.; and Universal Studios**
 2:17-cv-00460 **MONKEYmedia, Inc. v. Samsung Electronics Co., Ltd.**
 4:19-cv-04610 **MONKEYmedia, Inc. v. TiVo Corporation**
 1:20-cv-00010 **MONKEYmedia, Inc. v. Amazon.com, Inc.**

Greenberg Traurig, LLP – Testifying Expert Witness

Inter Partes Review 2019-01620 & 2019-01621 **ROKU, Inc. v. Universal Electronics Inc.**

Hagens Berman Sobol & Shapiro, LLP – Testifying Expert Witness

1:12-cv-00804 **Flatworld Interactives v. Samsung Electronics et al.**
 1:12-cv-00964 **Flatworld Interactives v. LG Electronics et al.**

Jones Walker LLP – Testifying Expert Witness

2:19-cv-10156 **Express Lien, Inc. v. Handle, Inc. et al.**

McDonnell Boehnen Hulbert & Berghoff LLP – Testifying Expert Witness

1:10-cv-00715 **Trading Technologies International, Inc. v. BGC Partners, Inc.**
 1:10-cv-00721 **Trading Technologies International, Inc. v. IBG, LLC, et al.**
 1:10-cv-00884 **Trading Technologies International, Inc. v. TradeStation Securities, et al.**

McKool Smith Hennigan P.C. – Testifying Expert Witness

3:13-cv-02371 **Mad Catz Interactive, Inc. v. Razer USA, Ltd.**

Troutman Pepper Hamilton Sanders LLP – Testifying Expert Witness

1:21-cv-01376 **Design With Friends, Inc. v. Target Corporation**

Warner Norcross & Judd, LLP – Testifying Expert Witness

2:14-cv-00940 **Tactile Feedback Technology v. Samsung Electronics America, Inc.**
 2:14-cv-00943 **Tactile Feedback Technology v. ZTE (USA) Inc.**

Whitmyer IP Group, LLP – Testifying Expert Witness

3:14-cv-00876 **Karl Storz Endoscopy v. Stryker Corporation et al.**
 1:18-cv-01691 **Karl Storz Endoscopy v. Steris Corporation**

Wolf, Greenfield & Sacks, P.C. – Testifying Expert Witness

1:20-cv-00689 **LiTL LLC v. Lenovo (United States), et al.**

CORPORATE

Curb, Inc. – Austin, Texas

2015 to 2020

Investor, Director, CXO & Corp. Secretary

CURB® is an award-winning energy tech startup that builds the world's most powerful and intelligent integrated hardware/software system for visualizing and managing energy in residential and commercial settings. It provides insight into energy usage, giving people knowledge and tools to make their homes and buildings safer, more energy efficient and more affordable. Was responsible for end-to-end customer experience (including brand, product design, product management, software engineering, customer support), patent portfolio & legal. Sold the company in 2020 to Elevation Home Energy Solutions.

MONKEYmedia, Inc. – Austin, Texas

1994 to Present

Founder, President & CEO

Launched MONKEYmedia® in San Francisco in 1994 to provide desktop computing, new media and consumer electronics industries a design resource focused on human-computer interaction. Relocated to Austin in 1996. Developed portfolio of licensed intellectual property. Formulated structured design & development process with flexibility to meet variety of product requirements and business approaches. Partnered with client leaders in planning and focusing design and development activities; crafting teams to ensure timely shipment of outstanding experiences.

Shipped **Walk-in Theater™** for iOS in 2012 [<http://walk-in-theater.com/>], featuring body-based interaction techniques for 3D audio and video. Adapted to human-scale exhibition at Blanton Museum of Art, Yale and other venues from 2014. In 2017, shipped **Teleport™** for iOS, a first-person drone flight experience powered by intuitive body movement. In 2018, released **BodyNav®** XDK (extended reality development kit) for reducing motion sickness on Oculus Rift & HTC Vive. The **BodyNav** family of technologies are covered by at least nine US patents.

Monetizing inventions of the early-1990s through patent licensing and enforcement litigation. Launched **SeamlessTV® Partner Program** [<http://seamless.tv/>] in 2009. Notable legal matters:

- Sold five families of user interface patents in 2005 (represented by Susman Godfrey)
- Licensed interactive video patents to Microsoft in 2006 (represented by Susman Godfrey)
- **MONKEYmedia, Inc. v. Apple, Inc.** – 2010 (represented by Graves, Dougherty, Hearon & Moody) SETTLED 2016
- **MONKEYmedia, Inc. v. Sony Electronics, Sony Computer Entertainment America, Sony Pictures, The Walt Disney Company, Twentieth Century Fox, Lions Gate Entertainment, Paramount Pictures, Warner Bros, and Universal Studios** – 2010 (represented by GDH&M) SETTLED 2015-2017
- **MONKEYmedia v. Samsung Electronics Co., Ltd.** – 2017 (represented by GDH&M) SETTLED 2018
- **MONKEYmedia v. TiVo Corporation** – 2019 (represented by GDH&M / Finnegan) SETTLED 2019
- **MONKEYmedia v. Amazon.com, Inc.** – 2020 (represented by GDH&M)

Industry recognition for MONKEYmedia's design leadership:

40th Annual CLIO Awards 1999 – Self-Promotional Website Design: Silver
 Communication Arts Interactive Design Annual 1999 – Award of Excellence
 HOW Design Competition 1999 & 2000 – Interactive Design & Multimedia Merit Awards
 SXSW Interactive Website Competition 1999 – Best Use of Animation & Best Use of Audio
 One Show Interactive Awards 1999 – Self-Promotional Website Design: Silver
 Macromedia Sites with Life Gallery – Shocked Site of the Week 1999, Shocked Site of the Day 1998
 New Media Invision Awards 1999 – Creative & Technical Excellence: Gold for Interface Design

Representative clients:

Austin Children's Museum – interactive electronic playscape design
 Chiron Informatics – task analysis & product design for medical informatics suite
 CPB (Corporation for Public Broadcasting) – interactive TV design consulting
 FastTrack Systems – interaction design for suite of handheld medical applications

frogdesign – various product interaction & navigational architectures
 GSD&M – guidelines and architecture for client extranet
 Human Code – school of the future interaction design & B2B process design
 Interval Research Corporation – interface design for broadband interactivity
 marchFIRST – various e-commerce UI blueprints, including ToysRus.com & JCPenney.com
 Microsoft / WebTV – next generation set-top product specification & UI production
 pcOrder.com – interface design for web-based product ordering system
 Portal Communications – user interface for Disney/Epcot Center’s “Home of the Future”
 Regis McKenna / Hands On Technology – product and demo design of targeted market analysis tools
 Sega of America – advanced technology set-top box UI design and global gaming portal
 Sprint PCS – wireless web UI design evaluation & concept development
 Texas Instruments – next-generation wireless calculator network UI design & specification
 Viacom / Noggin – interface design & developer guidelines for children’s TV + web channels

Yahoo! Inc. – Sunnyvale, California

2004 to 2005

Senior Director of User Experience, Communications & Consumer Services

Grew and lead team of 55 interaction designers, visual designers, user researchers, ethnographers, and prototype engineers responsible for crafting the user experience of Yahoo!’s core communications applications and services. These products collectively served over 340 million people worldwide. Developed thematic roadmap for business unit; established new techniques for rapidly incubating next generation product concepts. Introduced tactical quality control metrics and held ultimate responsibility for the design and integration of email, messaging, VoIP, address book, photo sharing, mobile products, set-top products, dating / match-making apps, and partner-bundled desktop applications.

Microsoft Corporation – Redmond, Washington

2001 to 2003

Interaction Design Manager, Windows Hardware Innovation Group

Joined the Windows Hardware Innovation Group at inception to formulate and drive interaction design strategy, counterbalanced against business planning and platform architecture. Championed consistent user experiences across Microsoft products and established cross-company task forces for establishing consensus between Windows shell, Tablet PC, Media Center, Pocket PC, Smart Phone, Smart Display, SPOT, and Office. Established methodologies for designing and validating scalable hardware user experiences for Longhorn, built publicly acclaimed hardware interaction prototypes (*Athens Communications PC* and *Microsoft Navigation Signature*), and set precedent for seeding internal developers with hardware convergence fixtures (e.g. navigation controls, auxiliary displays, actuator/indicator simulators, and communications panel hardware development kit). Lead design of modality-agnostic interactions for real-time telecommunications and video conferencing. First named inventor on over 30 patent applications for notification, navigation, power, security, and telephony control.

User Experience Manager, Tablet PC

Framed user experience agenda for the Tablet PC SKU, brought user-centric perspectives to the corporate business plan, delivered world-class Tablet PC product. Managed 32 interface design, industrial design, user research, and user assistance experts; organizing separate disciplines into a unified practice to maximize quality, efficiency and collaboration. Bridged communications with other organizations (e.g. program management, product development, business/marketing groups, OEMs, ISVs, Windows, Office, and other product divisions).

Vivid Studios – San Francisco, California

1993 to 1994

Senior Interaction Engineer

Responsibilities included leadership of information architecture, interface design, and functional specification services as well as creative direction and code architecture on select projects. Representative clients include:

Delphi – information architecture & interface for proof of concept graphical online services
 Regis McKenna / Hands On Technology – product design of targeted market analysis tools
 Sega of America – advanced technology set-top box UI design
 The WELL – information architecture & interface for early prototypes of graphical online services

Element Systems – New York, NY / San Francisco, CA**1984 to 1993***Interaction Engineer*

As an independent contractor, responsibilities included information architecture, interface design, functional specification and code engineering services. Representative clients include:

- Aetna Life Insurance** – first generation GUI for online customer financial information services
- Byrnes & Associates** – applications for collecting data & generating statistical results
- Kaleida Labs (Apple / IBM)** – desktop & handheld multimedia GUI toolkit and developer guidelines
- New York University / Bell Atlantic** – "YORB" interactive television program
- SoftWriters** – network-updating routines for *VersionTerritory* remote administration tool
- Wesleyan University Psychology Department** – test tools for millisecond timing of visual search tasks

Apple, Inc. – Cupertino, CA**Summer 1992***Design Intern, Advanced Technology Group*

As a student intern in the Human Interface Group, designed and programmed Macintosh user interfaces for docking handheld devices and navigating audio content on the desktop.

UNIVERSITY APPOINTMENTS**University of Texas – Austin, Texas****1996 to 1999***Senior Lecturer & Research Fellow in New Media Design, Department of Radio-TV-Film*

Established intensive New Media program. Advised graduate and undergraduate students. Courses taught:

- Basics of Multimedia Interaction Design** – interface design perspectives & processes
- Advanced Interaction Design** – cutting-edge experimental interaction design
- Advanced Interface Design** – advanced applied interface and information design

San Francisco State University (SFSU) – San Francisco, California**1994 to 1996***Faculty, Multimedia Studies Program*

Empowering the Audience: Basics of Multimedia Interaction Design

NON-PROFIT**Born Free USA – Silver Spring, Maryland****2020 to Present***Honorary Council*

Born Free USA is an internationally recognized leader in animal welfare and compassionate conservation. Born Free USA works tirelessly to ensure that all wild animals, whether living in captivity or in the wild, are treated with compassion and respect and are able to live their lives according to their needs.

Blue Lapis Light, Inc. – Austin, Texas**2007 to 2020***Director (Board Chair 2009-2016)*

Blue Lapis Light is an innovative site-specific aerial dance company founded by Artistic Director Sally Jacques to explore movement through the air: extending boundaries, defying edges, suspending graceful athleticism for the risk of igniting ephemeral beauty, and connecting audiences to a sense of wonder, possibility and hope.

