

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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Title: THREE-DIMENSIONAL PRINTER WITH FORCE DETECTION

DECLARATION OF ANDREW WOLFE

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I, Andrew Wolfe, PhD, declare that:

I. INTRODUCTION

1. My name is Andrew Wolfe, and I have been retained by counsel for Shenzhen Tuozhu Technology Co., Ltd. (“Shenzhen Tuozhu”/“Petitioner”) as an expert witness to provide assistance regarding U.S. Patent No. 10,556,381 (“the ’381 Patent”). Specifically, I have been asked to consider the validity of claims 1-16 of the ’381 Patent (the “Challenged Claims”).

2. I am being compensated for my time at my standard consulting rate. I am also being reimbursed for expenses that I incur during the course of this work. My compensation is not contingent upon the results of my study, the substance of my opinions, or the outcome of any proceeding involving the Challenged Claims. I have no financial interest in the outcome of this matter or on related litigation involving the ’381 Patent. I am being compensated at my standard consulting rate of \$750/hr.

3. My analysis here is based on my years of education, research and experience, as well as my investigation and study of relevant materials, including those cited herein. I may rely upon these materials, my knowledge and experience, and/or additional materials to further explain and corroborate my analysis, and to respond to critiques of my analysis raised by the Patent Owner or the Patent Trial and Appeal Board (“Board”).

4. My analysis of the materials produced in this proceeding is ongoing and I will continue to review any new material as it is provided. This declaration represents only those opinions that I have formed to date. I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information and on my continuing analysis of the materials already provided.

II. BACKGROUND AND QUALIFICATIONS

5. I am over the age of 18 and am competent to provide this testimony. I have personal knowledge, or have developed knowledge of the technologies addressed in this declaration based upon my education, training, experience, and my review of the '381 Patent, its file history, and the related prior art. I am well qualified to serve as a technical expert in this matter based upon my qualifications, discussed in detail below.

6. In formulating my opinions, I have relied on my knowledge, training, and experience in the relevant field. My education and experience are described more fully in the attached curriculum vitae (Appendix A). For ease of reference, I have highlighted certain information below.

7. I have more than 40 years of experience in consumer electronics and interactive graphics and interactive video computer systems, including as a computer architect, computer system designer, PC graphics designer, educator, and as an executive in the consumer electronics business.

8. In 1985, I earned the B.S.E.E. degree in Electrical Engineering and Computer Science from the Johns Hopkins University. In 1987, I received the M.S. degree in Electrical and Computer Engineering from Carnegie Mellon University and then in 1992, I received a Ph.D. in Computer Engineering from Carnegie Mellon University. My doctoral dissertation proposed a new approach for the architecture of a computer processor.

9. In 1983, I began designing Touch Sensing systems as a senior design engineer for Touch Technology, Inc. In some of these design projects, I designed interrupt-based I/O cards for PC-compatible computer systems including the IBM PC-AT to interface interactive touch-based computer terminals that I designed for use in public information systems. I later worked for the Carroll Touch division of AMP where I designed additional touchscreen technologies, developed system firmware, and designed the company's first custom integrated circuit. I designed the touch/pen input system for the Linus WriteTop, which many believe to be the first commercial tablet computer. Between 1983 and 2003 I designed many different devices which detected touch and/or measured forces.

10. From 1986 through 1987, I designed and built a high-performance computer system at Carnegie Mellon University. From 1986 through 1988, I also developed the curriculum and supervised the teaching lab for the processor design courses.

11. In 1987-88, I worked as a senior design engineer for ESL-TRW Advanced Technology Division. I designed and built a bus interface and memory controller for a workstation-based computer system and worked on the design of a multiprocessor system.

12. At the end of 1989, along with some partners, I reacquired the technology I had developed at Touch Technology and at AMP and founded The Graphics Technology Company. As an officer and a consultant, I managed engineering development activities at that company and personally developed dozens of touch sensing devices over the next seven years. Many of these could distinguish between different levels of touch force.

13. I have consulted, formally and informally, for a number of consumer electronics design companies. In particular, I have served on the technical advisory boards for two media processor design companies, BOPS, Inc., where I chaired the board, and Siroyan Ltd. I served in a similar role for three networking chip companies, Intellon, Inc., Comsilica, Inc., and Entridia, Inc. and one 3D game accelerator company, Ageia, Inc. I have also served as a technology advisor to Motorola and to several venture capital funds in the U.S. and Europe. Currently, I am a director of Turtle Beach Corporation, providing guidance in its development of premium audio peripheral devices for a variety of commercial electronic products.

14. From 1991 through 1997, I served on the Faculty of Princeton University as an Assistant Professor of Electrical Engineering. At Princeton, I taught undergraduate and graduate-level courses in Computer Architecture, Advanced Computer Architecture, Display Technology, and Microprocessor Systems courses as well as conducting sponsored research in the area of computer systems and related topics. My courses included teaching about electromechanical sensors and actuators. From 1999 through 2002, I also taught the Computer Architecture course to both undergraduates and graduate students at Stanford University several times as a Consulting Professor. At Princeton, I received several teaching awards, both from students and from the School of Engineering. I have also taught advanced microprocessor architecture to industry professionals in IEEE and ACM sponsored seminars. I currently teach at Santa Clara University including courses on Embedded Systems, Real-Time Computing, Mechatronics, and Engineering Practice. Since 2014, these classes have included comprehensive instruction and experimentation with sensors and actuators for measuring distance, force, and other physical phenomena. I have also worked with two undergraduate teams to design and construct material extruders for 3D printing. Additionally, I teach all of these students to use 3D FDM printers and use them myself.

15. From 1997 through 2002, I held a variety of executive positions at a publicly-held PC graphics company originally called S3, Inc. and later called

Sonicblue Inc. These included Chief Technology Officer, Vice President of Systems Integration Products, Senior Vice President of Business Development, and Director of Technology. At the time I joined S3, it supplied graphics accelerators for more than 50% of the PCs sold in the United States.

16. In these roles, I managed teams of engineers developing complex graphics chips for use in personal computers. I also managed the video research lab. I was involved in every aspect of the relationship with PC manufacturers ranging from discussions of product requirements, testing and qualification procedures, and competitive analysis, to market segmentation and pricing discussions. I met with senior executives in major PC manufacturers on numerous occasions to discuss business opportunities and general market trends. I also developed numerous consumer audio and video products including the Rio MP3 players, the ReplayTV digital video recorders, certain Löewe televisions, and the GoVideo DVD and VCR products. I also developed user interfaces and remote control protocols. I further assisted in the launch of streaming services. During my time at SonicBlue we launched more than 30 new consumer electronics products.

17. I have published more than 50 peer-reviewed papers in computer architecture and computer systems design including papers related to video streaming. I have also chaired IEEE and ACM conferences in microarchitecture and integrated circuit design. I am a named inventor on at least fifty-seven U.S. patents

and thirty-seven foreign patents, more than ten related to touch and/or force sensing.

I am an IEEE Fellow and an IEEE Computer Society Distinguished Contributor.

18. I have been the invited keynote speaker at the ACM/IEEE International Symposium on Microarchitecture and at the International Conference on Multimedia. I have also been an invited speaker on various aspects of technology or the PC industry at numerous industry events including the Intel Developer's Forum, Microsoft Windows Hardware Engineering Conference, Microprocessor Forum, Embedded Systems Conference, Comdex, and Consumer Electronics Show as well as at Harvard Business School and the University of Illinois Law School. I have been interviewed on subjects related to computer graphics and video technology and the electronics industry by publications such as the Wall Street Journal, New York Times, LA Times, Time, Newsweek, Forbes, and Fortune as well as CNN, NPR, and the BBC. I have also spoken at dozens of universities including MIT, Stanford, University of Texas, Carnegie Mellon, UCLA, University of Michigan, Rice, and Duke.

19. In summary, I have extensive familiarity with fields involving electromechanical devices, sensors, and material deposition. I am familiar with the state of this field at the time of the '381 Patent, which I have been informed by Petitioner's counsel to assume as being October 29, 2012, for the purposes of this proceeding.

III. LEVEL OF ORDINARY SKILL IN THE ART

20. In rendering the opinions set forth in this declaration, I was asked to consider the patent claims and the prior art through the eyes of a person of ordinary skill in the art as of the effective filing date of the '381 Patent ("POSITA"), which, as I have explained above, is assumed to be October 29, 2012. I understand that the factors considered in determining the ordinary level of skill in a field of art include the level of education and experience of persons working in the field; the types of problems encountered in the field; the teachings of the prior art; and the sophistication of the technology at the time of the alleged invention. I understand that a POSITA is not a specific real individual, but rather is a hypothetical individual having the qualities reflected by the factors above. I understand that a POSITA also would have knowledge from the teachings of the prior art, including the art cited below.

21. Taking these factors into consideration, I believe the range of qualifications for a POSITA, on or before October 29, 2012, would have included a bachelor's degree in Mechanical Engineering, Electrical Engineering, Computer Engineering, or a comparable field and at least two years of experience (e.g., research or industry experience) related to 3D printing. For example, a POSITA would have possessed background knowledge and understanding of the pertinent technologies employed by the '381 patent, including implementing sensor based

systems, which would have been well within the capabilities of a junior engineer. Sensor based technologies, such as sensors used to determine force, were commonplace and readily available commercially available long before 2012.

22. I also believe that a POSITA could reach the same level of ordinary skill even without a formal degree or formal training. For example, as with the junior engineer I mentioned above, experienced users of 3D printers would have understood the purpose and the operation of sensor based force measurement, as well as the concerns a designer might consider in developing these components. Such a person would have acquired sufficient skills through (i) their individual use and testing with different 3D printing configurations, (ii) their exchange of knowledge in online communities, and (iii) their review of technical literature.

23. My analysis and conclusions expressed in this Declaration are based on the perspective of a POSITA having this level of knowledge and skill. My education, technical expertise and personal knowledge discussed in Section II shows that I meet the qualifications of a POSITA by October 29, 2012. I am qualified to provide opinions concerning what a POSITA would have known and understood at that time, and my analysis and conclusions herein are from the perspective of a POSITA as of that date.

IV. MATERIALS CONSIDERED AND RELIED UPON

24. In forming my opinions and reaching the conclusions described in this declaration, I have relied on the documents and materials cited herein as well as those identified in this declaration, including the '381 Patent, the prosecution history of the '381 Patent, and prior art references cited herein. These materials comprise patents, related documents, and printed publications. Each of these materials is a type of document that experts in my field would have reasonably relied upon when forming their opinions. I have also relied on my education, training, research, knowledge, and personal and professional experience in the relevant technologies and systems that were already in use prior to, and within the timeframe of the earliest effective filing date of the '381 Patent (October 29, 2012).

25. Accordingly, as part of my independent analysis of the '381 Patent, I have analyzed the following publications and materials:

- U.S. Patent No. 10,556,381 to Kemperle et al. (“the '381 patent”; EX1001)
- Excerpts from the Prosecution History of the '381 Patent (“the Prosecution History”; EX1002)
- US20030100824A1 to Warren et al (“Warren”; EX1004)
- US 9,031,680 to Napadensky (“Napadensky”; EX1005)
- US20090273122A1 to Batchelder et al (“Batchelder122”; EX1006)
- US20070228592A1 to Dunn et al (“Dunn”; EX1007)

- US20070179656A1 to Eshed et al (“Eshed”; EX1008)
- US 6,629,011 B1 to Calderon et al (“Calderon”; EX1009)
- RepRap Discussion Thread “Genetic Algorithm” (available at <https://reprap.org/forum/read.php?1,20208,page=1>) (“RepRap20208”; EX1010)
- US7552543B2 to Tomelleri (“Tomelleri”; EX1011)
- US20070056176A1 to Matsumiya et al (“Matsumiya”; EX1012)
- Evans, *Practical 3D Printers, The Science And Art Of 3D Printing* (2012) (“Evans”; EX1013)
- Exhibit E of Infringement Contentions from Stratasys, Inc., v. Shenzhen Touzhu Technology Co., Ltd., et al., Case Nos. 2:24-cv-00644-JRG and 2:24-cv-00645-JRG (E.D. Tex. Nov. 14, 2024) (EX1016)
- US20080195353A1 to Igasaki et al (“Igasaki”; EX1017)
- J.E. Carryer, R.M. Ohline, and T.W. Kenny, *Introduction to Mechatronic Design*, ISBN-13: 978-0-13-143356-4, Pearson Education, Inc., Upper Saddle River, New Jersey 07458 (2011) (EX1018)
- J. Srihohi, I. Chopra, *Fundamental Understanding of Piezoelectric Strain Sensors*, Journal of Intelligent Material Systems and Structures, Vol. 11, P. 246-257, April 2000 (EX1019)
- https://web.archive.org/web/20060615115221/http://www.allectronics.com/cgi-bin/item/PE-49/466/PIEZO_ELEMENT_.html (piezoelectric element

product discussed in <https://reprap.org/forum/read.php?1,8028,8276#msg-8276>) (EX1020)

- US5,340,433 to Crump (“Crump”) (EX1021)

26. Although this declaration refers to selected portions of the cited references, it should be understood that these are examples, and I recognize that a POSITA would have viewed the references cited herein in their entirety and in combination with other references cited herein or cited within the references themselves. Moreover, some of the prior art documents are not used in the proposed grounds but rather as corroboration and/or illustration of the knowledge of a POSITA.