EDUCATION

Master's Degree in Interactive Telecommunications – 1993

New York University – New York, New York

Awarded Graduate Assistantship

Bachelor's Degree in Cognitive Science – 1991

Wesleyan University – Middletown, Connecticut

International exchange at Doshisha University, Kyoto, Japan

ASSOCIATION MEMBERSHIPS

Association for Computing Machinery – 1992 to present (*Lifetime Member*)

Special Interest Group on Computer Human Interaction

Computer Professionals for Social Responsibility – 1992 to present (*Lifetime Member*)

Austin Intellectual Property Law Association – 2012 to present

INDUSTRY PRESENCE – CONFERENCES & TALKS

Silicon Valley International Invention Festival 2020 – *Santa Clara, California*

Senior Advisor, Geneva Invention Fair

Epic Events: State of Hardware 2020 – *San Francisco, California*

Panel & Judge: “Hardware Investor Panel”

SXSW (South by Southwest) Interactive 2019 – *Austin, Texas*

Panel: “The Role of Wearables as User Interface”

Empowering Texas Communities Conference 2018 – *Galveston, Texas*

Panel: “Pioneering Technologies to Reduce Energy Burden”

Carnegie Mellon Sustainability Conference 2017 – *Pittsburgh, Pennsylvania*

Keynote: “The Intersection Between Technology and Human Behavior”

SXSW (South by Southwest) Interactive 2017 – *Austin, Texas*

Panel: “IP: What You Need to Know to Protect Your Business”

Smart Cities Innovation Summit 2016 – *Austin, Texas*

Panel: “How Smart Meters Make Cities, Utilities and Consumers Smarter”

AlphaLab Gear National Hardware Cup 2016 – *Austin, Texas*

Judge: Pitch competition for early-stage hardware startups

BIT World Congress of U-Homes 2013 – *Dalian, China*

Presentation: “Interactive Video and Body-Based User Interfaces”

The TV of Tomorrow Show 2012 – *New York, New York*

Panel: “Beyond the Screen”

Computer-Human Interaction Forum of Oregon 2010 – *Portland, Oregon*

Presentation: “Designing into the Path of Disruptive Technology”

McGraw-Hill Media Summit 2010 – *New York, New York*

Panel: “Video Advertising: How New Consumer Habits Are Driving the Community to Innovate”

International CES (Consumer Electronics Show) 2010 – Las Vegas, Nevada

Panel: “Television and Video as an Interactive Content Experience”

The TV of Tomorrow Show 2010 – San Francisco, California

Panel: “Interactive Television Trend Analysis”

Digital Hollywood 2009 – Santa Monica, California

Panel: “Television and Video as an Interactive Content Experience”

Presentation: “Breakthroughs in Entertainment and Technology”

Windows Hardware Engineering Conference 2003 – New Orleans, Louisiana

Presentation: “Designing Intuitive Hardware Controls”

SXSW (South by Southwest) Interactive 2003 – Austin, Texas

Panel: “Convergent Devices of the Future”

ACM SigCHI (Human Factors in Computing Systems) 2001 – Seattle, Washington

Paper: “Poly-Vectoral Reverse Navigation: Simplifying Traversal to and from Shared Nodes”

American Intellectual Property Lawyers Association 2000 – Pittsburgh, Pennsylvania

Panel: “Incubating an eCommerce Company Effectively”

OzCHI (Human Factors in Computing Systems) 2000 – Sydney, Australia

Paper: “Virtual Force-Feedback: Kinesthetic Engagement without Custom Hardware”

Paper: “Multidimensional Topic Space: From Search to Browse with Relative Salience Controls”

ACM SigCHI (Human Factors in Computing Systems) 2000 – Den Hague, The Netherlands

Tutorial: “Interactive Television: New Possibilities, Techniques & Metrics”

Paper: “Seamless Video Expansion: Shaping the Contour of Streams for Personalized TV”

SXSW (South by Southwest) Interactive 2000 – Austin, Texas

Sponsor: Interactive Art Exhibition on Emerging Cultural Renaissance

SXSW (South by Southwest) Interactive 1999 – Austin, Texas

Panel Moderator: “Interface Design as Social Architecture”

SXSW (South by Southwest) Interactive 1997 – Austin, Texas

Panel: “The Future of Interface Design: Wherever You Are, Interaction Is.”

SXSW (South by Southwest) Interactive 1996 – Austin, Texas

Panel: “Making Your Content Meaningful”

Multimedia Live! 1995 – San Francisco, California

Panel: “Cutting Edge Interface Design”

ACM InterCHI (Human Factors in Computing Systems) 1993 – Amsterdam, The Netherlands

Paper: “Relativity Controller: Reflecting User Perspective in Document Spaces”

INDUSTRY PRESENCE – OTHER PUBLICATIONS

Bear, Eric J. Gould (2014). Model Intellectual Property Report: High-Tech Expert. In J. Mangraviti, Jr., Esq., S. Babitsky, Esq., & N. Nasser Donovan, Esq. (Eds.), *How to Write an Expert Witness Report* (pp. 395-410). Falmouth, MA: SEAK, Inc.

Bear, Eric J. Gould (2014). Model CV. In J. Mangraviti, Jr., Esq., S. Babitsky, Esq., & N. Nasser Donovan, Esq. (Eds.), *How to Be a Successful Expert Witness: A-Z Guide* (pp. 565-575). Falmouth, MA: SEAK, Inc.

In the Supreme Court of the United States

On Petition for a Writ of Certiorari to the United States Court of Appeals for the Federal Circuit: Brief of Amici Curiae Trading Technologies International, Inc., et al., in Support of Petitioner, *Alice Corporation Pty. Ltd., v. CLS Bank International, et al.*, Civil Action No. 13-298, (filed Oct 7, 2013).

On Writ of Certiorari to the United States Court of Appeals for the Federal Circuit: Brief of Amici Curiae Trading Technologies International, Inc., et al., in Support of Petitioner, *Alice Corporation Pty. Ltd., v. CLS Bank International, et al.*, Civil Action No. 13-298, (filed Jan 28, 2014).

IP Watchdog – Leesburg, Virginia

“Designing Into the Path of Disruptive Technology: An Interview with Software Expert Eric Gould Bear”
IPWatchdog.com, April 28, 2013.

“Software Patents: Drafting for Litigation and a Global Economy”
IPWatchdog.com, April 30, 2013.

“Software Patents: The Engineer vs. Designer Perspective”
IPWatchdog.com, May 5, 2013.

“False Distinctions Between Hardware and Software Patents are Not the Answer”
IPWatchdog.com, June 9, 2013.

“Prelude to SCOTUS Oral Arguments in Alice v. CLS Bank: A Conversation with Eric Gould Bear”
IPWatchdog.com, March 28, 29 & 30, 2014.

Interactive TV Today – San Francisco, California

“Radio Show: Interview with MONKEYmedia’s Eric Gould Bear”
ITVT.com, October 8, 2009.

“ITV Doctor: MONKEYmedia Defines ‘True Telescoping’”
ITVT.com, June 7, 2010.

ACM Interactions (Association of Computing Machinery) – New York, New York

“Industry Snapshot: MONKEYmedia”
ACM Interactions, 2001, March/April, pp. 63-70.

InterActivity Magazine (Miller Freeman) – San Mateo, California

User Interface Design Columnist

“Empowering the Audience: The Interface as a Communications Medium”
Interactivity Magazine, 1995, September/October, pp. 86-88.

“Connecting Participants to Content: Five Styles of Engagement”
Interactivity Magazine, 1996, January, pp. 76-80.

“Software Interaction Device Characteristics: A Functional Taxonomy”
Interactivity Magazine, 1996, February, pp. 76-80.

“Decoupling the Cursor from the Mouse & Fashioning Their Relationship by Choice (Part I)”
Interactivity Magazine, 1996, March, pp. 70-73.

“Fashioning Practical Relationships between the Cursor and the Mouse (Part II)”
Interactivity Magazine, 1996, April, pp. 78-82.

“Fashioning Creative Relationships between the Cursor and the Mouse (Part III)”
Interactivity Magazine, 1996, July, pp. 68-71.

“Shock Treatment: Redefining Interactivity on the Net”
Interactivity Magazine, 1996, July, pp. 40-52.

“What OS Toolkits Do with Buttons that Authoring Tools Don’t”
Interactivity Magazine, 1996, October, pp. 60-63.

“Respect Thy Audience: Raising the Lowest Common Denominator”
Interactivity Magazine, 1996, December, pp. 60-63.

“Diversity in Your Audience: What’s Worth Worrying About?”
Interactivity Magazine, 1997, February, pp. 68-69.

“Personal Perception (Part I): Preparing Interfaces for Human Variation”
Interactivity Magazine, 1997, April, pp. 66-67.

“Personal Perception (Part II): Preparing Interfaces for Human Variation”
Interactivity Magazine, 1997, July, pp. 68-70.

“Personal Perception (Part III): How Friendly is Friendly?”
Interactivity Magazine, 1997, October, pp. 80 & 72.

MIT Press Journals – Cambridge, MA

Rachel Strickland, Eric Gould Bear, and Jim McKee.

“Walk-in Theater: Interaction Design for a Miniature Experience with Peripatetic Cinema.”
Leonardo, Volume 51, Issue 5, October 2018, pp. 482-490.

PATENTS

*Inventor on the following families of United States patents and published patent applications.
(international catalog available upon request)*

<u>Title</u>	<u>App. Date</u>	<u>App. #</u>	<u>Patent #</u>	<u>Issue Date</u>	<u>Inventor(s)</u>
Computer User Interface with Non-Salience Deemphasis <i>(AKA "Relativity Controller")</i>	12/14/1992	07/990,339	5,623,588	04/22/1997	Gould; Eric Justin (Austin, TX)
	04/18/1997	08/844,466	6,177,938	01/23/2001	
	11/30/1999	09/451,594	6,335,730	01/01/2002	
	11/30/1999	09/451,595	6,219,052	04/17/2001	
	11/30/1999	09/452,275	6,215,491	04/10/2001	
	09/04/2001	09/947,196	8,381,126	02/19/2013	
Method for Video Seamless Contraction	10/30/2007	11/978,945	8,370,745	02/05/2013	Gould; Eric Justin (Austin, TX)
Video Player with Seamless Contraction	10/30/2007	11/978,965	8,370,746	02/05/2013	
Electronic Calendar Auto-Summarization	10/10/2008	12/248,931	8,392,848	03/05/2013	
Virtual Force Feedback Interface	03/25/1999	09/276,617	6,433,775	08/13/2002	Gould; Eric Justin (Austin, TX), Trisnadi; Paulus W. (Austin, TX), Ho; Tina Chia (Plano, TX), Wilkins; S. Todd (San Francisco, CA)
	01/20/2000	09/488,616	6,583,782	06/24/2003	
Method and Storage Device for Expanding and Contracting Continuous Play Media Seamlessly	04/23/1999	09/298,336	6,393,158 Re-Exam C1	05/21/2002 02/22/2013	Gould; Eric Justin (Austin, TX), Strickland; Rachel M. (San Francisco, CA)
	03/26/2002	10/107,945	6,615,270 <i>disclaimed</i>	09/02/2003 05/24/2011	
	06/24/2003	10/603,581	7,467,218 <i>disclaimed</i>	12/16/2008 09/30/2013	
Method and Apparatus for Seamless Expansion of Media	04/23/1999	09/298,681	6,621,980	09/16/2003	Gould; Eric Justin (Austin, TX), Strickland; Rachel M. (San Francisco, CA)
Audiovisual Presentation with Interactive Seamless Branching and/or Telescopic Advertising	10/30/2007	11/978,966	7,890,648 <i>disclaimed</i>	02/15/2011 09/30/2013	
	11/08/2010	12/941,830	8,122,143 <i>cancelled</i>	02/21/2012 01/18/2017	
	01/11/2012	13/348,624	9,185,379	11/10/2015	
	09/10/2012	13/609,157	9,247,226	01/26/2016	
	11/06/2015	14/934,950	10,051,298	08/14/2018	
Method, Apparatus and Article of Manufacture for Displaying Traversing and Playing Content in a Multi-Dimensional Topic Space	06/08/1999	09/327,893	6,281,899	08/28/2001	Gould; Eric Justin (Austin, TX), Strickland; Rachel M. (San Francisco, CA)
	06/08/1999	09/328,051	6,326,988	12/04/2001	
	09/14/2001	09/952,908	6,556,226	04/29/2003	
	03/11/2003	10/387,359	7,689,935	03/30/2010	

Poly-Vectoral Reverse Navigation	11/02/1999	09/433,614	6,505,209	01/07/2003	Gould; Eric Justin (Austin, TX), Buckmaster; Janna (Austin, TX), Wilkens; Todd (San Francisco, CA), Trisnadi; Paulus W. (Austin, TX)
	10/08/2002	10/268,109	6,745,201	06/01/2004	
	04/08/2004	10/822,155	7,461,426	12/09/2008	
	08/31/2006	11/514,373	7,953,768	05/31/2011	
	05/19/2011	13/111,513	8,577,932	11/05/2013	
Display Interface for Navigating Search Results	08/31/2006	11/514,287	7,668,827	02/23/2010	
	02/28/2012	13/407,744	8,606,829	12/10/2013	

User Interface for Simultaneous Management of Owned and Unowned Inventory	12/28/1999	09/473,901	6,693,236	02/17/2004	Gould; Eric Justin (Austin, TX), West; Nick (Austin, TX), McCaskill; Donald (Austin, TX), Clark; Alice (Austin, TX), Trisnadi; Paulus (Austin, TX)
	10/29/2003	10/696,379	7,173,177	02/06/2007	
	08/29/2006	11/512,893	7,642,443	01/05/2010	
	08/29/2006	11/512,894	7,321,093	01/22/2008	

System, Method, and Article of Manufacture for Seamless Integrated Searching	03/23/2000	09/534,912	6,633,903	10/14/2003	Gould; Eric Justin (Austin, TX)
	08/05/2003	10/635,880	7,653,704	01/26/2010	
	08/29/2006	11/512,904	7,739,357	06/15/2010	

Ergonomic and Functionally-Efficient One-Hand User Input Interface	05/02/2003	D/180,925	D517,070	03/14/2006	Bear; Eric Justin Gould (Austin, TX), Teasley; Barbee Eve (Leavenworth, WA), Keely; Leroy Bertrand (Portola Valley, CA), Vong; William Hong (Seattle, WA)
	01/13/2004	D/197,249	D508,492	08/16/2005	
	01/16/2004	D/197,605	D506,747	06/28/2005	
	01/16/2004	D/197,610	D506,757	06/28/2005	
	01/16/2004	D/197,633	D508,048	08/02/2005	
	01/16/2004	D/197,689	D506,197	06/14/2005	
	01/23/2004	D/198,054	D524,294	07/04/2006	
	01/23/2004	D/198,073	D505,952	06/07/2005	
	01/23/2004	D/198,075	D505,953	06/07/2005	
	01/23/2004	D/198,076	D507,572	07/19/2005	
	01/23/2004	D/198,082	D508,049	08/02/2005	
	01/23/2004	D/198,091	D506,467	06/21/2005	
	01/30/2004	D/198,537	D506,468	06/21/2005	
	01/30/2004	D/198,560	D508,050	08/02/2005	
	01/30/2004	D/198,581	D505,954	06/07/2005	

Computer System with Do Not Disturb System and Method	05/05/2003	10/429,903	7,443,971	10/28/2008	Bear; Eric Gould (Austin, TX), Magendanz; Chad (Issaquah, WA), Adams; Aditha May (Seattle, WA), Ledbetter; Carl (Mercer Island, WA), Kaneko; Steve (Medina, WA)
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Record Button on a Computer System	05/05/2003	10/429,904	7,827,232	11/02/2010	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA)
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Real-time Communications Architecture and Methods for Use with a Personal Computer System	08/10/2007	11/837,302	7,577,429	08/18/2009	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA), Crosier; Dale C. (WA), Plank; Robert Scott (WA), Van Flandern; Michael W. (WA), DeMaio; Pasquale (WA)
Method and System for Standby Auxiliary Processing of Information for a Computing Device	05/05/2003	10/429,930	7,240,228	07/03/2007	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA), Schoppa; Chris (WA), Chandley; Adrian M. (WA), Westerinen; William J. (WA), Crosier; Dale C. (WA)
Notification Lights, Locations and Rules for a Computer System	05/05/2003	10/429,931	7,372,371	05/13/2008	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA), Chandley; Adrian M. (WA)
Method and System for Auxiliary Display of Information for a Computing Device	05/05/2003	10/429,932	7,221,331	05/22/2007	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA), Schoppa; Chris (WA), Chandley; Adrian M. (WA), Westerinen; William J. (WA), Crosier; Dale C. (WA), Plank; Robert Scott (WA)
	08/23/2006	11/509,437	7,913,182	03/22/2011	
Computer Camera System and Method for Reducing Parallax	05/05/2003	10/429,943	7,551,199	06/23/2009	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA)
Method and System for Activating a Computer System	05/05/2003	10/430,369	7,424,740	09/09/2008	Bear; Eric Gould (Austin, TX), Magendanz; Chad (WA), Adams; Aditha May (WA), Ledbetter; Carl (WA), Kaneko; Steve (WA), Schoppa; Chris (WA), Chandley; Adrian M. (WA), Westerinen; William J. (WA)
System and Method for Using Telephony Controls on a Personal Computer	09/30/2003	10/677,084	7,440,556	10/21/2008	Bear; Eric Gould (Austin, TX), Magendanz; Chad (Issaquah, WA), Adams; Aditha May (Seattle, WA), Ledbetter; Carl (Mercer Island, WA), Kaneko; Steve (Medina, WA), Crosier; Dale C. (Kirkland, WA), Plank; Robert Scott (Bellevue, WA)

Method and System for Capturing Video on a Personal Computer	09/30/2003	10/677,118	7,548,255	06/16/2009	Bear; Eric Gould (Austin, TX), Magendanz; Chad (Issaquah, WA), Adams; Aditha May (Seattle, WA), Ledbetter; Carl (Mercer Island, WA), Kaneko; Steve (Medina, WA)
Method and System for Navigation Using Media Transport Controls	09/30/2003	10/677,106	7,194,611	03/20/2007	Bear; Eric Gould (Austin, TX), Magendanz; Chad (Issaquah, WA), Adams; Aditha May (Seattle, WA), Ledbetter; Carl (Mercer Island, WA), Kaneko; Steve (Medina, WA), Crosier; Dale C. (Kirkland, WA)
Method and System for Unified Audio Control on a Personal Computer	09/30/2003	10/677,101	7,216,221	05/08/2007	Bear; Eric Gould (Austin, TX), Magendanz; Chad (Issaquah, WA), Adams; Aditha May (Seattle, WA), Ledbetter; Carl (Mercer Island, WA), Kaneko; Steve (Medina, WA), Crosier; Dale C. (Kirkland, WA)
	11/14/2006	11/559,821	8,245,027	08/14/2012	
	03/12/2007	11/685,014	7,624,259	11/24/2009	
	04/28/2009	12/431,597	8,127,125	02/28/2012	
	09/18/2009	12/563,026	8,166,287	04/24/2012	
	09/18/2009	12/563,041	8,644,481	02/4/2014	
	04/12/2012	13/445,221	8,443,179	05/14/2013	
Systems and Methods for Interfacing with Computer Devices	01/30/2004	10/768,777	7,469,386	12/23/2008	Bear; Eric Justin Gould (Austin, TX), Vong; William Hong (Seattle, WA), Keely; Leroy Bertrand (Portola Valley, CA), Teasley; Barbee Eve (Leavenworth, WA), Richardson; Adam John (Oakland, CA), Tsang; Michael H. (Bellevue, WA), Greene; Richard (San Rafael, CA), Fogarty; Michael David (San Francisco, CA), Hinckley; Kenneth Paul (Redmond, WA)
Symbolic Representation of Protocol-Specific Information	12/19/2006	11/612,639			Frishberg; Leo David (Portland, OR), Bear; Eric Gould (Austin, TX)
Schematic Display of Protocol-Specific Information	04/25/2007	11/740,135	8,837,294	09/16/2014	
Data Object Based Data Analysis	08/09/2007	60/954,873	provisional	n/a	
	09/27/2007	11/862,830	7,827,209	11/02/2010	

Method and System for Maintaining Data Recoverability	09/03/2009	12/553,579			Bear; Eric Justin Gould (Austin, TX), Bouteruche; David (Austin, TX), Debrouette; Stephane (Lambersart, France), Leman; Christian (Austin, TX), Power-Freeman; Mark Benjamin (Austin, TX), Moorman; Jan (Austin, TX), Sayre; Vasken N. (Austin, TX), Oshima; Peter (Austin, TX)
Method and System for Backup and Recovery	06/04/2009	61/184,267	provisional	n/a	
	11/06/2009	12/613,689			
Home Intelligence System	06/21/2016	14/944,118	10,187,707	01/22/2019	Norwood; Erik (Austin, TX), Bohde; Josh (Austin, TX), Bear; Eric Gould (Austin, TX)
	01/21/2019	16/253,164			
Head-mounted (or Handheld) Display Device for Navigating Virtual & Augmented Reality (AKA "Portable Proprioceptive Peripatetic Polylinear Video Player")	06/29/2012	61/666,216	provisional	n/a	Bear; Eric Justin Gould (Austin, TX), Strickland; Rachel M. (San Francisco, CA), McKee; James (San Francisco, CA)
	07/25/2015	14/810,262	9,791,897	10/17/2017	
	06/20/2016	15/186,776	9,612,627	04/04/2017	
	02/07/2017	15/426,828	9,656,168	05/23/2017	
	02/26/2018	15/905,182	10,596,478	03/24/2020	
	02/18/2020	16/793,056	11,266,919	03/08/2022	
	01/25/2022	17/583,940			
	02/18/2022	17/676,082			
Remote Controlled Vehicle with Head-mounted (or Handheld) Display Device & Augmented Reality	06/20/2016	15/186,783	9,563,202	02/07/2017	
	06/20/2016	15/186,793	9,579,586	02/28/2017	
	02/06/2017	15/425,666	9,658,617	05/23/2017	
	02/07/2017	15/426,697	9,782,684	10/10/2017	
	09/01/2017	15/694,210	9,919,233	03/20/2018	

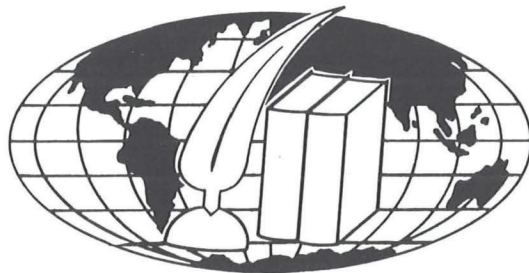
APPENDIX B

A Definition of Orientation

Funk & Wagnalls

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accompanied the plain song with another part. See ORGANUM (def. 2).

or-gan-i-za-tion (ôr'gân-ə-zā'shən, -ī-zā-) *n.* 1 The act of organizing, or the state of being organized; also, that which is organized. 2 An animal or vegetable organism. 3 A number of individuals systematically united for some end or work: a military organization. 4 The officials, committeemen, etc., who control a political party: also called *machine*. 5 Any combination of parts. Also *Brit.* **organ-i-sa'tion**.

or-gan-ize (ôr'gân-īz) *v.* **-ized, -izing** *v.t.* 1 To bring together or form as a whole or combination, as for a common objective. 2 To arrange systematically; order. 3 To furnish with organic structure. 4 **a** To enlist (workers) in a trade union. **b** To unionize the workers of (a factory, etc.). —*v.i.* 5 To form or join an organization. Also *Brit.* **organ-ise**. See synonyms under INSTITUTE. [*<Med. L. organizare <L. organum ORGAN*] —**or'gan-iz-a-ble** *adj.* —**or'gan-iz-er** *n.*

organo- *combining form* 1 *Biol.* Related to anorgan, or to the organs of the body: *organogenesis*. 2 *Chem.* Organic: *organometallic*. [*<Gk. organon an instrument, organ*]

organ of Corti A complex structure in the human ear directly involved with the perception of sound: discovered by Alfonso Corti.

or-ga-no-gen-e-sis (ôr'gā-nō-jen'ə-sis) *n. Biol.* The development of organs in animals and plants. —**or'ga-no-ge-net'ic** (-jə-net'ik) *adj.*

or-ga-nog-ra-phy (ôr'gā-nog'rā-fē) *n.* Scientific description of organs; descriptive organology. —**or'ga-no-graph'ic** (-nō-grāf'ik) or **-i-cal** *adj.*

or-ga-no-lep-tic (ôr'gā-nō-lep'tik) *adj. Physiol.* 1 Having an effect upon one of the organs of sense, as taste or smell. 2 Of or pertaining to sense impressions and their evaluation: applied especially to laboratory tests of food, flavors, and odors. [*<F. organoleptique <Gk. organon organ + lep-, stem of lambainein take*]

or-ga-nol-o-gy (ôr'gā-nō-lō-jē) *n.* The branch of biology that treats of organs of the body. —**or'ga-no-log'ic** (-nō-lōj'ik) or **-i-cal** *adj.* —**or'ga-nol'o-gist** *n.*

or-ga-no-me-tal-lic (ôr'gā-nō-mə-tal'ik) *adj. Chem.* Designating or pertaining to a compound of metal and carbon.

or-ga-non (ôr'gā-nōn) *n. pl. -na* (-nə) or **-nons** A system of rules and principles considered as an instrument of guidance, as of knowledge or thought. Also *organum*. [*<Gk., organ*]

or-ga-no-sil-i-con (ôr'gā-nō-sil'ə-kōn) *n. Chem.* Any of an important class of compounds or polymers containing silicon and carbon; a silicene.

or-ga-no-ther-a-py (ôr'gā-nō-ther'ə-pē) *n. Med.* The treatment of disease by remedies derived from animal organs. Also **or'ga-no-ther-a-peu'tics** (-ther'ə-pyōō'tiks).