V. LEGAL STANDARDS

27. I am not a lawyer and do not provide any legal opinions, but I have been advised that certain legal standards are to be applied by technical experts in forming opinions regarding meaning and validity of patent claims I have applied the legal standards described below, which were provided to me by counsel for the Petitioners.

28. It is my understanding that assessing the validity of a U.S. patent based on a prior art analysis involves two steps. First, one construes the terms of the patent claims to understand what meaning one of ordinary skill in the art would have given the terms. Second, after the claim terms have been construed, one then assesses validity by comparing the patent claim properly construed to the “prior art.” I

understand that the teaching of the prior art is viewed through the eyes of a POSITA as of the effective filing date of the '381 Patent. My analysis as to what constitutes a POSITA is set forth above (§III).

A. Legal Standards for Prior Art

29. I understand that a patent or other publication must first qualify as prior art before it can be used to invalidate a patent claim. Counsel for Petitioners have informed me that Warren (EX1004), Napadensky (EX1005), Batchelder122 (EX1006), Dunn (EX1007), Eshed (EX1008), Calderon (EX1009), RepRap20208 (EX1010), Tomelleri (EX1011), Matsumiya (EX1012), Evans (EX1013), Igasaki (EX1017), Carryer (EX1018), Srihohi (EX1019), EX1020, and Crump (EX1021) all qualify as prior art to the '381 Patent. In particular, I was informed that all of these publications were published or at least filed before the filing date of the '381 patent (October 29, 2012).

B. Legal Standard for Anticipation

30. I have been informed that a patent claim is unpatentable as anticipated under 35 U.S.C. § 102 if each and every element of a claim is found either explicitly or inherently in a single prior art reference. Under the principles of inherency, if the prior art necessarily functions in accordance with, or necessarily includes the claimed elements, it anticipates.

C. Legal Standard for Obviousness

31. I have been informed that a patent claim is invalid as “obvious” in light of one or more prior art references if it would have been obvious to a person of ordinary skill in the art at the time of the alleged invention (“POSITA”), taking into account (1) the scope and content of the prior art, (2) the differences between the prior art and the claims, (3) the level of ordinary skill in the art, and (4) any so called “secondary considerations” of non-obviousness (e.g., evidence of “long felt need” for the claimed invention, commercial success attributable to the claimed invention, unexpected results of the claimed invention, and “copying” of the claimed invention by others).

32. While I do not know the exact date that the alleged invention of the ’381 patent was made, I do know that the ’381 patent’s earliest claimed priority date is October 29, 2012. For purposes of my obviousness analysis in the Grounds below, I have applied a date of October 29, 2012 as the date of the alleged invention, although my opinions expressed below may hold true even if the date of the alleged invention were earlier, such as any time prior to the earlier 2010s.

33. I have been informed that a claim can be obvious in light of a single prior art reference or multiple prior art references. To be obvious in light of a single prior art reference or multiple prior art references, there must be a reason that would have prompted a POSITA to modify or supplement the single prior art reference, or to combine two or more references, in a manner that provides the elements of the

claimed invention. This reason may come from a teaching, suggestion, or motivation to combine, or may come from the reference(s) themselves, the knowledge or “common sense” of a POSITA, or from the nature of the problem to be solved, and this reason may be explicit or implicit from the prior art as a whole. I have been informed that, under the law, the combination of familiar elements according to known methods is likely to be obvious when it does no more than yield predictable results. I also understand it is improper to rely on hindsight in making the obviousness determination.

34. To the extent that a party presents any evidence of alleged “secondary considerations” of non-obviousness (refer to ¶31 above), the evidence must demonstrate a “nexus” between that secondary consideration and the invention recited in the patent claim.

VI. OVERVIEW OF THE '381 PATENT

A. Subject Matter Overview

35. In the context of a “three-dimensional printer to accurately fabricate objects,” the '381 patent describes “pressure-sensing extruders and methods for using same.” EX1001, 1:14-21. “An extruder or other tool head of a three-dimensional printer is instrumented to detect contact force against the extruder, such as by a build platform or an object being fabricated.” *Id.*, Abstract, 1:25-33. “The

resulting feedback data can be used in a variety of ways to control operation of the three-dimensional printer during fabrication or diagnostics.” *Id.*

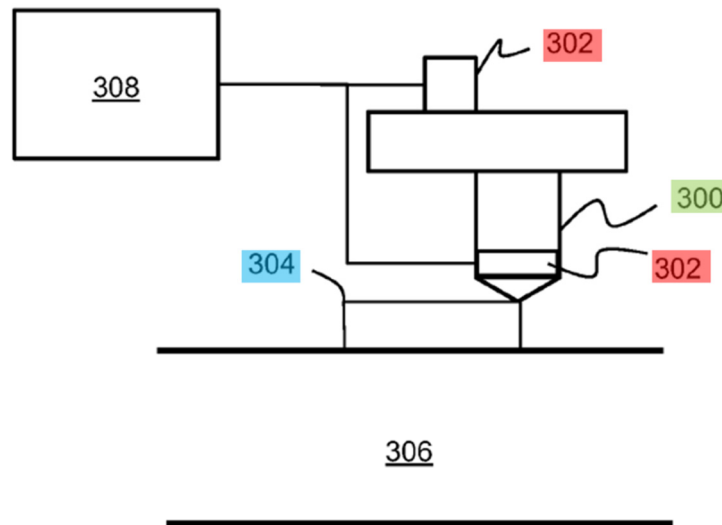


Fig. 3

EX1001, FIG. 3 (annotated)

36. As depicted in FIG. 3 (annotated above), “a fabrication tool for use in a three-dimensional printer,” which includes “an extruder or other tool operable to add build material to an object 304 during a build process.” EX1001, 8:55-64. “One or more sensors 302 may be mechanically coupled or otherwise included in the fabrication tool 300.” *Id.* “Each sensor 302 may be operable to sense a contact force between the fabrication tool 300 and a separate structure, such as the object 304, the build platform 306, or some other structure.” *Id.* Additionally, “each sensor 302

may be in data communication with a controller” and “operable to transmit a signal to the controller,” such that “the controller may...transmit[] a control signal to various actuators or other components of the three-dimensional printer to control the three-dimensional printer in a manner responsive to the detected forces.” *Id.*, 9:9-23. Notably, the ’381 patent does not confine itself to any particular type of contact force sensors. *Id.*, 9:11-24. According to the ’381 patent, “sensors that are collectively operable to sense any force or displacement of the fabrication tool and separate structure, or any related properties such as compression or strain, may be used as sensors 302, so long as the contact force(s) described above may be calculated from the sensed physical characteristics.” *Id.*, 8:65-9:10.

37. The ’381 patent includes 16 claims, of which claim 1 is independent.

B. Prosecution History

38. The ’381 patent issued on February 11, 2020, from U.S. Patent Application No. 14/922,267 (“the ’267 application”), which was filed on October 26, 2015, as a continuation application of U.S. Patent Application No. 14/065,516 (Now U.S. Patent No. 9,168,698) claiming priority to provisional application 61/719,874 filed October 29, 2012. EX1002, 91-144.

39. The Examiner initially rejected original claims 1-13 as being anticipated by Bonassar (US 7,939,003) and rendered obvious over Jang (US 6,129,872) and Lipson (US 7,625,198). EX1002, 63-80 (Office Action on

9/13/2018). In response, Applicant cancelled then dependent claim 2 and rolled the substance into independent claim 1 to particularly recite “one or more sensors mechanically coupled to the extruder [configured to extrude build material to fabricate an object during a build process], wherein the one or more sensors are collectively operable to sense a contact force between the extruder and the separate structure distinct from the fabrication tool.” EX1002, 51-62 (Response on 12/10/2018). Applicant asserted that, e.g., the force sensor of Lipson “is included on the substrate (i.e., the build surface), not on an extruder (e.g., the syringe).” *Id.*

40. The Examiner repeated substantially the same prior art rejections because “it would have been obvious ... to modify Jang by providing a force sensor at the injecting tip of the nozzle as taught by Lipson.” EX1002, 41-50 (Office Action on 4/5/2019). In response, Applicant further amended independent claim 1 to require “a controller configured to receive a signal from the one or more sensors on the extruder and to calculate the contact force between the extruder and the separate structure.” EX1002, 24-40 (Response on 9/5/2019) (cancelling dependent claim 12 and adding new claims 14-18). Applicant faulted the Examiner for failing to “demonstrate a motivation to move the sensors based on facts *gleaned from the prior art*” and asserted that the additional controller feature is missing from all cited prior art. *Id.* (emphasis original).

41. The Examiner subsequently allowed the remaining claims by noting “The prior art fails to teach or suggest a three-dimensional printer comprising: ... one or more sensors mechanically coupled to the extruder, wherein the one or more sensors are collectively operable to sense a contact force between the extruder and a separate structure distinct from the fabrication tool....” EX1002, 7-23 (Response on 9/5/2019) (emphasis original).

42. In my opinion, the Examiner allowed these claims prematurely. Examiners have limited time and resources and cannot review the entirety of the prior art. After a more comprehensive evaluation, the Challenged Claims are obvious, and this conclusion would have been apparent had the Examiner vetted the Challenged claims in view of the prior art and opinions presented below.

VII. OVERVIEW OF THE CITED REFERENCES

A. Warren (EX1004)

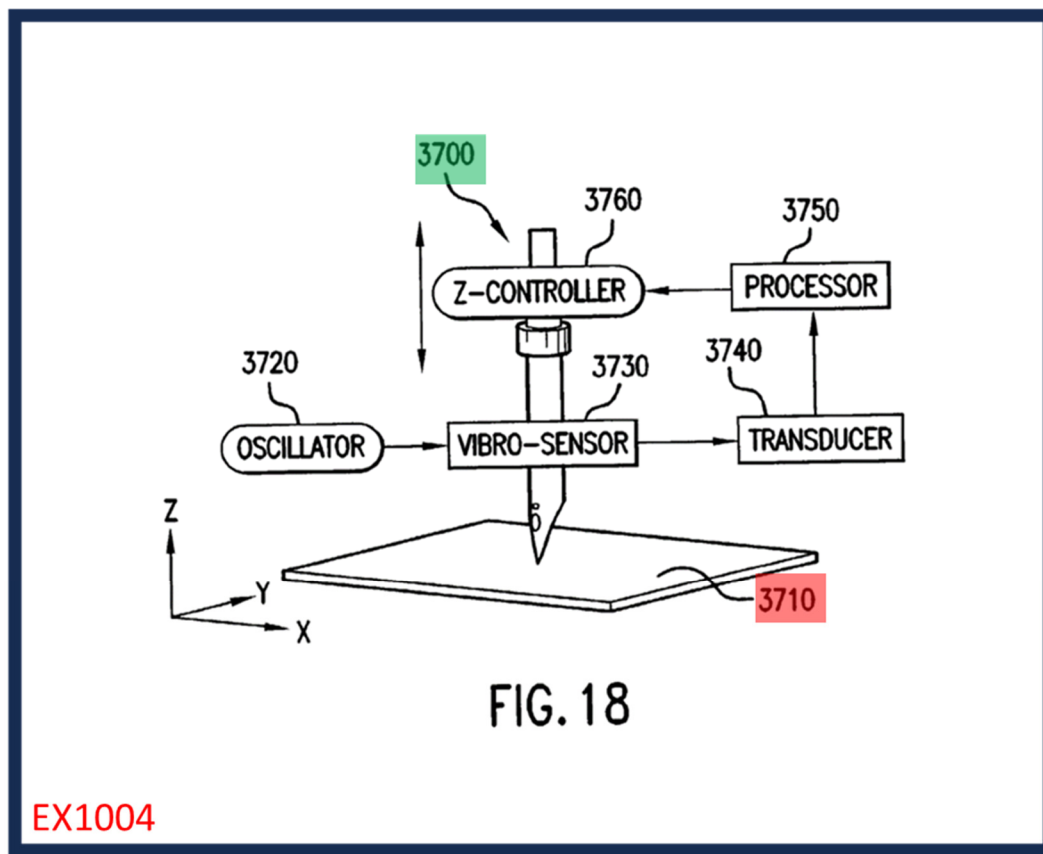
43. Like the '381 patent, Warren is about 3D printing. Specifically, Warren teaches a kind of 3D printing called “direct-write deposition technology” (“DWDT”), which can be used “for dispensing uniform lines of viscous solutions, suspensions, sols, or pastes to create exact replicas of stored patterns.” EX1004 [0010-0011]. DWDT is broadly applicable to a variety of settings, “including organic and inorganic applications.” *Id.*, [0013]. When a DWDT 3D printing apparatus is employed for “biological, medical, bioengineering, and tissue-engineering,” Warren

uses the label “human architecture tool” (“HAT”). *Id.*, [0014]. In short, Warren’s “DWDT/HAT technology has a plurality of aspects that ...combine to make a tool capable of producing a modeled structure through 3D direct construction of various materials into complex shapes.” *Id.*, [0093]. Below, I group a few selected aspects to facilitate my explanation.

44. According to Warren, the “DWDT/HAT may include a material dispenser that facilitates the fabrication and assembly of biocompatible scaffolds, cells, nutrients, growth factors, ECM proteins, therapeutics, and other biological, organic, or inorganic components as desired to form various components, such as 3D engineered tissue constructs (ETC).” EX1004, [0061] (reference number omitted). “The precise 3D in vivo direct deposition of cells, bioactive factors, and supportive 3D scaffolding using the miniaturized dispensing nozzle deposition system may help harness the potential of modern biology to deliver therapeutic regenerative medicine. The ability to precisely and selectively add, in real time, supportive 3D matrices, bioactive factors, and cells that differentiate and grow brings about a new-to-the-world advance to the metabolic- and tissue-engineering communities.” *Id.*, [0063], [0007] (“3D requirements for metabolic and tissue engineering”), [0321] (“the bioscaffold can require 3D fabrication processes” so as “to fabricate scaffold microstructure with controlled spatial gradients of cells, growth factors, and other desired ingredients”), [0324] (3D layered fabrication to

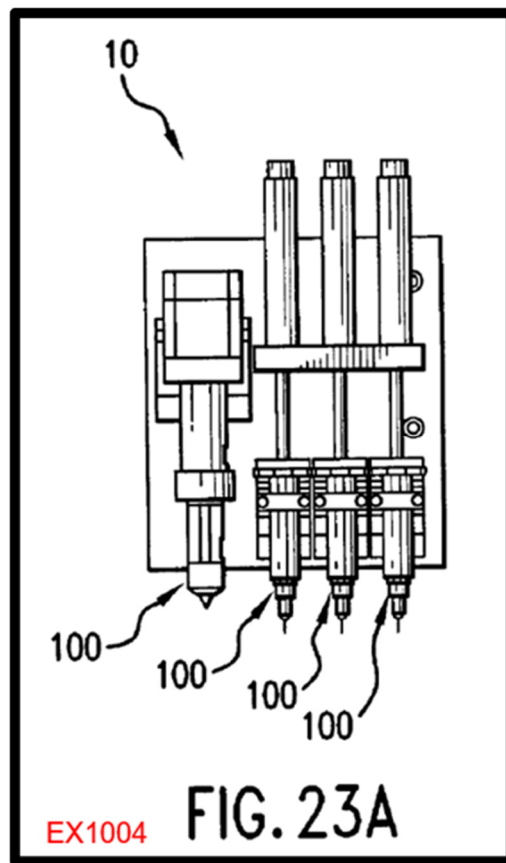
deposit cells atop a layer of polyurethane and bio scaffold material “using the vibro-sensoric capillary dispensing system”), [0446] (“The disclosed apparatuses, tools and methods can also be used to create specific 3D scaffolding out of biologically compatible material”).

45. Just like the '381 patent, and in the context of his DWDT/HAT technology, Warren discloses the aspect of “controlling the position of one or more elements of a depositing system that accurately determines the intensity of the contact force between a dispensing tip and a substrate surface to maintain a desired contact force between the dispenser and the substrate.” EX1004, [0287], [0288-290], [0283-84].

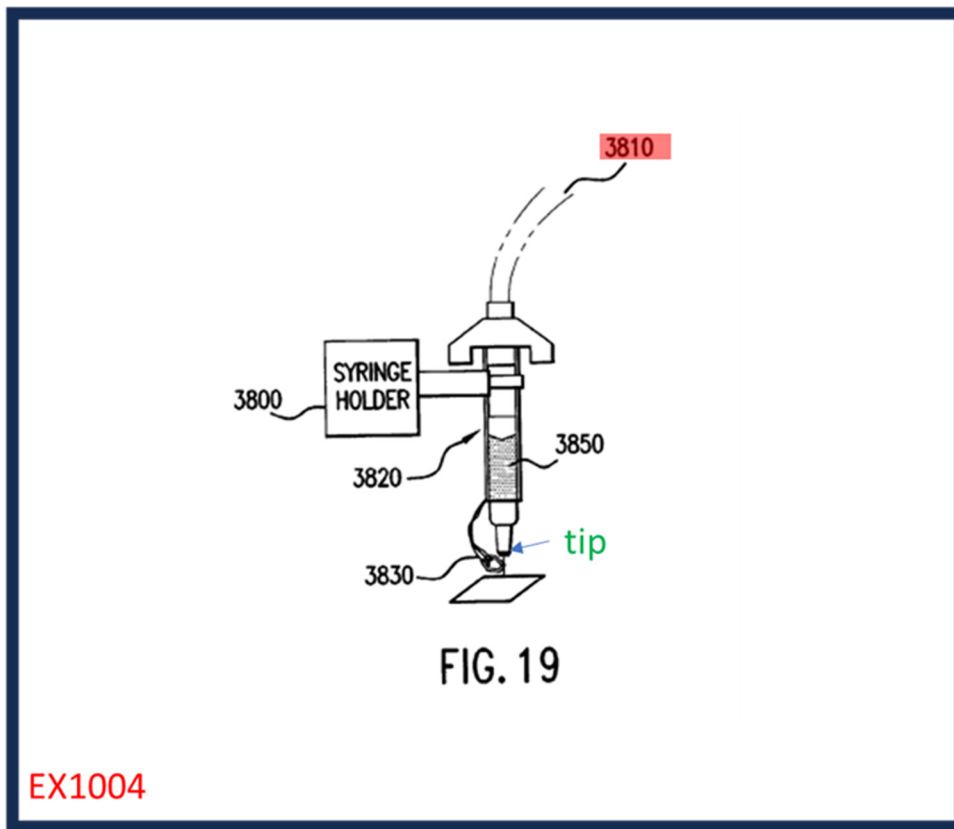


46. As depicted in FIG. 18 (annotated above), Warren discloses “an exemplary system for controlling the position of a dispenser 3700 relative to a substrate 3710 [which] may have irregular surfaces.” *Id.*, [0293]. “A vibration sensor 3730 and a transducer 3740 are attached to the dispenser 3700.” *Id.*, [0300], [0315] (“vibration sensor ... attached to the dispenser”). Warren teaches imposing vibration on the dispenser 3700, and when “[t]he vibration imposed on the dispenser 3700 is changed, e.g., modulated, by the contact of the 3700 dispenser with the substrate 3710... [t]he transducer 3740 senses and transfers the changed vibration signal to an amplifier...which then creates a feedback signal that is generally proportional to the intensity of the physical contact of the dispenser 3700 with the substrate 3710.” *Id.*, [0302], [0303-307] (additional details on force sensing). In one example, “the feedback signal may be used by a z-controller processor 3750 to control the z positioning of the dispenser 3700 via a z-controller step motor 3760.” *Id.*, [0313], [0308] (“... allowing the dispenser to move in relation to the substrate while maintaining sufficient dispensing or writing force.”); *see generally*, [0283-0318] (describing FIGS. 18-22A).

47. Warren further describes that its DWDT/HAT tool (“apparatus 10”) can have one or multiple material dispensers (“dispensers 100”), and provides the example of FIGS. 23A-23C including “four material dispensers, one through-nozzle dispenser and three capillary-based dispensers.” EX1004, [0278].



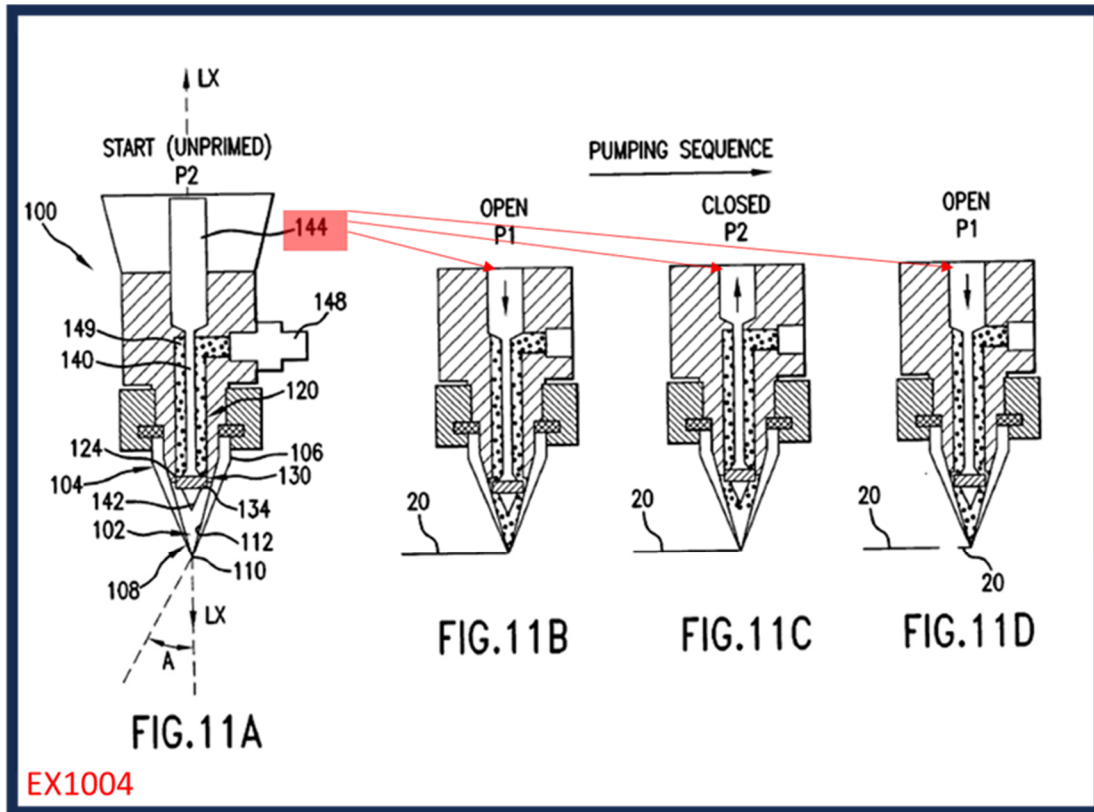
48. The capillary-based dispensers, referred to as a capillary vibro-sensor dispensing unit is “shown in FIGS. 19 [annotated below], 20A and 20B”, which can be “implemented in the system shown in in FIG. 18 [where a vibrating force sensor is used].” EX1004, [0299]. According to Warren, “[t]his type of dispenser forces, e.g., fluid or paste, in a reservoir 3850 through the tip 3840 of a syringe using air pressure applied from a source 3810 to the top side of a plunger 3820.” *Id.*, [0295].



49. As to the controller implementation, Warren describes an example that includes a “Windows based PC, indexer, and translation system” where “the indexer accepts commands from the PC and computes the necessary commands that need to be sent to the translation system.” EX1004, [0226-0229] (“Most indexers either plug-in to the PC bus or communicate with the PC via Ethernet. The indexer will preferably have a large memory cache and be capable of operating in the Khz range. The translation system is comprised of translation stages to give motion control in the required axes. The translation stages may be of the ball-screw variety. They may have associated linear encoders to improve positional accuracy but can typically operate with 1-2 um of accuracy without them.”).

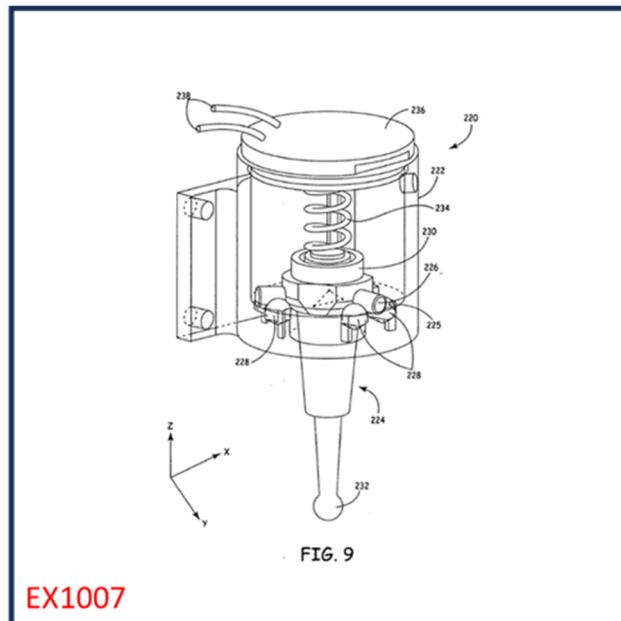
50. Warren additionally teaches temperature control techniques “to provide a suitable environment for delicate or temperature-sensitive constituent materials.” (EX1004, [0211-0217] (“enabl[ing] the user slowly and deliberately to change the temperature of the tool head or constituent materials”)).

51. Warren also discloses a through-nozzle design capable of precise control of “the amount of material dispensed per second” using, e.g., linear actuator 144 (as annotated in FIGS. 11A-D (below) “to control valve opening and closing.” EX1004, [0230-0252].