organ pipe One of the long tubes of a pipe organ, in which a column of air is made to vibrate so as to produce a tone of definite pitch.

or-ga-num (ôr'gā-nōm) *n. pl. -na* (-nə) or **-nums** 1 An organon. 2 In medieval music, a part sung as an accompaniment to the melody or plain song at an interval of a fourth or a fifth above or below it; also, this method of part singing. [*<L. ORGAN*]

or-gan-za (ôr-gan'zə) *n.* A sheer, crisp fabric used for evening dresses, trimming, etc. [Origin uncertain]

or-gan-zine (ôr'gân-zēn) *n.* 1 A silk thread made of several single threads twisted together; thrown silk. 2 A fabric made of orgazine. [*<F. organsin <Ital. organzine; ult. origin unknown*]

or-gasm (ôr'gaz-əm) *n.* 1 Immoderate or extreme excitement or behavior. 2 *Physiol.* The acme of excitement at the culmination of the sexual act, followed by detumescence. [*<F. orgasme <Gk. orgasmos a swelling <orgaîn swell, be excited*] —**or-gas-mic** (ôr-gaz'mik), **or-gas-tic** (ôr-gas'tik) *adj.*

or-geat (ôr'zhat, *Fr.* ôr-zhâ') *n.* A sirup made from barley water and sugar flavored with almonds, orange flowers, etc. [*<MF <Provençal orjat <ordi, orge barley <L. hordeum*]

Or-get-or-ix (ôr-jet'ə-riks) Helvetian chief of the first century B.C. who opposed Julius Caesar.

or-gi-as-tic (ôr'jē-as'tik) *adj.* Pertaining to or resembling the Greek orgies; hence, marked by wild revelries. Also **or'gi-ac**, **or'gic**. [*<Gk. orgiastikos <orgâtes a celebrator of an orgy <orgiizein celebrate orgies*]

or-gone (ôr'gōn) *n.* In the psychobiology of Wilhelm Reich, biological energy, accumulated from

the environment and discharged gradually in all activity but suddenly in the orgasm: identified with the libido, as defined by Freud and, tentatively, with the ether of older physical theories.

or-gy (ôr'jē) *n. pl. -gies*. 1 Wild or wanton revelry; a drunken carousal; debauch. 2 Any immoderate or excessive indulgence in something; an orgy of reading. 3 *pl.* The secret rites in honor of certain ancient Greek and Roman deities, as Dionysus, marked by ecstatic or frenzied songs and dances. [Earlier orgies, *pl.* *<MF <L. orgia <Gk., secret rites*]

or-i-bi (ôr'ə-bē, or'ə-) *n. pl. -bis* or **-bi** A small, dun-colored African antelope (genus *Ourebia*), about two feet high at the shoulder: also spelled *ourebi*. [*<Afrikaans <Hottentot arab*]

or-i-chalc (ôr'ī-kalk, or'ə-) *n.* In ancient Greece, an alloy of copper and zinc, resembling gold; brass. Also **or'ī-chalch**. [*<L. orichalcum <Gk. oreichalkon, lit., mountain copper <oros, oreos a mountain + chalkos copper, brass*]

or-iel (ôr'ē-əl, ôr'ē-) *n. Archit.* A bay window; especially, one built out from a wall and resting on a bracket or similar support. [*<OF. oriol a porch, gallery, ? <Med. L. oriolum; ult. origin unknown*]

or-ient (ôr'ē-ənt, ôr'ē-) *n.* 1 The east; opposed to *occident*. 2 The eastern sky; also, dawn; sunrise. 3 The iridescent luster of a pearl. —*v.t.* 1 To cause to face or turn to the east. 2 To place or adjust, as a map, in exact relation to the points of the compass. 3 To adjust according to first principles or recognized facts or truths; adapt (oneself) mentally to a situation. 4 To adjust in relation to something else: His experience oriented his ideas toward science. —*adj.* 1 Resembling sunrise; bright. 2 Ascending. [*<OF. <L. oriens, -entis rising sun, east, orig. ppr. of oriri rise*]

O-ri-ent (ôr'ē-ənt, ôr'ē-) The East; Asia, especially eastern Asia: opposed to *Occident*.

or-ien-tal (ôr'ē-en'təl, ôr'ē-) *adj.* 1 *Astron.* Eastern; appearing or being in the eastern sky: said of stars and planets. 2 Specially bright, clear, and pure: said of gems. 3 Noting a variety of precious corundum, especially sapphire, marked by colors suggestive of other gems: an *oriental* amethyst, *oriental* aquamarine, *oriental* emerald, *oriental* topaz. —**or'ien-tal-ly** *adv.*

O-ri-en-tal (ôr'ē-en'təl, ôr'ē-) *adj.* 1 Of or pertaining to the Orient; eastern. 2 Magnificent; gorgeous; sumptuous: *Oriental* luxury. 3 Designating a zoogeographical realm or region which includes India, southern Asia, the East Indies, and the Philippine Islands. —*n.* An inhabitant of Asia; an Asian. Opposed to *Occidental*. Also **or'ien-tal**.

O-ri-en-tal-ism (ôr'ē-en'təl-iz'əm, ôr'ē-) *n.* 1 An Oriental quality or character of thought, speech or manners, or the disposition to adopt such a quality or character. 2 Knowledge of or proficiency in Oriental languages, literature, etc. Also **or'ien-tal-ism**. —**O-ri-en-tal-ist** *n.*

O-ri-en-tal-ize (ôr'ē-en'təl-īz, ôr'ē-) *v.t. & v.i. -ized, -izing* To make or become Oriental. Also *Brit.* **O-ri-en-tal-ise**.

Oriental rug A rug or carpet hand-woven in one piece in the Orient.

oriental topaz A yellow form of corundum used as a gemstone.

or-ien-tate (ôr'ē-en-tāt', ôr'ē-) *v. -tated, -tat-ing* *v.t.* To orient —*v.i.* To face or turn eastward or in some specified direction; be oriented. [*<F. orienter <OF. orient ORIENT*]

or-ien-ta-tion (ôr'ē-en-tā'shən, ôr'ē-) *n.* 1 The act of orienting, or the state of being oriented. 2 Position, or the determining of position, with relation to the points of the compass. 3 The determination or adjustment of one's position with reference to circumstances, ideals, etc. 4 *Psychol.* Awareness of one's own temporal, spatial, and personal relationships. 5 *Archit.* The construction of a church upon an east-west axis, so as to have the altar in the eastern end. 6 The homing instinct, as in pigeons. 7 *Chem.* The particular disposition of the constituent atoms in a compound, especially as determined by electrical forces.

O-ri-en-te (ôr'ē-en'tā, ôr'ē-) 1 A province of eastern Cuba; 14,132 square miles; capital, Santiago de Cuba: formerly *Santiago de Cuba*. 2 A region and former province of Ecuador, comprising all its territory east of the Andes.

o-ri-en-ted (ôr'ē-en-tid, ôr'ē-, -ən-tid) *adj.* 1 Directed toward; interested in: *oriented* to the arts. 2 Directed or centered: used in combination: *child-oriented*.

or-i-fice (ôr'ə-fis, or'ə-) *n.* A small opening into a cavity; an aperture. See *HOLE*. [*<MF <LL. orificium <L. os, oris mouth + facere make*]

or-i-flamme (ôr'ə-flam, or'ə-) *n.* 1 The red banner of the abbey of St. Denis, used as a battle standard by the kings of France until the 15th century. 2 *Her.* A blue banner charged with three fleurs-de-lis of gold. 3 Any flag or standard. Also spelled *auriflamme*. [*<F. <OF. oriflambe <Med. L. auriflamma <L. aurum gold + flamma a flame*]

or-i-ga-mi (ôr'ī-gā'mē) *n.* The ancient Japanese art of folding single sheets of paper into animal and other forms, usually without the aid of scissors or paste. [*<Japanese*]

or-i-gan (ôr'ə-gan, or'ə-) *n.* The wild marjoram (*Origanum vulgare*), an important source of carvacrol: its fragrant leaves are esteemed as a seasoning. Also spelled *oregano*. [*<OF. <L. origanum <Gk. origanon, an herb like marjoram <oros, oreos a mountain + ganos brightness, joy*]

O-ri-gen (ôr'ə-jen, -jən, or'ə-), 185?-254?, Greek theologian.

or-i-gin (ôr'ə-jin, or'ə-) *n.* 1 The commencement of the existence of anything. 2 A primary source; cause. 3 Parentage; ancestry. 4 *Anat.* The relatively fixed point of attachment of a muscle. Compare *INSERTION*. 5 *Math.* a The point at which the axes of a Cartesian coordinate system intersect; the point where the ordinate and abscissa equal zero. b The point in a polar coordinate system where the radius vector equals zero. See *ILLUSTRATION* under *QUADRANT*, *OCTANT*. See synonyms under *BEGINNING*. [Appar. *<OF. origine <L. origo, -inis a rise, beginning*]

or-ig-i-nal (ə-rij'ə-nəl) *adj.* 1 Of or belonging to the beginning, origin, or first stage of existence of a thing. 2 Immediately produced by one's own mind and thought; not copied or produced by imitation. 3 Able to produce works requiring thought, without copying or imitating those of others; creative; inventive. See synonyms under *AUTHENTIC*, *FIRST*, *NATIVE*, *PRIMEVAL*, *RADICAL*, *TRANSCENDENTAL*. —*n.* 1 The first form of anything. 2 The language in which a book is first written. 3 A person of unique character or genius; also, an eccentric. 4 Originator; also, origin. See synonyms under *IDEAL*, *MODEL*.

or-ig-i-nal-ity (ə-rij'ə-nəl'ə-tē) *n. pl. -ties* 1 The power of originating inventiveness. 2 The quality of being original or novel.

or-ig-i-nal-ly (ə-rij'ə-nəl-ē) *adv.* 1 At the beginning. 2 In a new and striking manner.

original sin *Theol.* The natural corruption and depravity inherent in mankind because of Adam's first sinful disobedience.

or-ig-i-nate (ə-rij'ə-nāt) *v. -nat-ed, -nat-ing* *v.t.* To bring into existence; create, initiate. —*v.i.* To come into existence; have origin; arise. See synonyms under *INSTITUTE*, *PRODUCE*, *PROPAGATE*. —**or-ig'i-na'tion** *n.* —**or-ig'i-na'tive** *adj.* —**or-ig'i-na'tive-ly** *adv.* —**or-ig'i-na'tor** *n.*

or-i-na-sal (ôr'ə-nā'zəl, or'ə-) *adj.* 1 *Anat.* Of or pertaining to the mouth and nose: the *orinasal* duct. 2 *Phonet.* Pronounced with the nasal and oral passages both open, as the French nasal vowels. —*n. Phonet.* An orinasal vowel. [*<L. os, oris mouth + NASAL*]

O-ri-no-co (ôr'ə-nō'kō, or'ə-) A river in Venezuela, flowing about 1,700 miles NW and north to the Atlantic Ocean.

or-i-ole (ôr'ē-əl, ôr'ē-) *n.* 1 Any of a family (*Oriolidae*) of black-and-yellow passerine birds of the Old World, related to the crows; the common *European* (or *golden*) *oriole* (*Oriolus oriolus*) is bright yellow with sharply contrasting black wings and tail, and builds a hanging nest. 2 One of various black-and-yellow American songbirds (family *Icteridae*) building a hanging nest; especially, the Baltimore oriole and the orchard oriole. [*<OF. oriol <Med. L. oriolus <L. aureolus, dim. of aureus golden <aurum gold*]

O-ri-on (ôr'ī-ən) 1 In Greek and Roman mythology, a giant hunter who pursued the

APPENDIX C

Tilt Sensing Using a Three-Axis Accelerometer

Tilt Sensing Using a Three-Axis Accelerometer

by: Mark Pedley

1 Introduction

Accelerometers are sensitive to both linear acceleration and the local gravitational field. The former provides information on taps and other handset motions allowing the development of 'gesture' user interfaces while the latter provides information on the accelerometer orientation which allows a smartphone or tablet display to automatically switch between portrait and landscape settings.

This application note documents the mathematics of orientation determination using a three-axis accelerometer. The techniques are applicable to both digital accelerometers and, after signal digitization, to analog accelerometers. For convenience, it is assumed that the accelerometer is mounted in a smartphone or tablet but the arguments apply to any product with an embedded three-axis accelerometer.