B. Dunn (EX1007)

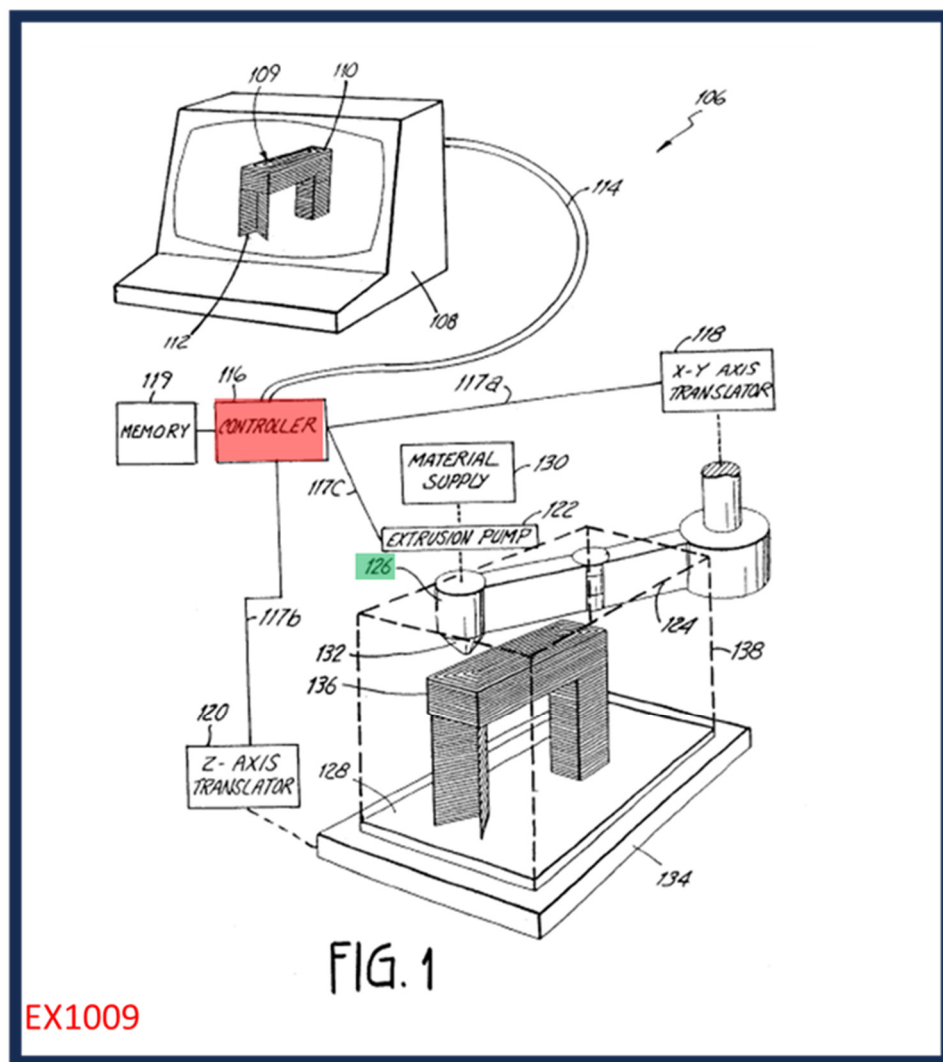
52. Like the '381 patent, Dunn is also directed to “a deposition device in a three-dimensional modeling machine that deposits a material to build up three-dimensional objects as directed by a controller on a substrate mounted on a platform.” EX1007, Abstract. Specifically, Dunn discloses a “multi-axis sensor assembly” with “the capability of sensing surfaces in the X and Y directions” in addition to “sensing surfaces in the Z-direction.” *Id.*, [0069].



53. As depicted in FIG. 9 (above), Dunn teaches that “[t]he multi-axis sensor assembly 220 [is] used to sense not only a top surface of a material pad, but also the sides of the material pad as well.” EX1007, [0070].

C. Calderon (EX1009)

54. Similar to the '381 patent, Calderon discloses “modeling machines which form three-dimensional objects by depositing modeling material onto a substrate mounted to a modeling platform.” EX1009, 1:5-10, Abstract. FIG. 1 (below) depicts an “extrusion-based layered modeling system 106” where “[a] computer aided design (CAD) program resident in a processor 108 generates a file describing the geometry of a part 109 to be created.” *Id.*, 4:20-33.



55. “An **electronic controller 116**, in response to receiving three-dimensional shape data from processor 108 ..., controls the extrusion of modeling material in an xyz-coordinate reference frame so that beads of modeling material are extruded layer-by-layer in a pattern defined by the volume elements 110 and 112.” EX1009, 4:34-52. While “sequentially position[ing] an extrusion head 126 carried by the arm 124 within an xy-plane with respect to a modeling substrate 128,” Calderon teaches “[e]xtrusion pump 122 synchronously provides modeling material from a material supply 130 to **extrusion head 126**” so that “[t]he modeling material is extruded from nozzle 132 onto the substrate 128 ... to build up a model 136 layer-by-layer on the substrate 128.” *Id.*, 4:34-5:10.

56. Calderon emphasizes that “[b]efore building up a model in commercially available modeling machines ..., the z-axis position of the platform requires initialization.” EX1009, 2:2:35-53. “An incorrect z-start position can result in failure in forming a model.” *Id.*, 2:63-3:1 (“...if the substrate is not mounted flat to the platform, or if the substrate is deformed or improperly mounted so that it lacks a horizontal planar surface, the model quality will be adversely affected regardless of the z-start position selected”). Calderon further explains that “achieving the correct position of a modeling platform by a manual or ‘eyeball’ method can be unreliable and time-consuming.” EX1009, 2:54-62 (“if the top surface of the substrate is not in an xy plane, nozzle tip depth will be incorrect at some locations

of the substrate. This results in “modeling in air” or in too much “plowing” by the tip”).

57. To address the “need for a z-axis initialization routine that does not require operator intervention or judgment,” Calderon describes “an automated apparatus and method for initialization of a computer-controlled modeling machine that builds up three-dimensional objects on a substrate supported by a modeling platform.” EX1009, 3:1-10.

58. Calderon teaches using a “sensor assembly ... mounted to an extrusion head of an extrusion-based layered modeling system,” such as the one depicted in FIG. 1, to sense “the force of contact of the [sensor] tip against the substrate.” EX1009, 5:10-24, 6:16-18 (reference numbers omitted), 6:37-47 (“Sensor [of FIGS. 2-4] may be interchanged with any sensing means which can detect and signal contact between the plunger and the substrate”).

59. The sensing means of Calderon encompasses “[a]ny manner of sensing a surface at selected coordinates to detect the corresponding Z-axis coordinate.” EX1009, 6:62-7:5. “Suitable sensing means include but are not limited to visible imaging devices, tactile detection devices and pneumatic detection devices.” *Id.* Calderon enumerates a long list of conventional sensors including “a magnet proximity switch, a Hall sensor, a Wiegand wire, a reed switch, a capacitive sensor or an inductance sensor.” *Id.*, 6:37-47. Calderon also provides a “plunging means”

for sensing “force of contact with the substrate such as a cam, pawl, cantilever, screw or membrane, or other mechanical structure” where “the plunging means need not move upward in response to contact with the substrate.” *Id.* 6:47-61. In one example, “a pzt; voice coil or similar transducer is used to vibrate the plunger [i.e., interchangeable with any plunging means] at a relatively high frequency (greater than 100 Hz, preferably greater than 10 kHz) and the transducer serves also as a sensing means to monitor the magnitude of the vibration” so that “[c]ontact is detected by the snubbing of the vibrational motion of the [plunging means].” *Id.*

60. In its Example 3, Calderon describes that “the tip of nozzle 132 ... can be used as a plunging means to find z-axis positions of the platform.” *Id.*, 9:63-10:23. “The initialization routine is performed by positioning the nozzle 132 above pre-selected locations of the substrate and raising the platform 134 until the nozzle tip contacts the substrate. Contact between the tip of nozzle 132 and the substrate 128 is monitored by a sensing means and the controller 116 electrically records the z-axis position of platform 134 at the time contact is detected.” *Id.* Calderon provides an example of “using servo drive motors” where “contact with the substrate 128 can be detected [from] the servo drive current without need for any special purpose sensing means.”) *Id.* A POSITA would have understood that while Calderon included examples that do not rely on a separate sensor, Calderon also included examples that incorporate many kinds of conventional sensors. The POSITA would

have understood that Calderon was suggesting that the mechanism for force measurement can include any known sensing mechanism using a conventional sensor such as a strain gauge, which was known as “a common sensor.” EX1001, 9:17-23.

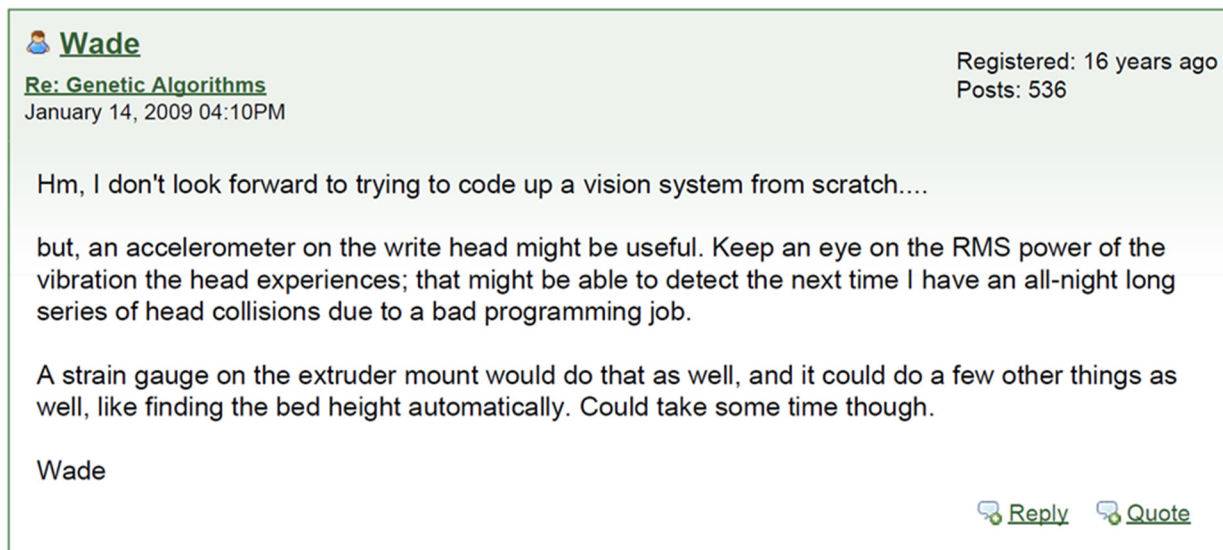
61. Calderon further teaches applying its Find-Z program that “uses the recorded z-axis positions to calculate a z-start position.” 8:11-37 (further discussing Step (4) “Add a constant value Z, representing the desired depth of the tip of nozzle 144 below the top surface of substrate 146, to the result of step (3), to arrive at the Z-Start position”), 10:9-15 (“The Find-Z program works much the same in the present example as described with respect to Examples, 1 or 2 above” except “Steps (1) and (3) of the algorithm above can be skipped” because “this approach eliminates the variables X and Y.”).

D. RepRap20208 (EX1010)

62. RepRap is short for “replicating rapid prototype,” which is a community project to develop low-cost 3D printers with an accompanying online public forum (i.e., reprap.org) accessible to the public at large without requiring login. RepRap20208 is a discussion thread posted on this on-line public forum around January 2009. Here, to improve control of the RepRap 3D printer, the developer community observed “it shouldn’t be too hard to hack together a bunch of

open source monitoring devices to record data like temperature, speed, vibration, etc.” EX1010, 13.

63. Among the different monitoring devices (sensors), the developer community particularly discussed implementation details of incorporating a force sensor, such as a strain gauge, for detecting extrusion head collisions and Z-axis calibration of the extrusion head relative to print bed position. For example, developer Wade suggested that “[a] strain gauge on the extruder mount would [show head collisions] as well, and it could do a few other things as well, like finding the bed height automatically.” EX1010, 13.



64. Another developer, Mr. Seeker, concurred about using a “strain gauge” and that “[y]ou could also use it to calibrate the Z-axis.” EX1010, 14. Wade later explains “I’d like to measure the important variable - nozzle to bed height - directly.” *Id.*, 18-19. And, another developer, fred, explains “It could also be used

for a calibration cycle where you touch down on the four corners of the bed or the maximum build area to check for alignment or height of Z; which in IMHO is the measurement that can be the most variable.” *Id.*, 19-20. Wade then replies “I was thinking a constant measurement of the force on the head (including it's [sic] weight) would be useful. That points more towards strain gauges. Yeah, the 4 corners calibration was what I was thinking as well.” *Id.*, 20.

65. It is fairly clear to me that these RepRap posters were discussing purposefully placing the print head into contact with the print bed, and then using the strain gauge on the extruder mount to identify that contact to establish a known relative position of the extrusion head and print bed for Z-axis calibration. In my view, this technique for Z-axis calibration was well known, and similar to the technique described by Calderon years earlier but reinforced using developers’ perspective. Since the posts were discussing a common technique, a POSITA would have understood these postings as a common disclosure, or at least have found it obvious to combine the teachings of the various posts on this topic.

VIII. GROUND 1A: WARREN’S COMBINED TEACHINGS WOULD HAVE RENDERED OBVIOUS CLAIMS 1-6, AND 9-16.

A. Overview of the Combination and Reasons to Combine

66. Based upon my knowledge and experience in the field and my review of Warren, it is clear that a POSITA would have been motivated to combine Warren’s disclosure of controlling a dispenser system using force feedback (EX1004,

[0283-0318] (describing FIGS. 18-22A) with other complementary aspects, such as Warren's through-nozzle design features for controlling material dispensing characteristics (e.g., *id.*, [0230-0252]).

**1. Incorporating Warren's through-nozzle dispenser
with a linear actuator into Warren's embodiment
using vibration force sensing**

67. In my opinion, a POSITA would have been motivated to apply features from Warren's through-nozzle dispenser (EX1004, [0230-0252] (describing FIGS. 11A-11D and 12A-12B)) as dispenser 3700 in Warren's vibrating force sensor configuration (*id.*, [0283-0318], [0226-0229]). *Id.*, [0239]. The predictable results of this combination include an integrated 3D printing system having a force feedback dispenser system equipped to provide an actuator-controlled "material dispensing rate." *Id.*, [0232]. Multiple independent reasons would have led a POSITA to this combination, as I explain below.