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The following Freescale application notes cover related topics:

- AN4399 "High Precision Calibration of a Three Axis Accelerometer" describes how a product containing a consumer grade accelerometer can be re-calibrated after manufacture to achieve a high level of accuracy.
- AN4248 "Implementing a Tilt-Compensated eCompass using Accelerometer and Magnetometer Sensors" contains the mathematics and reference source code for a tilt-compensated eCompass where the accelerometer is used to correct for the magnetometer tilt from horizontal.
- AN4249 "Accuracy of Angle Estimation in eCompass and 3-D Pointer Applications" documents the effect of accelerometer sensor errors on roll and pitch angle accuracy and ultimately on the eCompass heading accuracy.

1.1 Key Words

Accelerometer, Tilt, Roll, Pitch, Portrait, Landscape.

1.2 Summary

1. Accelerometer sensors measure the difference between any linear acceleration in the accelerometer's reference frame and the earth's gravitational field vector.
2. In the absence of linear acceleration, the accelerometer output is a measurement of the rotated gravitational field vector and can be used to determine the accelerometer pitch and roll orientation angles.
3. The orientation angles are dependent on the order in which the rotations are applied. The most common order is the aerospace sequence of yaw then pitch and finally a roll rotation.
4. Accelerometer sensors are insensitive to rotation about the earth's gravitational field vector. The equations for the roll and pitch angles therefore have mathematical instabilities when rotation axes happen to become aligned with gravity and point upwards or downwards. A workaround is presented to prevent this instability occurring.
5. Simple vector algebra expressions are derived for computing the tilt of the accelerometer from vertical or the rotation angle between any two accelerometer readings.
6. The most common application of accelerometers in consumer electronics is switching between portrait or landscape display modes. An algorithm is presented for controlling a tablet PC's display orientation.

2 Accelerometer Output Under Gravity and Acceleration

Accelerometers are sensitive to the difference between the linear acceleration of the sensor and the local gravitational field. The data sheet for any accelerometer will denote the positive x , y , and z axes on the sensor package and, by convention, these are defined so that a linear acceleration aligned in the direction of these axes will give a positive accelerometer output.

A gravitational field component aligned along the same axes directions will, however, result in a negative reading on the accelerometer. This can be understood by looking at an electron microscope image of a MEMS accelerometer. The upper proof mass is suspended by the restoring springs. Both a gravitational field directed to the left and a linear acceleration of the package to the right will deflect the proof mass to the left.

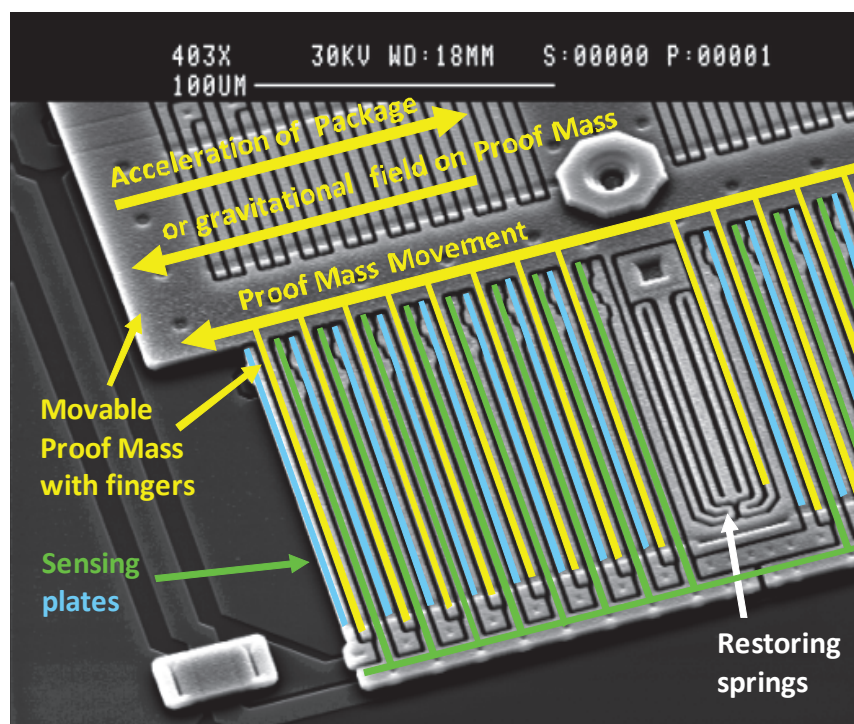


Figure 1. Electron Microscope Image of MEMS Accelerometer Proof Mass and Sensing Plates

The deflection of the proof mass is measured from the change in capacitance between the fingers of the proof mass and the sensing plates. A simplified transducer model and equivalent electrical circuit are shown in [Figure 2](#). Circuitry internal to the accelerometer sensor converts the tiny capacitance to a voltage signal which, in digital accelerometers, is then digitized and output as a digital word over a serial bus.

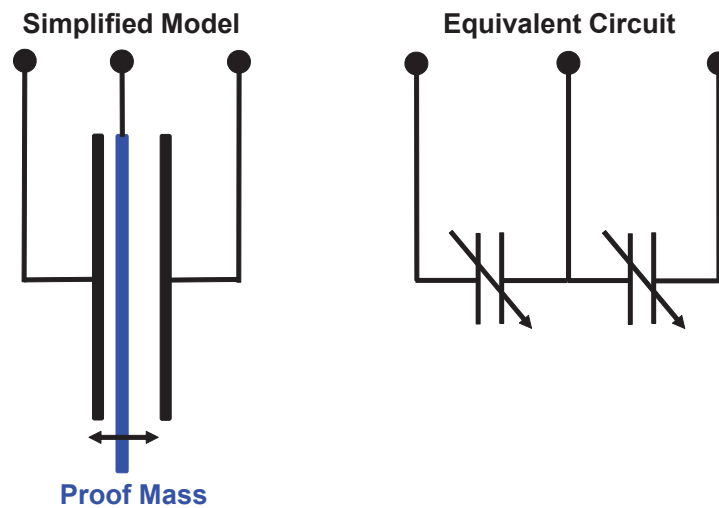


Figure 2. Simplified Transducer Model and Equivalent Electrical Circuit

The 'native' coordinate system of the accelerometer is not a convenient system to use when discussing the orientation of a consumer product, such as a smartphone, since the accelerometer can be mounted at any orientation on the circuit board which can, in turn, be mounted at an arbitrary angle in the final product. It is more sensible to use a coordinate system aligned with the smartphone product axes. [Figure 3](#) shows the coordinate system which will be used in this document:

- The *x-axis* is aligned along the body axis of the smartphone
- The *z-axis* points downwards so that it is aligned with gravity when the smartphone is flat on a table
- The *y-axis* is aligned at right angles to both the *x* and *z* axes so that the three axes form a right handed coordinate system.

Changes in orientation are described by rotations in roll ϕ , pitch θ and yaw ψ about the *x*, *y* and *z* axes respectively.



Figure 3. Definition of Coordinate System and Rotation Axes

In addition, since this document is concerned with measuring orientation in the earth's gravitational field, the convention will be adopted that the accelerometer output is negated to give value $+1g$ in any axis aligned with the earth's downward gravitational field.

With this assumption, a three-axis accelerometer mounted in a smartphone oriented in the earth's gravitational field $\mathbf{g}$ and undergoing linear acceleration $\mathbf{a}_r$ measured in the earth's reference frame r , will have output $\mathbf{G}_p$ given by:

$$\mathbf{G}_p = \begin{pmatrix} G_{px} \\ G_{py} \\ G_{pz} \end{pmatrix} = \mathbf{R}(\mathbf{g} - \mathbf{a}_r) \quad \text{Eqn. 1}$$

where $\mathbf{R}$ is the rotation matrix describing the orientation of the smartphone relative to the earth's coordinate frame.

It is further assumed that:

- The accelerometer has no linear acceleration $\mathbf{a}_p \approx 0$. This assumption is needed to solve Equation 1 for the rotation matrix $\mathbf{R}$ and, in consequence, any linear acceleration from handshake or other sources will introduce errors into the orientation estimate.
- The initial orientation of the smartphone is lying flat with the earth's gravitational field aligned with the smartphone z -axis:

With these additional assumptions, the smartphone accelerometer output $\mathbf{G}_p$ (measured in the native accelerometer units of g) is:

$$\mathbf{G}_p = \begin{pmatrix} G_{px} \\ G_{py} \\ G_{pz} \end{pmatrix} = \mathbf{R}\mathbf{g} = \mathbf{R} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 2}$$

The next section introduces the components of the rotation matrix $\mathbf{R}$ and describes how to determine the roll and pitch angles from the accelerometer reading.

3 Pitch and Roll Estimation

The orientation of the smartphone can be defined by its roll, pitch and yaw rotations from an initial position. The roll, pitch and yaw rotation matrices, which transform a vector (such as the earth's gravitational field vector $\mathbf{g}$) under a rotation of the coordinate system of Figure 3 by angles ϕ in roll, θ in pitch and ψ in yaw about the x , y and z axes respectively, are:

$$\mathbf{R}_x(\phi) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \phi & \sin \phi \\ 0 & -\sin \phi & \cos \phi \end{pmatrix} \quad \text{Eqn. 3}$$

$$\mathbf{R}_y(\theta) = \begin{pmatrix} \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \\ \sin \theta & 0 & \cos \theta \end{pmatrix} \quad \text{Eqn. 4}$$

$$\mathbf{R}_z(\psi) = \begin{pmatrix} \cos \psi & \sin \psi & 0 \\ -\sin \psi & \cos \psi & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad \text{Eqn. 5}$$

There are six possible orderings of these three rotation matrices and, in principle, all are equally valid. The rotation matrices do not, however, commute meaning that the composite rotation matrix $\mathbf{R}$ depends on the order in which the roll, pitch and yaw rotations are applied. It is instructive to compute the values of the six possible composite rotation matrices $\mathbf{R}$ and to determine their effect on the earth's gravitational field of $1g$ initially aligned downwards along the z -axis.

$$\mathbf{R}_{xyz} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_x(\phi) \mathbf{R}_y(\theta) \mathbf{R}_z(\psi) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 6}$$

$$= \begin{pmatrix} \cos \theta \cos \psi & \cos \theta \sin \psi & -\sin \theta \\ \cos \psi \sin \theta \sin \phi - \cos \phi \sin \psi & \cos \phi \cos \psi + \sin \theta \sin \phi \sin \psi & \cos \theta \sin \phi \\ \cos \phi \cos \psi \sin \theta + \sin \phi \sin \psi & \cos \phi \sin \theta \sin \psi - \cos \psi \sin \phi & \cos \theta \cos \phi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 7}$$

$$= \begin{pmatrix} -\sin \theta \\ \cos \theta \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 8}$$

$$\mathbf{R}_{yxz} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_y(\theta) \mathbf{R}_x(\phi) \mathbf{R}_z(\psi) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 9}$$

$$= \begin{pmatrix} \cos \psi \cos \theta - \sin \theta \sin \phi \sin \psi & \sin \psi \cos \theta + \sin \theta \sin \phi \cos \psi & -\sin \theta \cos \phi \\ -\cos \phi \sin \psi & \cos \phi \cos \psi & \sin \phi \\ \cos \theta \sin \phi \sin \psi + \sin \theta \cos \psi & -\cos \psi \cos \theta \sin \phi + \sin \psi \sin \theta & \cos \theta \cos \phi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 10}$$

$$= \begin{pmatrix} -\sin \theta \cos \phi \\ \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 11}$$

$$\mathbf{R}_{xzy} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_x(\phi) \mathbf{R}_z(\psi) \mathbf{R}_y(\theta) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 12}$$

$$= \begin{pmatrix} \cos \theta \cos \psi & \sin \psi & -\cos \psi \sin \theta \\ -\cos \phi \cos \theta \sin \psi + \sin \phi \sin \theta & \cos \phi \cos \psi & \cos \theta \sin \phi + \cos \phi \sin \theta \sin \psi \\ \cos \theta \sin \psi \sin \phi + \cos \phi \sin \theta & -\cos \psi \sin \phi & \cos \theta \cos \phi - \sin \theta \sin \phi \sin \psi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 13}$$

$$= \begin{pmatrix} -\cos \psi \sin \theta \\ \cos \theta \sin \phi + \cos \phi \sin \psi \sin \theta \\ \cos \phi \cos \theta - \sin \theta \sin \phi \sin \psi \end{pmatrix} \quad \text{Eqn. 14}$$

$$\mathbf{R}_{yzx} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_y(\theta) \mathbf{R}_z(\psi) \mathbf{R}_x(\phi) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 15}$$

$$= \begin{pmatrix} \cos \psi \cos \theta & \cos \phi \cos \theta \sin \psi + \sin \theta \sin \phi & \cos \theta \sin \phi \sin \psi - \sin \theta \cos \phi \\ -\sin \psi & \cos \phi \cos \psi & \cos \psi \sin \phi \\ \cos \psi \sin \theta & -\cos \theta \sin \phi + \cos \phi \sin \psi \sin \theta & \cos \theta \cos \phi + \sin \theta \sin \phi \sin \psi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 16}$$

$$= \begin{pmatrix} \cos \theta \sin \phi \sin \psi - \cos \phi \sin \theta \\ \cos \psi \sin \phi \\ \cos \theta \cos \phi + \sin \theta \sin \phi \sin \psi \end{pmatrix} \quad \text{Eqn. 17}$$

$$\mathbf{R}_{zxy} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_z(\psi) \mathbf{R}_x(\phi) \mathbf{R}_y(\theta) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 18}$$

$$= \begin{pmatrix} \cos \psi \cos \theta + \sin \theta \sin \phi \sin \psi & \cos \phi \sin \psi & \cos \theta \sin \phi \sin \psi - \sin \theta \cos \psi \\ -\cos \theta \sin \psi + \cos \psi \sin \phi \sin \theta & \cos \phi \cos \psi & \cos \psi \cos \theta \sin \phi + \sin \theta \sin \psi \\ \cos \phi \sin \theta & -\sin \phi & \cos \theta \cos \phi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 19}$$

$$= \begin{pmatrix} \cos \theta \sin \phi \sin \psi - \cos \psi \sin \theta \\ \cos \psi \cos \theta \sin \phi + \sin \theta \sin \psi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 20}$$

$$\mathbf{R}_{zyx} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \mathbf{R}_z(\psi) \mathbf{R}_y(\theta) \mathbf{R}_x(\phi) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 21}$$

$$= \begin{pmatrix} \cos \psi \cos \theta & \cos \phi \sin \psi + \cos \psi \sin \phi \sin \theta & \sin \phi \sin \psi - \cos \phi \cos \psi \sin \theta \\ -\cos \theta \sin \psi & \cos \psi \cos \phi - \sin \theta \sin \phi \sin \psi & \cos \psi \sin \phi + \cos \phi \sin \psi \sin \theta \\ \sin \theta & -\cos \theta \sin \phi & \cos \theta \cos \phi \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{Eqn. 22}$$

$$= \begin{pmatrix} \sin \phi \sin \psi - \cos \phi \cos \psi \sin \theta \\ \cos \psi \sin \phi + \cos \phi \sin \psi \sin \theta \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 23}$$

It can be readily seen from [Equations 6 to 23](#) that the six composite rotation matrices and the six values of the measured gravitational vector are all different. A consequence is that roll, pitch and yaw rotation angles are meaningless without first defining the order in which these rotations are to be applied.

Four of these rotation sequences can be immediately rejected as being unsuitable for determining the smartphone orientation. The accelerometer output has three components but, since the vector magnitude must always equal 1g in the absence of linear acceleration, has just two degrees of freedom. The accelerometer vector lies on the surface of a sphere with radius 1g. It is not therefore possible to solve for three unique values of the roll ϕ , pitch θ and yaw ψ angles. The four rotation sequences in [Equations 12 to 23](#) result in the accelerometer output being a function of all three rotation angles and cannot therefore be solved.

In contrast, the two rotation sequences in [Equations 6 to 11](#) depend only on the roll ϕ and pitch θ angles and can be solved. The lack of any dependence on the yaw rotation angle ψ is easy to understand physically since the first rotation is in yaw ψ around the smartphone z -axis which is initially aligned with the gravitational field and pointing downwards. All accelerometers are completely insensitive to rotations about the gravitational field vector and cannot be used to determine such a rotation.

It is conventional therefore to select either the rotation sequence $\mathbf{R}_{xyz}$ of [Equations 6 to 8](#) or the sequence $\mathbf{R}_{yxz}$ of [Equations 9 to 11](#) to eliminate the yaw rotation ψ and allow solution for the roll ϕ and pitch θ angles. The unknown yaw angle ψ represents the smartphone rotation from north but its determination requires the addition of a magnetometer sensor to create an eCompass. Further details of the operation of a tilt-compensated eCompass can be found in application note AN4248.

Solving R_{xyz} (Equations 6 to 8) for the Pitch and Roll Angles

Equation 8 can be rewritten in the form of Equation 24 relating the roll ϕ and pitch θ angles to the normalized accelerometer reading G_p :

$$\frac{G_p}{\|G_p\|} = \begin{pmatrix} -\sin \theta \\ \cos \theta \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \Rightarrow \frac{1}{\sqrt{G_{px}^2 + G_{py}^2 + G_{pz}^2}} \begin{pmatrix} G_{px} \\ G_{py} \\ G_{pz} \end{pmatrix} = \begin{pmatrix} -\sin \theta \\ \cos \theta \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 24}$$

Solving for the roll and pitch angles from Equation 24, and using the subscript xyz to denote that the roll and pitch angles are computed according to the rotation sequence R_{xyz} , gives:

$$\tan \phi_{xyz} = \left(\frac{G_{py}}{G_{pz}} \right) \quad \text{Eqn. 25}$$

$$\tan \theta_{xyz} = \left(\frac{-G_{px}}{G_{py} \sin \phi + G_{pz} \cos \phi} \right) = \frac{-G_{px}}{\sqrt{G_{py}^2 + G_{pz}^2}} \quad \text{Eqn. 26}$$

The rotation sequence R_{xyz} is widely used in the aerospace industry and is termed the 'aerospace rotation sequence'.

Solving R_{yxz} (Equations 9 to 11) for the Pitch and Roll angles

Equation 11 can be similarly solved for the roll and pitch angles from an arbitrary accelerometer reading G_p :

$$\frac{G_p}{\|G_p\|} = \begin{pmatrix} -\sin \theta \cos \phi \\ \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \Rightarrow \frac{1}{\sqrt{G_{px}^2 + G_{py}^2 + G_{pz}^2}} \begin{pmatrix} G_{px} \\ G_{py} \\ G_{pz} \end{pmatrix} = \begin{pmatrix} -\sin \theta \cos \phi \\ \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 27}$$

Solving for the roll and pitch angles from Equation 27, and using the subscript yxz to denote that the angles are computed according to the rotation sequence R_{yxz} , gives:

$$\tan \phi_{yxz} = \frac{G_{py}}{\sqrt{G_{px}^2 + G_{pz}^2}} \quad \text{Eqn. 28}$$

$$\tan \theta_{yxz} = \left(\frac{-G_{px}}{G_{pz}} \right) \quad \text{Eqn. 29}$$

Equations 25 and 26 and Equations 28 and 29 therefore give different results for the roll and pitch angles from the same accelerometer reading. As mentioned earlier, this is a simple consequence of the fact that rotation matrices do not commute. The order of rotations is important and must always be specified when referring to specific orientation angles.

Eliminating Duplicate Solutions by Limiting the Roll and Pitch Ranges

The next complication to be addressed is that the expressions for the roll ϕ and pitch θ angles in Equations 25 and 26 and Equations 28 and 29 have an infinite number of solutions at multiples of 360° . Restricting the range of the roll and pitch angles to lie in the range -180° to 180° helps somewhat but the next paragraph shows that this still leads to two unique solutions for the roll and pitch angles.

Evaluating Equation 8 for pitch angle $\pi - \theta$ and roll angle $\phi + \pi$ and applying standard trigonometric identities shows that the accelerometer measurement is the same as that resulting from rotations θ and ϕ .

$$\begin{pmatrix} -\sin(\pi - \theta) \\ \cos(\pi - \theta)\sin(\phi + \pi) \\ \cos(\pi - \theta)\cos(\phi + \pi) \end{pmatrix} = \begin{pmatrix} -\sin \theta \\ \cos \theta \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 30}$$

Similarly, evaluating Equation 11 for pitch angle $\theta + \pi$ and roll angle $\pi - \phi$ also shows that the accelerometer measurement is identical to that resulting from rotations θ and ϕ .

$$\begin{pmatrix} -\sin(\theta + \pi)\cos(\pi - \phi) \\ \sin(\pi - \phi) \\ \cos(\theta + \pi)\cos(\pi - \phi) \end{pmatrix} = \begin{pmatrix} -\sin \theta \cos \phi \\ \sin \phi \\ \cos \theta \cos \phi \end{pmatrix} \quad \text{Eqn. 31}$$

The solution is to restrict either the roll or the pitch angle (but not both) to lie between -90° and $+90^\circ$. The convention used in the aerospace sequence is that the roll angle can range between -180° to $+180^\circ$ but the pitch angle is restricted to -90° to $+90^\circ$. The convention used by Android™ smartphones and by Microsoft for its Windows 8 sensor platform is the reverse with the roll angle restricted between -90° and 90° but the pitch angle able to range between -180° and 180° . Whichever convention is used, the net result is to eliminate one of the two duplicate solutions and give a single solution except in the very specific orientations discussed later.

Worked Example 1

Determine the roll and pitch angles defining the orientation of the smartphone relative to the starting position with the smartphone flat on the table assuming the aerospace rotation sequence R_{xyz} for the smartphone accelerometer reading (in native units of g) below:

$$\mathbf{G}_p = \begin{pmatrix} 0.461105 \\ 0.082198 \\ -0.887432 \end{pmatrix}, |\mathbf{G}_p| = 1.006910 \quad \text{Eqn. 32}$$

Substituting the accelerometer reading into [Equations 25](#) and [26](#) gives:

$$\tan \phi_{xyz} = \frac{0.082198}{-0.887432} = -0.092625 \Rightarrow \phi_{xyz} = -5.2922^\circ \text{ or } 174.7081^\circ \quad \text{Eqn. 33}$$

$$\tan \theta_{xyz} = \frac{-0.461105}{\sqrt{0.082198^2 + 0.887432^2}} = -0.517380 \Rightarrow \theta_{xyz} = -27.3561^\circ \quad \text{Eqn. 34}$$

The range of θ_{xyz} is -90° to 90° so there is a unique solution for θ_{xyz} in [Equation 34](#). In [Equation 33](#), however, ϕ_{xyz} can vary between -180° and 180° giving two possible solutions of -5.29° and 174.71° . Comparison with [Equation 24](#) shows that the required solution which gives positive G_{py} and negative G_{pz} is 174.71° . In practice, this is not a problem for a software implementation provided that the ATAN2 function is used as $\phi_{xyz} = \text{ATAN2}(G_{py}, G_{pz})$. The ATAN2 function automatically returns the angle (in radians) in the correct quadrant based on the signs of the two arguments.

Regions of Instability

The final complication is that both [Equations 25](#) and [29](#) have a region where the calculation of the roll angle ϕ and pitch θ angle respectively become unstable.

The inverse tangent function for the aerospace rotation sequence in [Equation 25](#) is mathematically defined for all values of G_{py} and G_{pz} with the one exception where both G_{py} and G_{pz} equal zero. This condition occurs when the smartphone is aligned with its x -axis pointing vertically upwards or downwards. Even if the smartphone is not exactly vertical, the inverse tangent calculation is dominated by accelerometer noise in the numerator and denominator of [Equation 25](#) and produces an unstable and essentially random estimate of the roll angle. The physics is straightforward to understand: when the smartphone is vertical, the x -axis is vertical so that a rotation in roll is a rotation about the gravitational field vector which cannot be detected.

Similarly [Equation 29](#) is defined for all values of G_{px} and G_{pz} with the exception where both G_{px} and G_{pz} are zero. This occurs when the smartphone is oriented on edge with the y -axis vertical and parallel to the earth's gravitational field vector so that any pitch θ rotation cannot be detected.

Equations 26 and 28, in contrast, are always defined and stable when the accelerometer is held in the earth's gravitational field. Applying the constraint that $G_{px}^2 + G_{py}^2 + G_{pz}^2 = 1g^2$ in **Equations 26 and 28** shows that it is not possible for both numerator and denominator to be simultaneously zero and give an unstable angle estimate. When the numerator is zero, the denominator equals 1 and vice versa.

$$\tan \theta_{xyz} = \frac{-G_{px}}{\sqrt{1 - G_{dx}^2}} \quad (\text{Caution: do not use}) \quad \text{Eqn. 35}$$

$$\tan \phi_{yxz} = \frac{G_{py}}{\sqrt{1 - G_{dy}^2}} \quad (\text{Caution: do not use}) \quad \text{Eqn. 36}$$

Equations 35 and 36 should not, however, be used as alternatives to **Equations 26 and 28** because any handshake, linear acceleration, sensor noise or simply using the accelerometer in a region of the world where the local gravitational field exceeds that at the original accelerometer calibration site can lead to G_{px} or G_{py} exceeding $1g$ and the square root and angle calculation having no real-valued solution.