68. As a *first* reason, Warren invites the use of the vibrating force sensor concepts with other configurations of dispenser when it explains that the capillary dispensing unit is shown with the vibrating force sensor "by way of example only," "[t]he dispenser 3700 need not be limited to [the capillarity dispensing unit] implementations." EX1004, [0299], *see also*, [0294] ("dispenser 3700 may be implemented differently"). Doing so merely involves combining known elements using known techniques to achieve predictable and advantageous results.

69. As a ***second*** reason, a POSITA would have been motivated by the precise flow control capability of Warren's through-nozzle design, in which "linear actuator 144 controls the material dispensing rate and improves start and stop characteristics by controlling the position of the valve piston 140 and speed of displacement." EX1004, [0243]. "During the initial valve opening, the motion of the piston 140 transfers a momentum to the material and causes the material to flow at a specific flow rate...so that the material flowing through the valve 130 will have the same flow velocity, thereby leading to a smooth dispensing start." *Id.* A POSITA would have found it advantageous to employ features from Warren's through nozzle design (including linear actuator 144) to Warren's vibrating force sensing dispenser system 3700 so that "the initiation of material flow...can be smooth, seamless, and very reproducible." *Id.* Warren indicates "inconsistent volumes and inaccurate start times" in the absence of actuator control. *Id.*

70. As a ***third*** reason, Warren makes clear that its linear actuator 144 (to impart dynamic control) is "conventional," and the predictable use of such conventional linear actuator in Warren's dispenser system 3700 to "provide[] a means to control precisely the rate (speed) and the degree of valve opening and closing" (*id.*, [0243]) would have been obvious. Significantly, Warren explains that its "DWDT/HAT technology has a plurality of aspects that, in some embodiments, combine to make a tool capable of producing a modeled structure through 3D direct

construction of various materials into complex shapes.” *Id.*, [0093]. A POSITA would have recognized Warren’s express suggestion to add features from its through-nozzle design (such as linear actuator 144) to Warren’s dispenser system 3700 to pursue a predictable combination with known improvements.

71. As a *fourth* reason, a POSITA would have recognized the benefits of providing an instance of the through-nozzle dispenser with vibrating force sensor capabilities. As Warren explains, “for proper deposition some knowledge is required of the intensity of the contact force between the dispenser tip and surface where deposition is desired.” EX1004, [0286]. “Improper prediction of the intensity of this force may result in either destruction of the dispenser or the substrate as the tip crashes into the substrate material, or little to no control of the deposition geometry due to a large spacing between the tip and the substrate surface.” *Id.* Thus, my opinion is that, based on such revelation, a POSITA would have sought to apply Warren’s vibration force sensing to Warren’s through-nozzle dispenser to avoid damage to the substrate or nozzle. A POSITA would have also found motivation for the combination to facilitate control over the deposition geometry. *Id.* A POSITA would also have sought “to overcome issues regarding agglomeration and/or sticking of the constituent material” with the vibrating aspects. *Id.*, [0331]-[0332].

72. A POSITA would have reasonably expected success in the above-discussed combination. Combining the relevant aspects of Warren would have been

nothing more than integrating complementary teachings from within the same reference, all of which relate to the same DWDT/HAT technology. The fundamental aspects of Warren's embodiment for controlling the dispenser system using force feedback would remain intact, bolstered by the beneficial aspects of the through-nozzle design to arrive at the '381 patent's claimed invention with a reasonable expectation of success.

B. Independent Claim 1

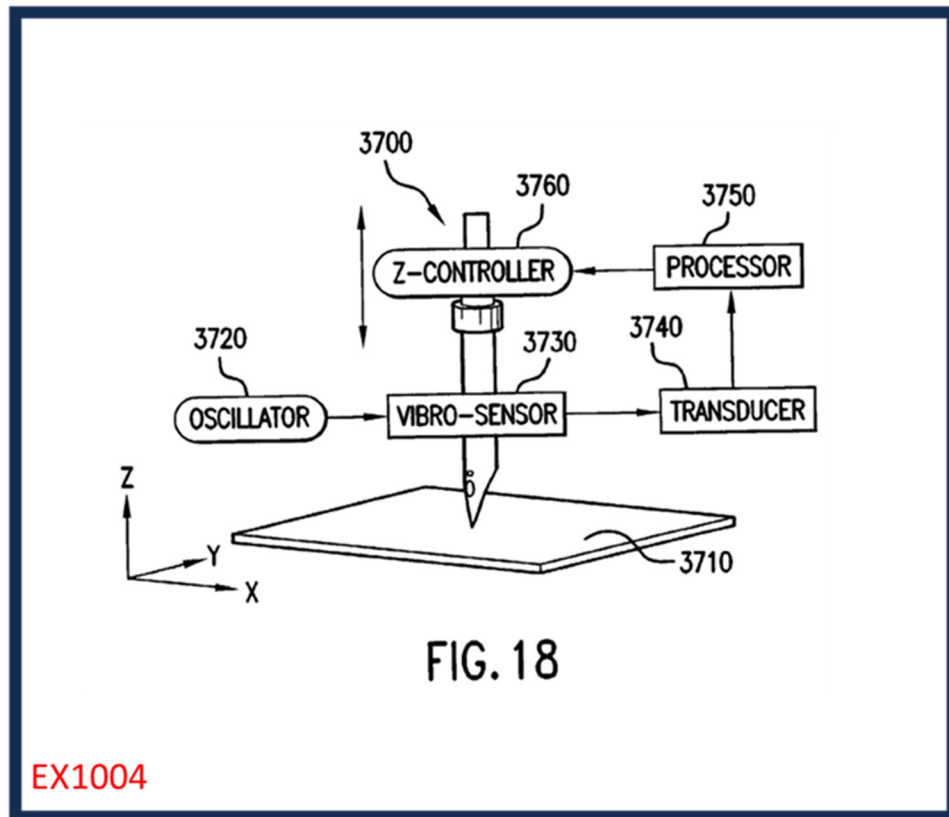
73. Independent claim 1 of the '381 Patent recites:

1. A three-dimensional printer comprising:
a fabrication tool including an extruder configured to extrude build material to fabricate an object during a build process;
one or more sensors mechanically coupled to the extruder, wherein the one or more sensors are collectively operable to sense a contact force between the extruder and a separate structure distinct from the fabrication tool;
and
a controller configured to receive a signal from the one or more sensors on the extruder and to calculate the contact force between the extruder and the separate structure.

74. As I explain in more detail below through my element-by-element analysis, the combined teachings of Warren render claim 1 obvious.

[1.pre] A three-dimensional printer comprising:

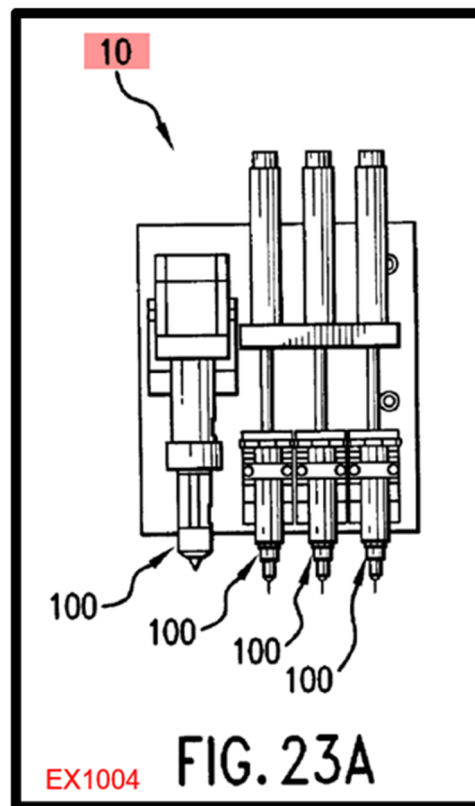
75. To the extent that the preamble is treated as a limitation, my review of Warren confirms that Warren teaches a printer for “producing a modeled structure through 3D direct construction of various materials into complex shapes.” EX1004, [0093], [0063] (“precise 3D in vivo direct deposition of cells, bioactive factors, and supportive 3D scaffolding using the miniaturized dispensing nozzle deposition system”), [0293-0321] (exemplary system at FIG. 18 where “the bioscaffold can require 3D fabrication”), [0288-290]; §§VII.A & VIII.A.



76. Therefore, the combined teachings of Warren provide Element [1.pre].

[1.a] a fabrication tool including an extruder configured to extrude build material to fabricate an object during a build process;

77. As I describe above in my analysis of Element [1pre], Warren includes *a fabrication tool*, e.g., the apparatus 10 shown in FIGS. 23A-23C:



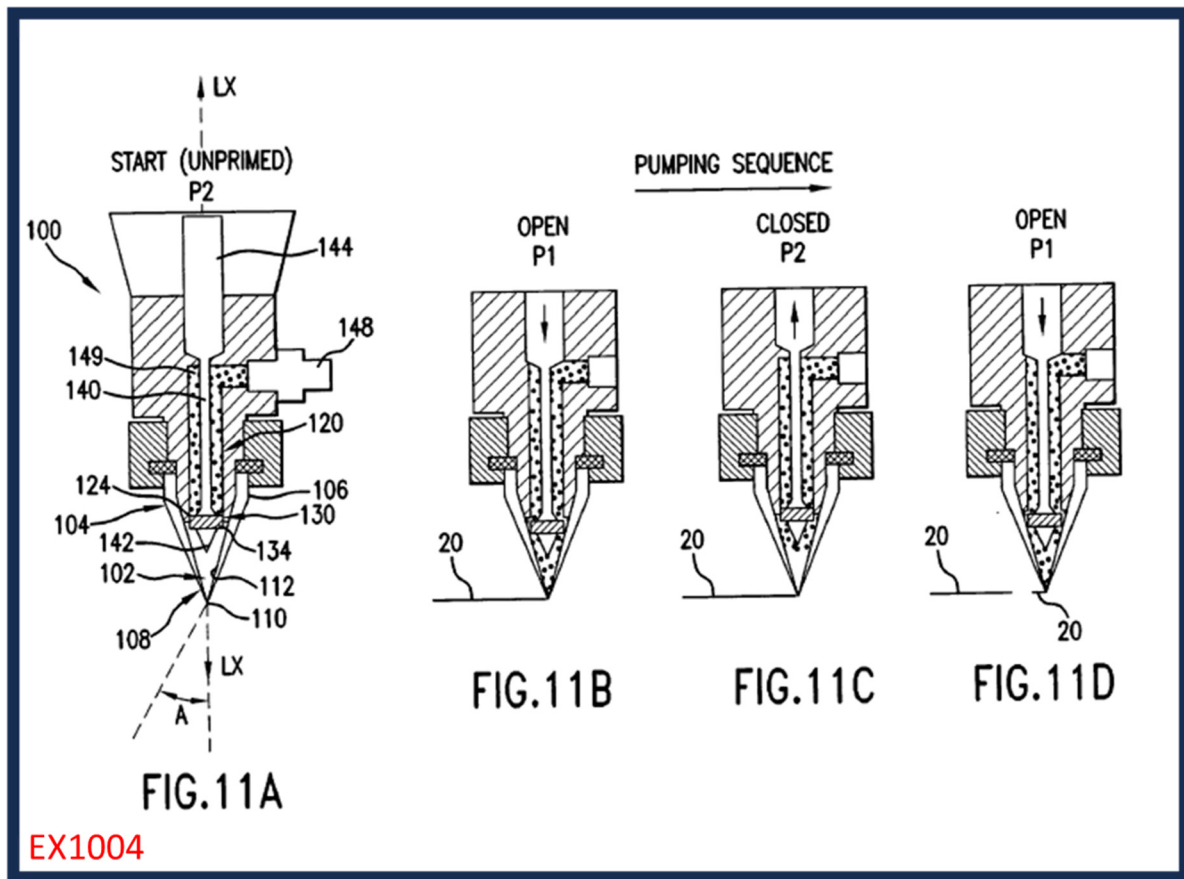
78. The fabrication tool includes *an extruder* (e.g., either the capillary vibro-sensor dispensing unit or the through-nozzle dispenser, both designated as 100 in FIG. 23A)) *configured to extrude build material to fabricate an object* (e.g., a modeled structure via the DWDT/HAT technology) *during a build process* (e.g., a 3D direct construction process).

79. As I describe above under Sections VII.A & VIII.A, the capillary vibro-sensor dispensing unit is expressly disclosed as used with Warren's vibrating force sensing and a POSITA would also have been motivated to configure the through-

nozzle dispenser with Warren's vibrating force sensing. Use of either, or both, satisfies claim 1.

80. The capillary vibro-sensor dispensing unit is *an extruder* in that it “forces, e.g., fluid or paste, in a reservoir 3850 through the tip 3840 of a syringe using air pressure applied from a source 3810.” EX1004, [0295], [0299], FIGS 18-20A, 20B.