There is no perfect solution to the problem of the roll and pitch angle singularities in **Equations 25 and 29**. One workaround, which is commonly used for the aerospace rotation sequence R_{xyz} , is to use the numerically stable **Equation 26** for calculation of the pitch angle θ but to modify **Equation 25** for the roll angle ϕ by mixing a fraction μ of the square of the accelerometer x -axis reading G_{px}^2 into the denominator to prevent the denominator ever being zero. The resulting equations are:

$$\tan \theta_{xyz} = \frac{-G_{px}}{\sqrt{G_{dx}^2 + G_{dy}^2 + G_{dz}^2}} \quad \text{Eqn. 37}$$

$$\tan \phi_{xyz} = \frac{G_{py}}{\sqrt{G_{dx}^2 + G_{dy}^2 + G_{dz}^2} \cdot \text{sign}(G_{pz})} \quad \text{Eqn. 38}$$

$\text{sign}(G_{pz})$ has a value +1 if G_{pz} is non-negative and -1 if G_{pz} is negative. This term is present to recover the loss sign of G_{pz} when taking the square root. Obviously **Equation 37** (which is identical to **Equation 26**) is mathematically correct for the aerospace sequence R_{xyz} and therefore always gives the correct pitch angle θ . **Equation 38** for the roll angle ϕ is an approximation but has several characteristics that make it attractive:

- It is impossible for both numerator and denominator of **Equation 38** to be simultaneously zero and give an undefined or unstable estimate of the roll angle.
- In the absence of any rotation in pitch θ , G_{px} equals zero and **Equation 38** reduces to **Equation 25** giving the correct roll angle ϕ .
- When the true roll angle is zero, G_{py} is also zero according to **Equation 8**. **Equation 38** therefore correctly gives zero roll angle ϕ for all pitch angles θ .
- **Equation 38** smoothly drives the roll angle ϕ to zero as the smartphone becomes oriented vertically upwards or downwards since G_{px}^2 approaches $1g^2$ and G_{py} and G_{pz} approach zero. This is reasonable behavior since the accelerometer reading is only dependent on the pitch angle θ when the smartphone is vertical and the roll angle is superfluous.

The roll angle error $\Delta\phi$ resulting from using the stable approximation of Equation 38 instead of the correct (but potentially unstable) Equation 25 is given by:

$$\Delta\phi = \tan^{-1}\left(\frac{G_{py}}{\sqrt{G_{pz}^2 + \mu G_{px}^2}}\right) - \tan^{-1}\left(\frac{G_{py}}{G_{pz}}\right) \quad \text{Eqn. 39}$$

Using the trigonometric identity:

$$\tan^{-1}a - \tan^{-1}b = \tan^{-1}\left(\frac{a-b}{1+ab}\right) \quad \text{Eqn. 40}$$

and Equation 8 allows Equation 39 to be simplified to:

$$\Delta\phi = \tan^{-1}\left(\frac{G_{py}(G_{pz} - \sqrt{G_{pz}^2 + \mu G_{px}^2})}{G_{py}^2 + G_{pz}\sqrt{G_{pz}^2 + \mu G_{px}^2}}\right) = \tan^{-1}\left(\frac{\sin\phi(\cos\theta\cos\phi - \sqrt{\cos^2\theta\cos^2\phi + \mu\sin^2\theta})}{\cos\theta\sin^2\phi + \cos\phi\sqrt{\cos^2\theta\cos^2\phi + \mu\sin^2\theta}}\right) \quad \text{Eqn. 41}$$

Figures 4 and 5 plot the absolute value of the resulting error $|\Delta\phi|$ in degrees computed from Equation 41 as a function of roll ϕ and pitch angles θ between -90° and 90° and with the contour mesh set to interval of 3° and μ equal to 0.01 and 0.1. It's clear that the stable approximation of Equation 38 gives an accurate estimate except at orientations approaching 90° where the roll angle error rises as its value is forced to zero for stability.

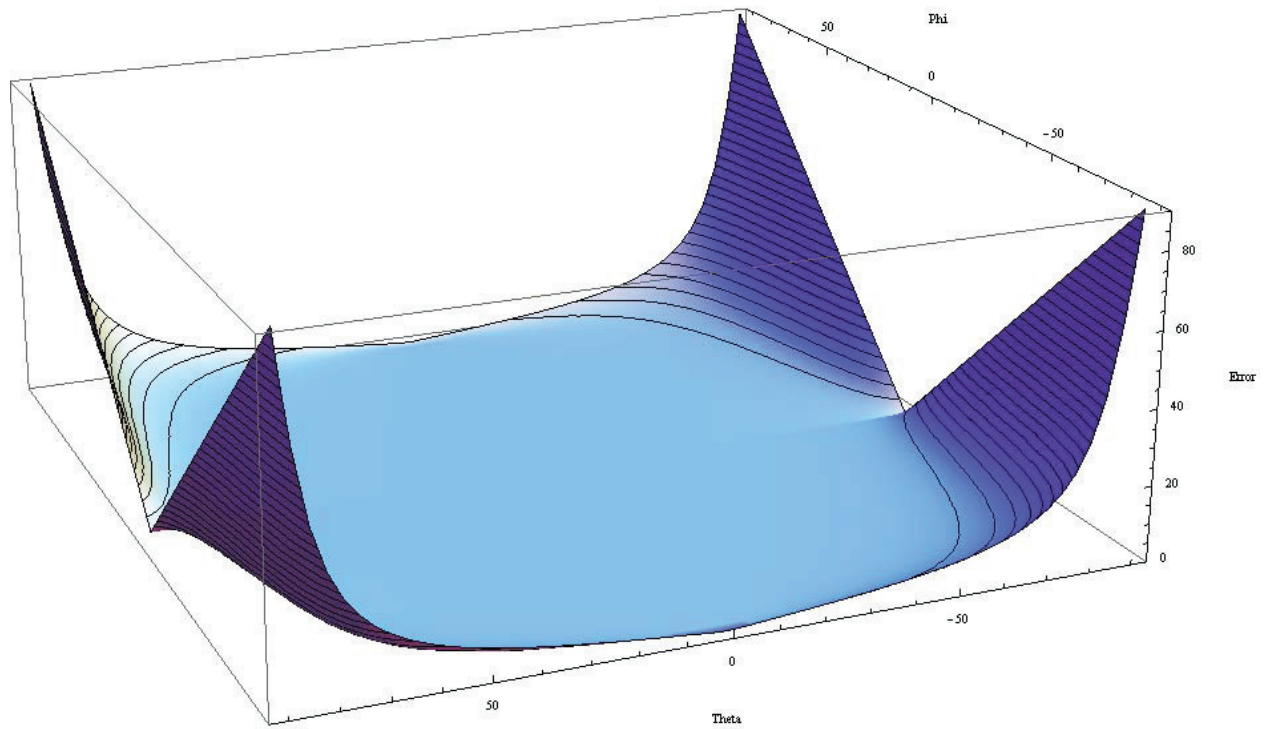


Figure 4. Roll Angle Error Surface $|\Delta\phi|$ for $\mu = 0.01$

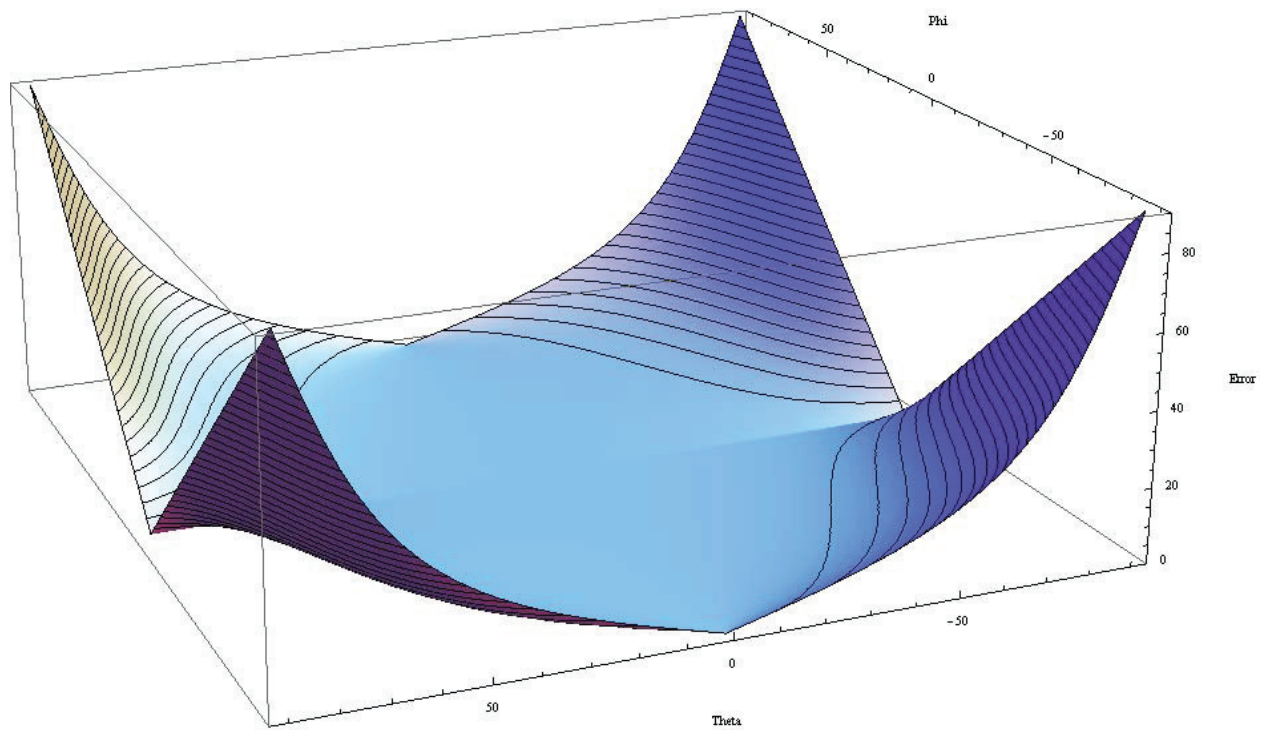


Figure 5. Roll Angle Error Surface $|\Delta\phi|$ for $\mu = 0.1$

A similar strategy can be used for the non-aerospace sequence R_{yxz} to stabilize Equation 29 to give the following equations:

$$\tan \theta_{yxz} = \frac{-G_{px}}{\text{sign}(G_{pz}) \sqrt{G_{pz}^2 + \mu G_{py}^2}} \quad \text{Eqn. 42}$$

$$\tan \phi_{yxz} = \frac{G_{py}}{\sqrt{G_{px}^2 + G_{pz}^2}} \quad \text{Eqn. 43}$$

The error surface for Equation 42 will have the same form as shown in Figures 4 and 5.

4 Calculating the Angle Between Two Accelerometer Readings

Simple vector algebra provides a means to calculate the angle change α of the apparent gravity vector between any two accelerometer readings.

The scalar product $\mathbf{a} \cdot \mathbf{b}$ between any two vectors $\mathbf{a}$ and $\mathbf{b}$ gives the angle α between the two vectors. This result is easily proved by applying the triangle cosine theorem to the triangle with sides comprised of the vectors $\mathbf{a}$, $\mathbf{b}$ and $\mathbf{a} - \mathbf{b}$.

$$\mathbf{a} \cdot \mathbf{b} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \cdot \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} = a_x b_x + a_y b_y + a_z b_z = |\mathbf{a}| |\mathbf{b}| \cos \alpha \quad \text{Eqn. 44}$$

$$\Rightarrow \cos \alpha = \frac{a_x b_x + a_y b_y + a_z b_z}{\sqrt{a_x^2 + a_y^2 + a_z^2} \sqrt{b_x^2 + b_y^2 + b_z^2}} \quad \text{Eqn. 45}$$

The unit vector $\hat{\mathbf{n}}$ which is normal to both $\mathbf{a}$ and $\mathbf{b}$, such that $\mathbf{a}$, $\mathbf{b}$, and $\hat{\mathbf{n}}$ form a right-handed triplet, is given by the vector product:

$$\mathbf{a} \times \mathbf{b} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \times \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} = \begin{pmatrix} a_y b_z - a_z b_y \\ a_z b_x - a_x b_z \\ a_x b_y - a_y b_x \end{pmatrix} = |\mathbf{a}| |\mathbf{b}| \hat{\mathbf{n}} \sin \alpha \quad \text{Eqn. 46}$$

$$\Rightarrow \hat{\mathbf{n}} \sin \alpha = \left(\frac{1}{\sqrt{a_x^2 + a_y^2 + a_z^2}} \right) \left(\frac{1}{\sqrt{b_x^2 + b_y^2 + b_z^2}} \right) \begin{pmatrix} a_y b_z - a_z b_y \\ a_z b_x - a_x b_z \\ a_x b_y - a_y b_x \end{pmatrix} \quad \text{Eqn. 47}$$

Figure 6 shows these vector relationships graphically.