81. The through-nozzle dispenser is likewise an extruder in that it features a “positive-displacement/suck-back pump system,” where “the pump 148 powers a simple process of applying positive pressure to a material in a reservoir 149, and the flow of material is controlled by adjusting the open position P1 and closed position P2 of the valve 130.” EX1004, [0232]; *see also generally* [0230-0252], FIGS. 11A-11D (annotated below), 12A-12B. The “valve 130 includes a linear-actuated piston 140..., the piston being operatively coupled to [the] miniature displacement pump 148.” *Id.*, [0242]. “[T]he linear actuator 144 [operating the valve piston 140] controls the material dispensing rate” through the nozzle tip orifice 110. *Id.*, [0243-0244].



82. Moreover, Warren’s teachings parallel the ’381 patent’s preferred embodiments, which “push the build material into the chamber 122 and/or through the extrusion tip 124.” EX1001, 2:28-52. Additionally, Warren also provides temperature control features that parallel the heating elements described by the ’381 patent, as I describe above in Section VII.A. And extruders in fused deposition modeling, like the ’698 patent, have long been referred to as “dispensers.” See, EX1021, 3:14-38 (30-year-old fused deposition patent with a “dispenser”).

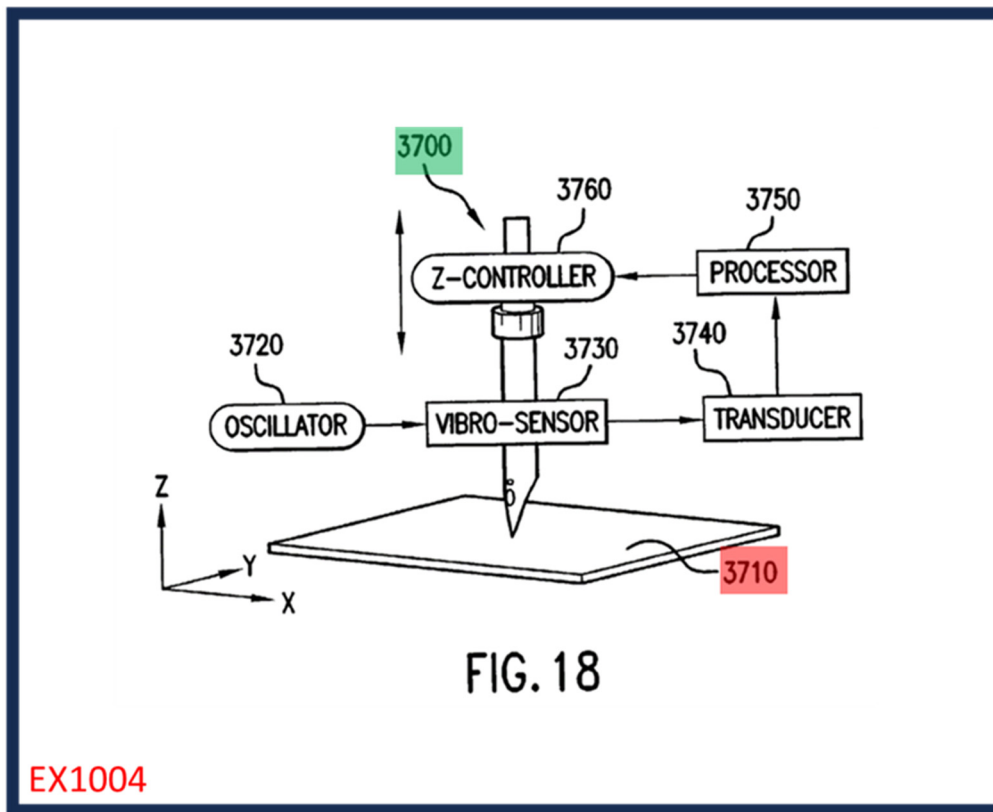
83. Both of Warren’s dispensers are *configured to extrude build material to fabricate an object during a build process*, including “to precisely and selectively

add, in real time, supportive 3D matrices, bioactive factors, and cells.” *Id.*, [0063]; see also, [0007], [0321], [0324], and [0446].

84. Therefore, Warren’s combined teachings provide Element [1.a].

[1.b] one or more sensors mechanically coupled to the extruder, wherein the one or more sensors are collectively operable to sense a contact force between the extruder and a separate structure distinct from the fabrication tool; and;

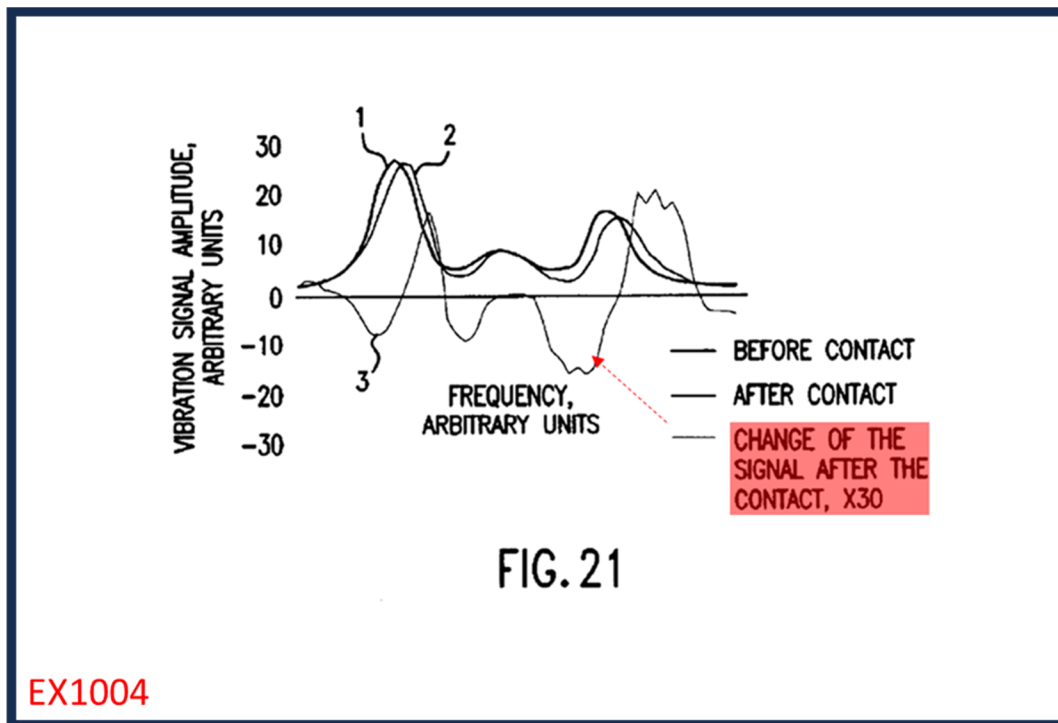
85. The combined teachings of Warren provide *one or more sensors* (e.g., vibration sensor 3730 and transducer 3740) *mechanically coupled to the extruder* (e.g., either capillary vibro-sensor dispensing unit or the through-nozzle design). See e.g., EX1004, [0300] (“A vibration sensor 3730 and a transducer 3740 are attached to the dispenser 3700”), [0315] (“vibration sensor ... attached to the dispenser [where the through-nozzle dispenser is implemented to push build material through the nozzle orifice]”), FIG. 18 (annotated below).



86. Warren’s *one or more sensors* are *collectively operable to detect a current contact force* (e.g., the force of contact) *between the extruder* (e.g., the nozzle of either capillary vibro-sensor dispensing unit or the through-nozzle dispenser) *and a separate structure* (including, e.g., substrate 3710). For example, Warren’s system includes “a vibration oscillator 3720...for imparting vibration to the dispenser 3700” and “[a] vibration sensor 3730 and a transducer 3740...for sensing the A and f of vibration of the dispenser 3700.” EX1002, [0300]. According to Warren, “[t]he vibration imposed on the dispenser 3700 is changed, e.g., modulated, by the contact of the 3700 [sic] dispenser with the substrate 3710” such that “[t]he transducer 3740 senses and transfers the changed vibration signal to an

amplifier.” EX1004, [0302], [0313] (“the contact force” determined “based on the detected change in amplitude”).

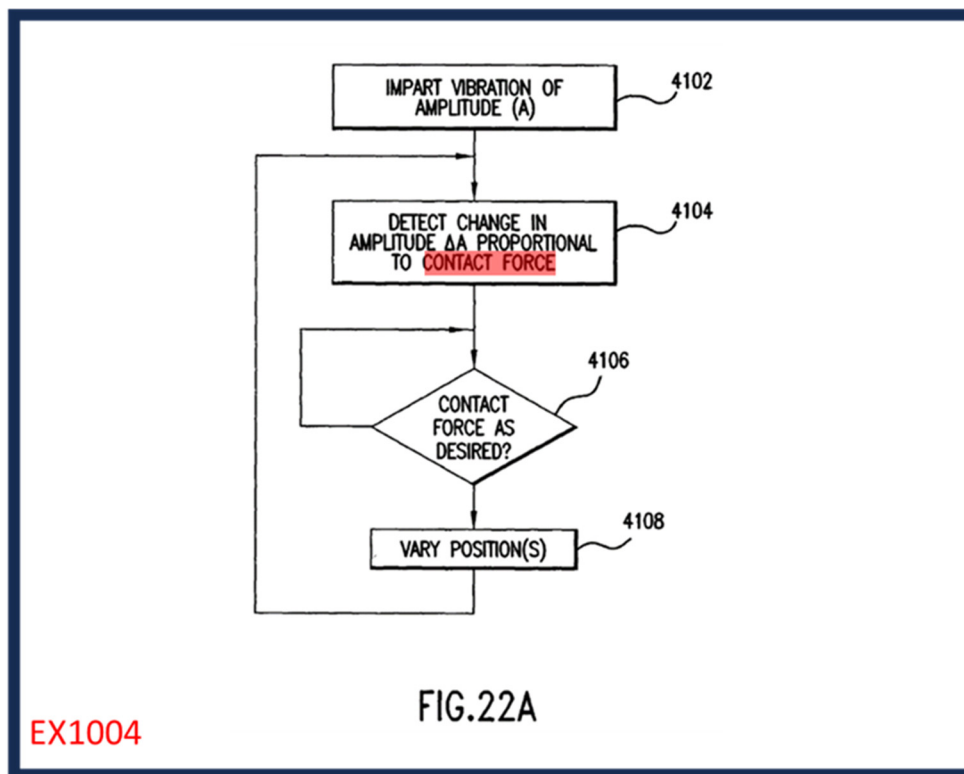
87. Warren explains that “the vibration imposed ... does not necessarily have to occur at $f=f_r$ of the piezoelement or the dispensing system” because “when a vibrating element contacts an object, it does not necessarily shift f_r .” EX1004, [0304-0305]. “In contrast, A is inevitably altered.” *Id.* Warren thus emphasizes that the detection of changed amplitude, known as ΔA , “brings additional flexibility and sensitivity to the system.” *Id.*, [0304].



88. As illustrated in FIG. 21 (above), Warren notes that “[t]he measured ΔA are widespread throughout the vibration spectrum, often staying apart from resonance lines. This enables the selection of a working f in a desirable region not

limited by the self-resonance of piezoelements.” EX1004, [0306]. “Another advantage of imposing vibration is that it is possible to observe ΔA on subharmonics and, especially, superharmonics, employing synchronous phase-sensitive detectors and f of the function generator as a standard. This may provide even better sensitivity and flexibility.” *Id.*, [0307].

89. Warren further explains that “a change in the amplitude of vibration of the dispenser and/or the substrate is *detected*,” where “this change in amplitude is proportional to *the force of contact* between the dispenser and the substrate.” *Id.*, [0313] (discussing FIG. 22A (annotated below showing “detect change in amplitude ΔA proportional to contact force”)).

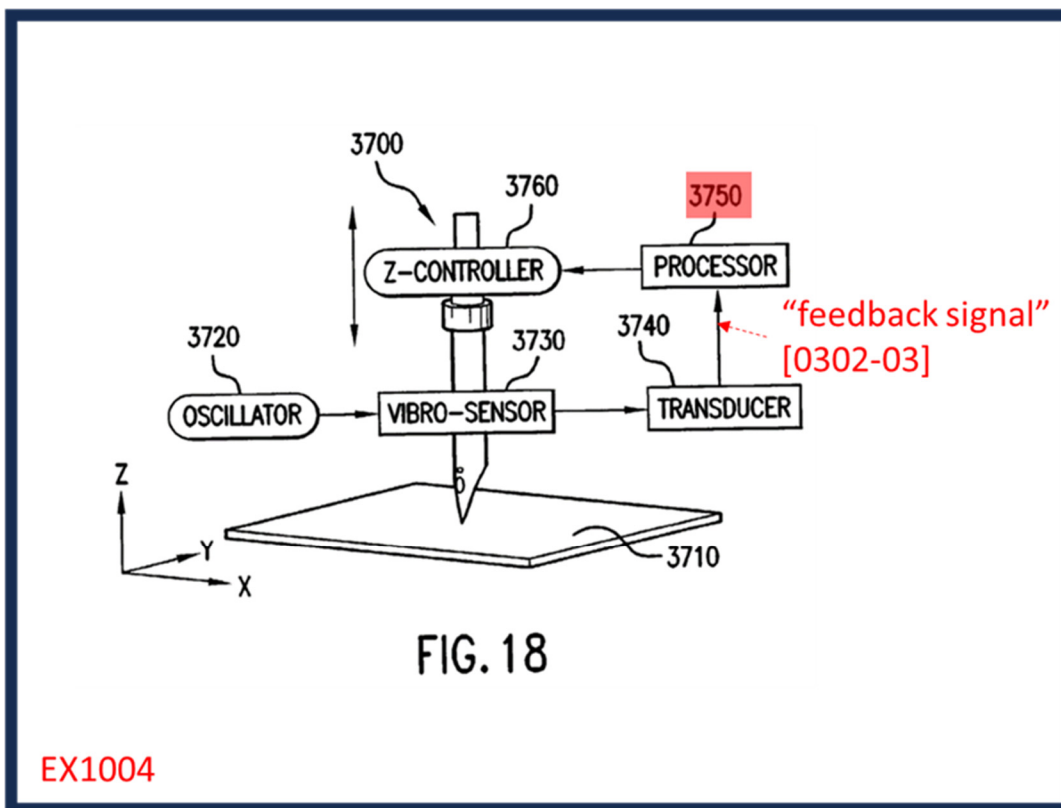


90. In view of the proportionality, calculating contact force is simple, predictable, math. In other words, a POSITA would have understood that the *contact force* can be calculated from the detected “change in the amplitude.” EX1004, [0313]. I have provided additional details of Warren’s sensing operations above and under Section VIIA, where I have cited, among others, Warren’s disclosure at [0301-0307] as well as FIGS. 18 and 19. Warren’s vibration sensor and transducer thus align with the specification of the ’381 patent, which describes its sensors broadly to sense anything, “so long as the contact force(s) ... may be calculated from the sensed physical characteristics,” EX1001, 8:49-61.

91. Therefore, Warren’s combined teachings render obvious Element [1.b].

[1.c] a controller configured to receive a signal from the one or more sensors on the extruder and to calculate the contact force between the extruder and the separate structure.

92. The combined teachings of Warren provide *a controller* (e.g., a “microprocessor” or “a personal computer”) *configured to receive a signal* (e.g., the feedback signal) *from the one or more sensors* (e.g., vibration sensor 3730 and transducer 3740) to calculate the contact force *between the extruder* (either capillary vibro-sensor dispensing unit or the through-nozzle design) *and a separate structure* (including, e.g., substrate 3710).



93. Referring to the 3D printing material dispensing system of FIG. 18 (annotated above), Warren discloses: “The transducer 3740 senses and transfers the changed vibration signal to an amplifier ... which then creates a feedback signal that is generally proportional to the intensity of the physical contact of the dispenser 3700 with the substrate 3710.” EX1004, [0302]. “The feedback signal is used to control the position of the dispenser 3700 to maintain a desired force of contact between the dispenser 3700 and the substrate 3710.” *Id.* In one example, “the feedback signal may be used by a z-controller processor 3750 to control the z positioning of the dispenser 3700 via a z-controller step motor 3760.” *Id.*; *see also id.*, [0313]. “The z-controller [processor] 3750 may be implemented with, e.g., a microprocessor,” and,

optionally, “[a] personal computer (PC) may be used in conjunction with z-controller [processor] 3750 for this purpose, in which case the feedback signal is fed directly to the PC.” *Id.*, [0302-0303].

94. Warren also explains the significance “to determine the intensity of contact force between elements” in that a system that “accurately determines the intensity of the contact force between a dispensing tip and a substrate surface” can be provided to further Warren’s objective, namely, “to maintain a desired contact force between the dispenser and the substrate.” EX1004, [0286-287], [0313-0316], FIG. 22A.

95. Thus, in my opinion, a POSITA would have known, or found it obvious, that Warren’s controller calculates the contact force based on the feedback signal using proportionality and other commonly used sensor conditioning math functions. The sensors discussed above are routinely used to measure force and the calculation of force values from the sensor signals was routine at the time. Indeed, specific conversion operations to calculate the contact force were well-known. *See e.g.*, Matsumiya (EX1012) at [0120-121] (“scanning measuring force”) and [0128-129] (“touch detecting measuring force”) and Igasaki (EX1017) at FIG. 4. Calculating contact force from a sensor intended to produce a signal proportional to contact force was rudimentary engineering and commonplace long before 2012 and would have led to many advantages in a control system designed to “maintain a desired contact

force” by virtue of directly operating in the force domain for simplicity. EX1004, [0286-287]. Among other reasons, a POSITA would have known that the comparison between the sensor signal and a “desired contact force” requires a conversion of the values to the same domain. Moreover, it was obvious to a POSITA to either compare the values in the force domain or in the sensor domain, and there are advantages of the controller operating in a force, rather than sensor signal, domain. For example, calculating the contact force would facilitate programming Warren’s controller to a desired contact force setpoint because the setpoint used by the controller and the desired contact force would be in the same units (force). Or, if the controller were configured to allow a user to change the setpoint, calculating contact force would facilitate a user’s interaction with the controller. The controller’s settings values could more readily be set, adjusted or displayed in meaningful (to a user) force-based units rather than in values of the proportional signal from Warren’s vibrating force sensor.

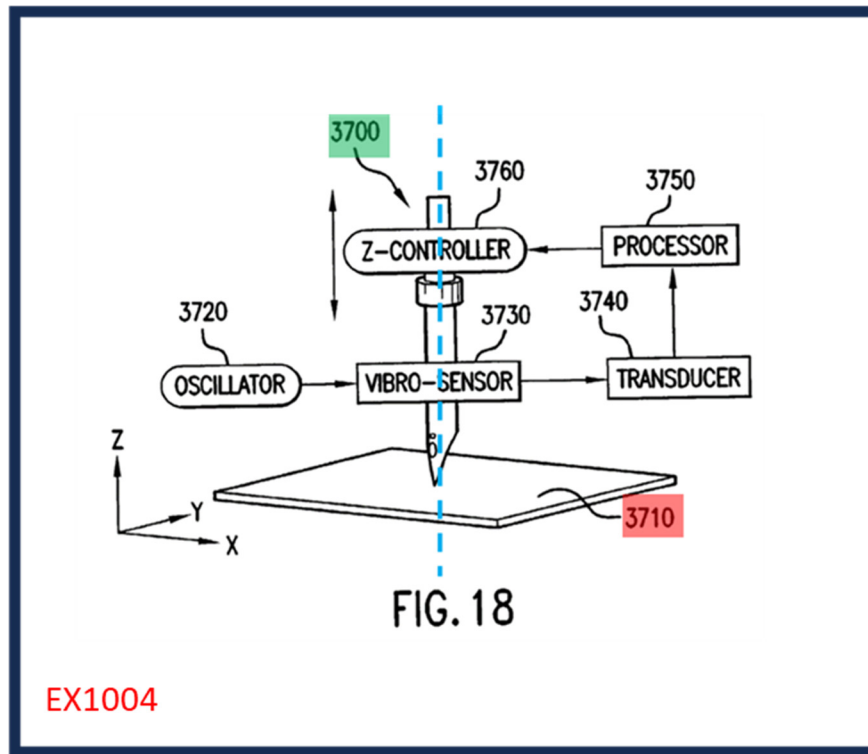
96. Therefore, for the reasons discussed above, Warren renders obvious all elements of claim 1.

C. Claim 2

97. Claim 2 of the ’381 Patent recites:

2. The three-dimensional printer of claim 1, wherein the contact force is a force along an extrusion axis of the extruder.

98. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren teaches that *the contact force is a force along an extrusion axis* (e.g., the z-axis) *of the extruder* (either the capillary vibro-sensor dispensing unit or the through-nozzle dispenser design). §§VII.A & VIII.A.



99. As annotated in FIG. 18 (above), Warren's dispenser is oriented along the z-axis, which serves as the extrusion axis in this configuration. EX1004, [0293-94]. When the substrate is aligned with the x-y plane, as in FIG. 18 reproduced above, the contact force exerted at the tip of dispenser is directed along the extrusion axis

in this configuration. *Id.* Warren further explains controlling the z-height of the substrate and/or dispenser in response to the contact force. EX1004, [0316] (“continuously corrects the dispensing structure's z-height position as the z height of the substrate surface changes, either by modifying the dispenser's position, the substrate's position, or both”). Moreover, even if the dispenser were not precisely oriented along the z-axis, a POSITA would have understood that there was a force component directed along the extrusion axis and that this force component is a contact force. For example, if the dispenser were at a slight angle to the z-axis, the contact force could be resolved into component vectors where one component contact force vector could be defined in the extrusion direction.

100. Therefore, the combined teachings of Warren render obvious claim 2.

D. Claim 3

101. Claim 3 of the '381 Patent recites:

3. The three-dimensional printer of claim 1, wherein the contact force includes a deflection force exerted by the separate structure on a tip of the extruder.

102. Each and every element of claim 1 is obvious as explained above. The '381 patent distinguishes a “deflection force” from a “normal force.” EX1001, 9:23-24. The contact force in Warren, however, also includes a deflection force due to friction from contact of the dispenser against the surface the material is being

dispensed on as the dispenser traverses its build path. EX1004, [0316] (describing use of the vibrating force sensor while dispensing material to “continuously correct[] the dispensing structure's Z-height position”), [0322] (“follow” curved surfaces).

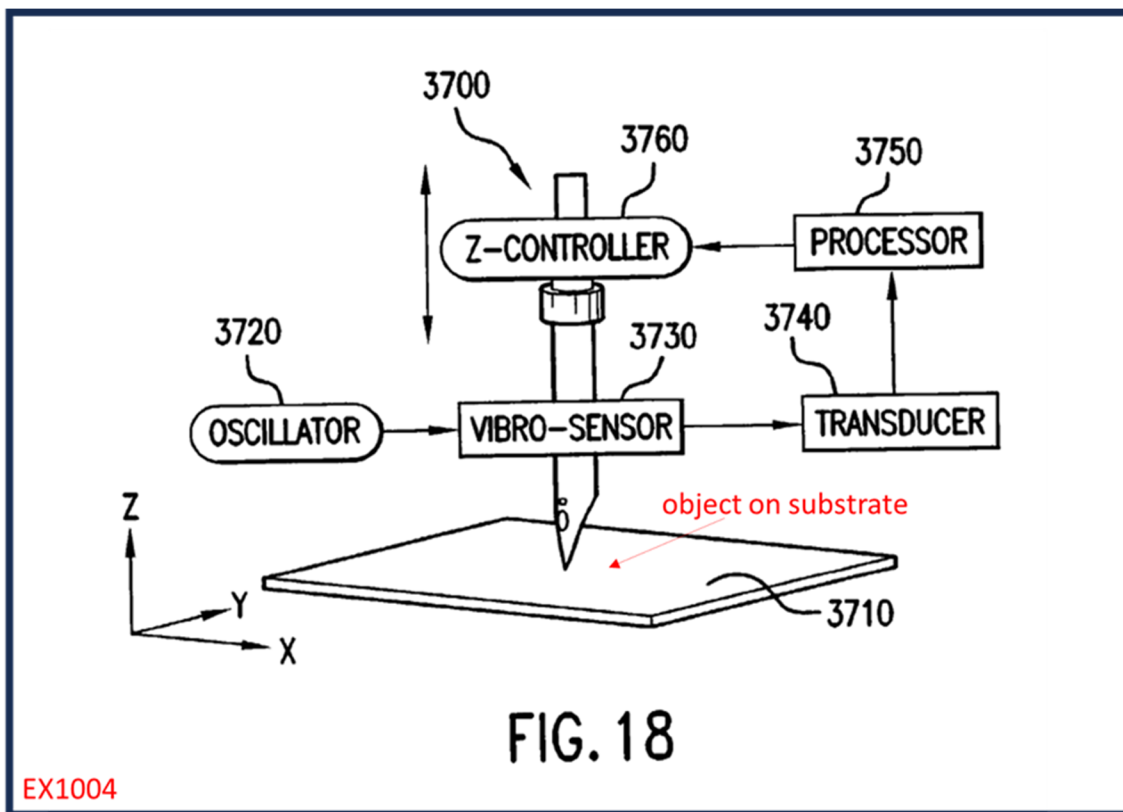
103. Accordingly, Warren’s combined teachings render obvious claim 3.

E. Claim 4

104. Claim 4 of the ’381 Patent recites:

4. The three-dimensional printer of claim 1, wherein the separate structure includes an object being fabricated by the three-dimensional printer.

105. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren teaches that *the separate structure includes an object being fabricated* (e.g., the modeled structure being built on substrate 3710) *by the three-dimensional printer*. §§VII.A & VIII.A.



106. As depicted in FIG. 18 (above), a modeled structure (i.e., *an object*) is being built on substrate 3710. *See, e.g.*, EX1004, [0295] (noting “multilayered” structure), [0324] (noting “four different layers”), [0088], [0093], [0427]. Warren describes that the vibrating force sensing “enables the dispenser to seek and find contact with a surface, maintain contact of a desirable intensity, accurate to a precision of micronewtons of force.” *Id.*, [0316]; *see also*, [0375], [0301-316]. In my opinion, a POSITA would understand Warren’s description of using a dispenser with the vibrating force sensor to “maintain contact” and to deposit material on “a layered surface” built on the substrate to be, or render obvious, sensing contact force

with a *separate structure* that *includes an object being fabricated*. EX1004, [0316], [0324].