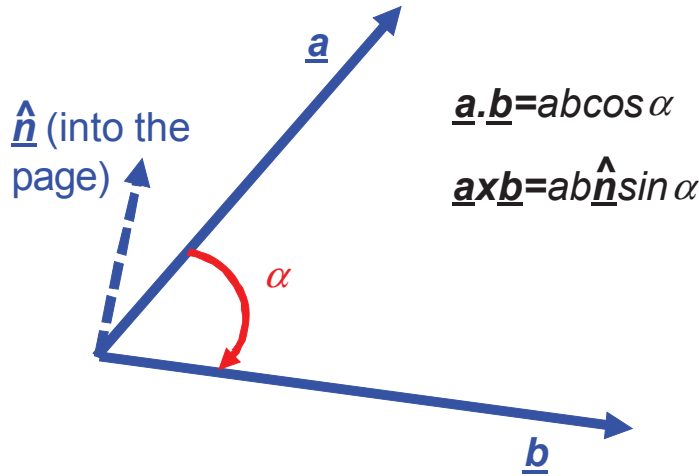


Figure 6. Definitions of the Scalar and Vector Products

Worked Example 2

Two accelerometer readings are recorded (in native units of g) as:

$$\mathbf{G}_{p1} = \begin{pmatrix} 0.745439 \\ 0.065434 \\ 0.674523 \end{pmatrix}, |\mathbf{G}_{p1}| = 1.007443 \quad \text{Eqn. 48}$$

$$\mathbf{G}_{p2} = \begin{pmatrix} 0.393567 \\ 0.348443 \\ 0.844523 \end{pmatrix}, |\mathbf{G}_{p2}| = 0.994750 \quad \text{Eqn. 49}$$

Note that as a result of noise or handshake, neither $\mathbf{G}_{p1}$ nor $\mathbf{G}_{p2}$ have modulus exactly equal to 1g.

Using Equation 45, the angle between the two vectors is:

$$\cos \alpha = \frac{0.745439 \times 0.393567 + 0.065434 \times 0.348443 + 0.674523 \times 0.844523}{1.007443 \times 0.994750} = 0.884606 \Rightarrow \alpha = 27.8^\circ \quad \text{Eqn. 50}$$

Using Equation 47, the vector $\hat{\mathbf{n}}$ is the instantaneous rotation axis and has direction:

$$\hat{\mathbf{n}} \sin \alpha = \left(\frac{1}{1.007443} \right) \left(\frac{1}{0.994750} \right) \begin{pmatrix} a_y b_z - a_z b_y \\ a_z b_x - a_x b_z \\ a_x b_y - a_y b_x \end{pmatrix} = \left(\frac{1}{1.007443} \right) \left(\frac{1}{0.994750} \right) \begin{pmatrix} -0.179772 \\ -0.364070 \\ 0.233990 \end{pmatrix} \quad \text{Eqn. 51}$$

$$\Rightarrow \hat{\mathbf{n}} = \begin{pmatrix} -0.383610 \\ -0.776878 \\ 0.499304 \end{pmatrix}, \sin \alpha = 0.467626 \Rightarrow \alpha = 27.8^\circ \quad \text{Eqn. 52}$$

The vector product calculation confirms the angle of 27.8° between the two gravitational vectors and also provides the vector of the rotation axis $\hat{\mathbf{n}}$ normal to the two accelerometer measurements. Direct evaluation proves that the vector $\hat{\mathbf{n}}$ is orthogonal to both $\mathbf{G}_{p1}$ and $\mathbf{G}_{p2}$.

$$\mathbf{G}_{p1} \cdot \hat{\mathbf{n}} = \begin{pmatrix} 0.745439 \\ 0.065434 \\ 0.674523 \end{pmatrix} \cdot \begin{pmatrix} -0.383610 \\ -0.776878 \\ 0.499304 \end{pmatrix} = 0 \quad \text{Eqn. 53}$$

$$\mathbf{G}_{p2} \cdot \hat{\mathbf{n}} = \begin{pmatrix} 0.393567 \\ 0.348443 \\ 0.844523 \end{pmatrix} \cdot \begin{pmatrix} -0.383610 \\ -0.776878 \\ 0.499304 \end{pmatrix} = 0 \quad \text{Eqn. 54}$$

5 Calculating the Tilt Angle

The techniques of the previous section can be used to calculate the angle ρ between the gravitational vector measured by the accelerometer and the initial orientation with the gravitational field pointing downwards along the z -axis.



Figure 7. Calculation of the Tilt Angle ρ from Vertical

If the accelerometer reading is $\mathbf{G}_p$, then in the absence of linear acceleration:

$$\mathbf{G}_p \cdot \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = G_{pz} = |\mathbf{G}_p| \cos \rho \Rightarrow \cos \rho = \frac{G_{pz}}{\sqrt{G_{px}^2 + G_{py}^2 + G_{pz}^2}} \quad \text{Eqn. 55}$$

Worked Example 3

The measured accelerometer reading $\mathbf{G}_p$ is below. By what angle ρ is the smartphone tilted from its original flat position?

$$\mathbf{G}_p = \begin{pmatrix} 0.324322 \\ -0.653423 \\ 0.684234 \end{pmatrix} \quad \text{Eqn. 56}$$

The modulus of $\mathbf{G}_p$ is easily determined to be:

$$\sqrt{G_{px}^2 + G_{py}^2 + G_{pz}^2} = 1.000161 \quad \text{Eqn. 57}$$

Using Equation 55, the tilt angle ρ is:

$$\cos \rho = \frac{0.684234}{1.000161} = 0.684124 \Rightarrow \rho = 46.8^\circ \quad \text{Eqn. 58}$$

6 Selecting Portrait and Landscape Modes

The first high volume use of accelerometers in consumer products was to switch a display between landscape and portrait orientations. A tablet PC, shown in Figure 8, has four possible display orientations labeled here as Bottom, Top, Right and Left, according to the location of the lower edge of the displayed text or imagery.

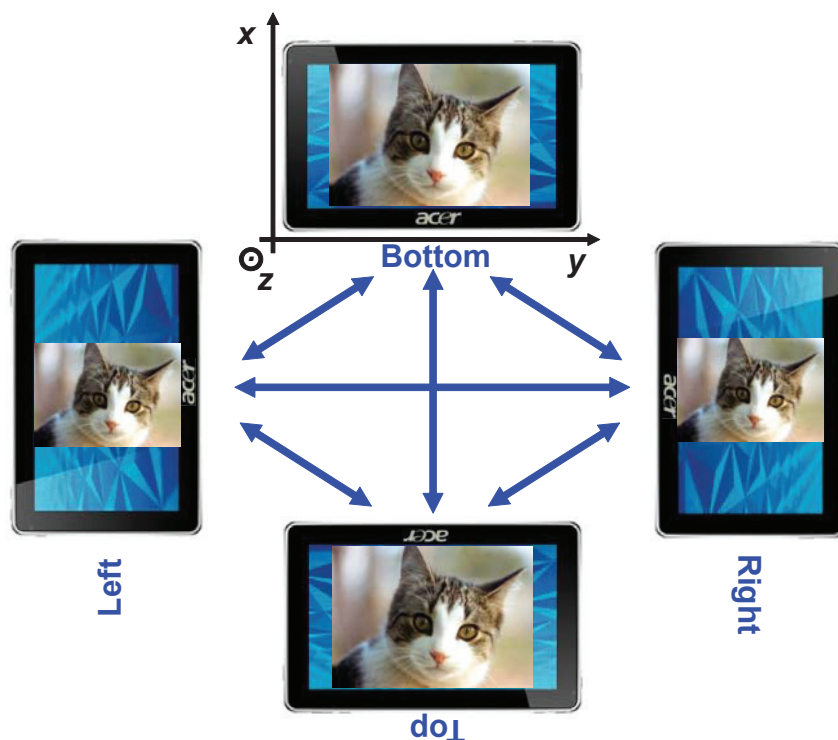


Figure 8. Portrait and Landscape Screen Orientations for a Tablet PC

This problem is rather more complex than it would appear at first sight since a direct mapping between the display orientation and the accelerometer reading is not ergonomically suitable. Specifically, a user viewing the screen in any of the four modes shown in Figure 8 expects that display mode to remain unchanged as the tablet is rotated to a flat orientation. The accelerometer reading resulting from the tablet being flat on the table can therefore be associated with any of the four display orientations.

The solution is a simple state machine in which the accelerometer reading leads to *transitions* between the screen orientations rather than directly defining the screen orientation. Simple state transition rules are listed below.

- $(|G_{pz}| < 0.5g) \text{ AND } (G_{px} > 0.5g) \text{ AND } (|G_{py}| < 0.4g)$: Change orientation to Top
- $(|G_{pz}| < 0.5g) \text{ AND } (G_{px} < -0.5g) \text{ AND } (|G_{py}| < 0.4g)$: Change orientation to Bottom
- $(|G_{pz}| < 0.5g) \text{ AND } (G_{py} > 0.5g) \text{ AND } (|G_{px}| < 0.4g)$: Change orientation to Right
- $(|G_{pz}| < 0.5g) \text{ AND } (G_{py} < -0.5g) \text{ AND } (|G_{px}| < 0.4g)$: Change orientation to Left.

The regions in the accelerometer measurement space G_{px} , G_{py} , and G_{pz} corresponding to these rules are shown in Figure 9 with the 1g sphere superimposed.

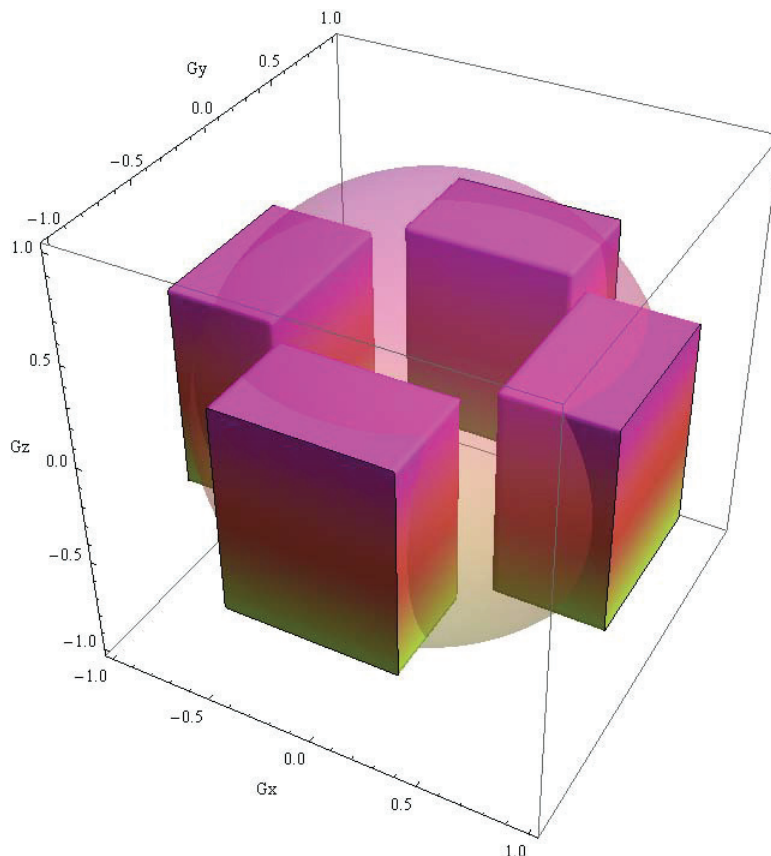


Figure 9. State Transition Zones for Display Orientation Changes

The restriction that $|G_{pz}| < 0.5g$ for a display transition to occur prevents any change in orientation when the tablet is within 0.5g of being complete flat or inverted (since $|G_{pz}| = 1g$ when the tablet is flat). This is known as *z-axis* lockout and ensures that the screen orientation remains unchanged as the user lowers the tablet to a flat orientation.

The remaining constraints define four non-overlapping regions for the transition between the four screen orientations to occur. The lack of overlap between the regions leads to a unique transition within each region and prevents the display orientation oscillating at the boundary between regions.

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