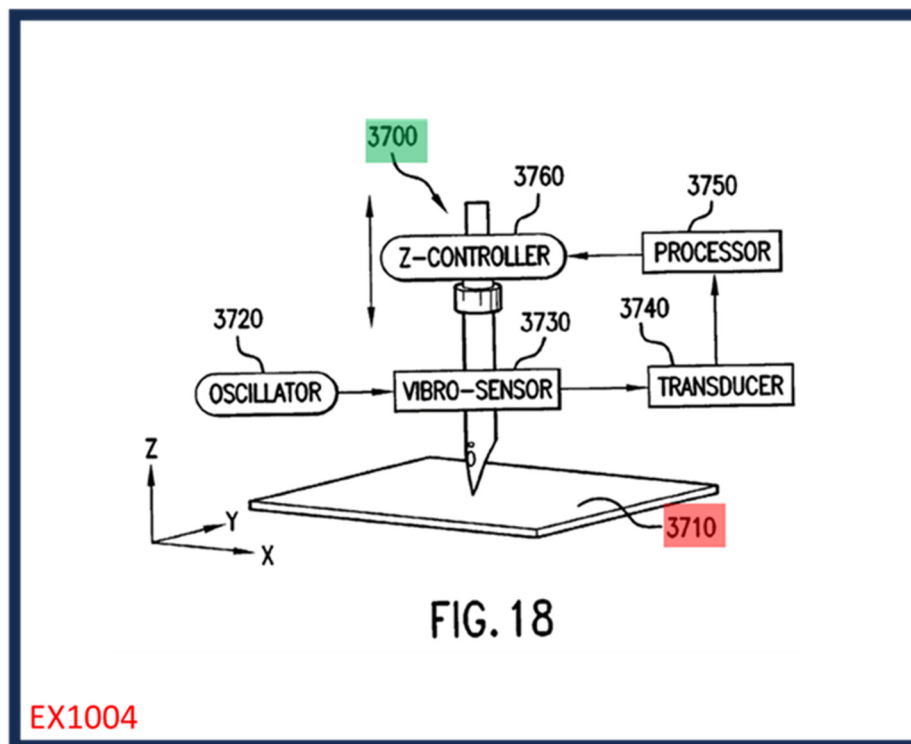
107. Accordingly, the combined teachings of Warren render obvious claim 4.

F. Claim 5

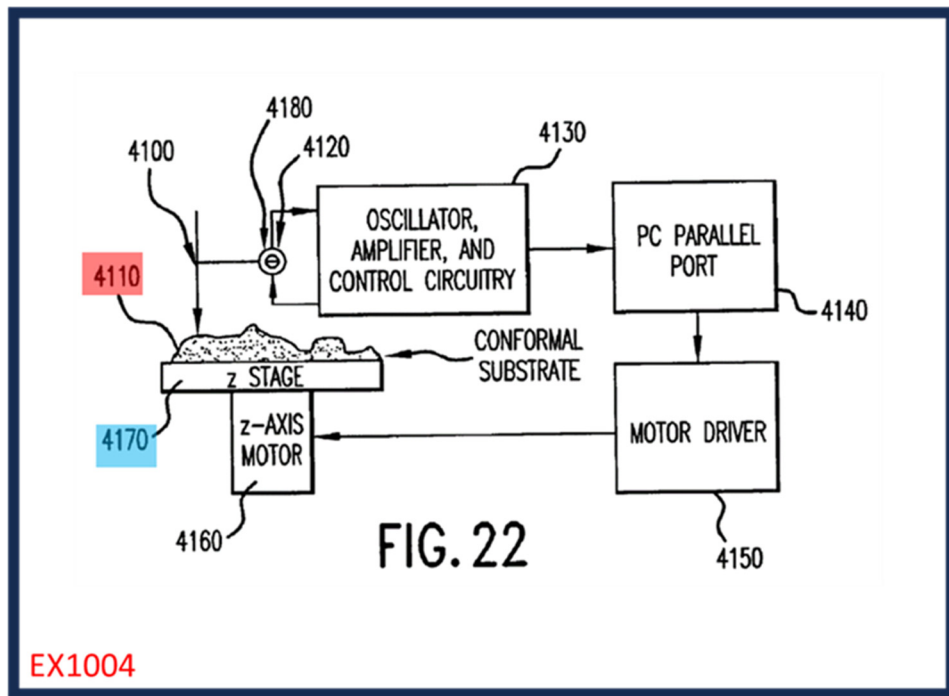
108. Claim 5 of the '381 Patent recites:

5. The three-dimensional printer of claim 1, wherein the separate structure includes a build platform of the three-dimensional printer.

109. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren teaches that *the separate structure includes a build platform* (e.g., the underlying build platform, or substrate, on which the modeled structure is being built) *of the three-dimensional printer*. §§VII.A & VIII.A.



110. As annotated in FIG. 18 (above), the substrate 3710 - on which the modeled structure is being built – is a build platform. The substrate 3710 and underlying structure could also provide the claimed build platform. As annotated below, FIG. 22 of Warren (“implemented in a manner similar to FIG. 18”) shows “the substrate 4110 rests” upon “z-axis stage 4170.” EX1004, [0311]. As explained above in Sections VII.A & VIII.A, Warren teaches measuring the contact force(s) between its dispenser and an underlying surface such as the surface of the substrate. This arrangement is consistent with the description of the ’381 patent. EX1001, 8:55-64 (“a separate structure, such as...the build platform 306...”).



111. Accordingly, Warren's combined teachings render obvious claim 5.

G. Claim 6

112. Claim 6 of the '381 Patent recites:

6. The three-dimensional printer of claim 1, wherein the contact force is a force normal to a surface of the separate structure.

113. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren's combined teachings provide a contact force as a force normal to a surface of the separate structure (including, e.g., a substrate).

114. As shown in FIG. 18 (annotated supra claim 3), Warren depicts substrate 3710 as positioned on an underlying build platform, which lies in the X-

Y plane. EX1004, [0293-294, 0301-303] (describing FIG. 18). The contact force at the tip of dispenser 3700 acts along the z-axis, and therefore normal to the surface of the separate structure positioned in the X-Y plane. Warren's description thus comports with the '381 specification at 8:65-9:10 ("... a normal force (e.g., instantaneous contact force) between the fabrication tool 300 and the build platform 306 may be sensed"). Moreover, even if the dispenser were not precisely normal to the surface of the substrate, a POSITA would have understood that there was a force component directed normal to the substrate and that this force component was a contact force. For example, if the dispenser were at a slight angle to normal, the contact force could be resolved into component vectors where one component contact force vector would be normal to the surface of the separate structure.

115. Accordingly, Warren's combined teachings render obvious claim 6.

H. Claim 9

116. Claim 9 of the '381 Patent recites:

9. The three-dimensional printer of claim 1, wherein each of the one or more sensors are selected from the group consisting of: capacitive sensors, electromagnetic sensors, optical sensors, potentiometric sensors, and piezoelectric sensors.

117. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren's combined teachings provide *each of the one or*

more sensors as *optical sensors* and *piezoelectric sensors*—e.g., piezoelements, piezomembranes, and piezotransducers—to measure contact forces while the modeled structure is being built. EX1004, [0283-0306]. Warren explains its (e.g., vibration sensor 3730 and a transducer 3740) are “attached to the dispenser 3700 for sensing ...vibration of the dispenser 3700.” *Id.*, [0300]. According to Warren: “The vibration imposed on dispenser 3700 is changed, e.g., modulated, by the contact of the 3700 dispenser with the substrate 3710. The transducer 3740 senses and transfers the changed vibration signal to an amplifier ..., which then creates a feedback signal that is generally proportional to the intensity of the physical contact of the dispenser 3700 with the substrate 3710.” *Id.*, [0302]. Warren explains: “According to one embodiment, a noncontact, high accuracy (submicrometer) fiber optic sensor may be used as the sensor element to monitor vibration.” *Id.*, [0297]. A “fiber optic sensor” is an *optical sensor*. Warren also explains: “The oscillator 3720 and the transducer 3740 may be implemented with any suitable conventional devices. . . According to one embodiment, these elements may be implemented in a piezoelectric bimorph ceramic element,” which is a piezoelectric sensor. EX1004, [0300].

118. Accordingly, Warren’s combined teachings render obvious claim 9.

I. Claim 10

119. Claim 10 of the ’381 Patent recites:

10. The three-dimensional printer of claim 1, wherein the one or more sensors include one or more strain gauges.

120. Each and every element of claim 1 is obvious as explained above. As further discussed under claim 9, Warren provides several examples of piezoelectric devices as sensors “for sensing ...vibration of the dispenser 3700.” EX1004, [0300-302]. It was general knowledge that piezoelectric devices convert input mechanical displacement/strain to a change in electrical output based on the piezoelectric effect. In my opinion, a POSITA would have understood piezoelectric devices to be strain gauges, because piezoelectric devices produce electrical signals in response to their deformation or strain. See e.g., EX1019. A POSITA would have at least found it obvious to configure, e.g., vibration sensor 3730 of Warren, as a strain gauge to sense the displacement of the vibrating dispenser 3700 in determining its amplitude and frequency of vibration. Warren also provides a broad disclosure that the relevant sensor “transducer 3740 may be implemented with any suitable conventional devices.” EX1004, [0300]. In light of that teaching, it would have been obvious to a POSITA to use a conventional strain gauge sensor as the conventional sensor to implement transducer 3740. “The transducer 3740 senses and transfers the changed vibration signal to an amplifier (not shown), which then creates a feedback signal that is generally proportional to the intensity of the physical contact of the dispenser 3700 with the substrate 3710.” EX1004, [0302]. Because the vibrating dispenser

3700 of Warren experiences mechanical distortion, a POSITA would also have found it obvious to configure, e.g., vibration sensor 3730 of Warren, to sense mechanical properties, such as strain, of the vibrating dispenser 3700. For example, Matsumiya (EX1012) at [0034] describes force detection based on a vibrating stylus by using “a strain gauge for detecting distortion of the stylus.” *See also* EX1006, [0044-45], FIG. 7.

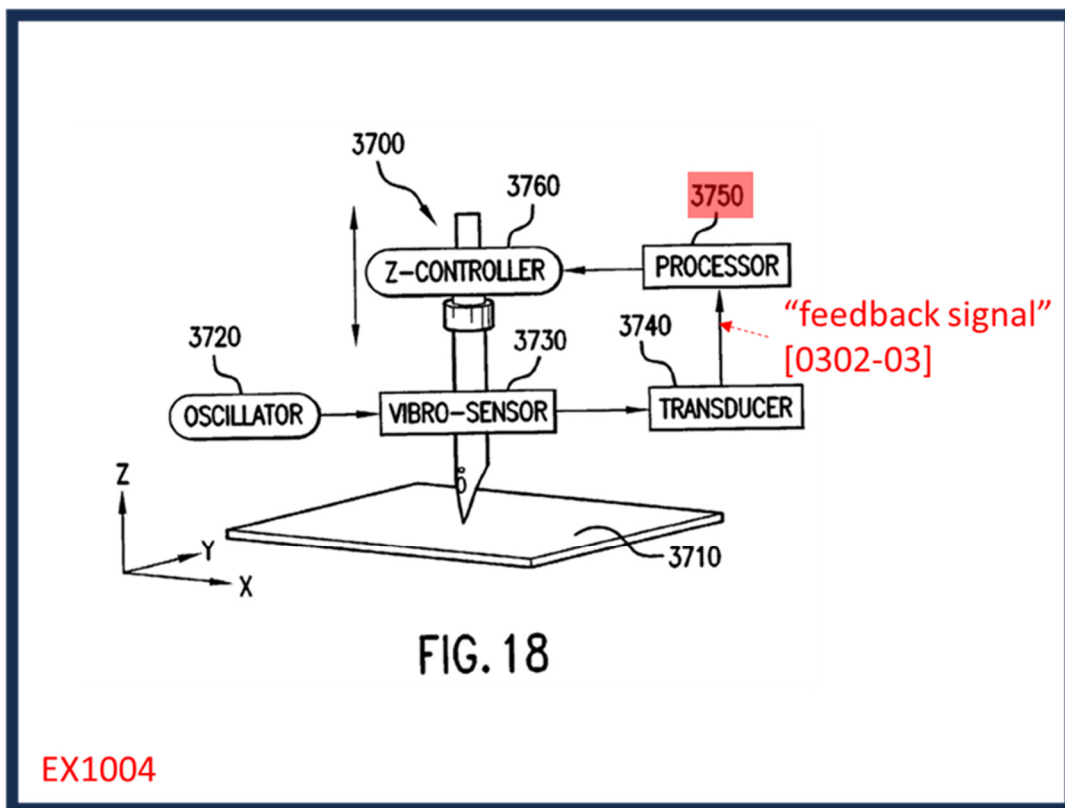
121. Accordingly, Warren’s combined teachings render obvious claim 10.

J. Claim 11

122. Claim 11 of the ’381 Patent recites:

11. The three-dimensional printer of claim 1, further comprising:
one or more actuators mechanically coupled to the fabrication tool, and a control circuit in data communication with the one or more actuators and the one or more sensors, the control circuit configured to control the one or more actuators to achieve a specified contact force between the one or more sensors and the separate structure.

123. Each and every element of claim 1 is obvious as explained above. In the context of claim 1, Warren’s combined teachings provide *one or more actuators* (e.g., z-controller step motor 3760) *mechanically coupled to the fabrication tool* (e.g., dispensing system 3700).



124. As annotated in FIG. 18 (above), Warren teaches using “a z-controller processor 3750 to control the z positioning of the dispenser 3700 via a z-controller step motor 3760,” EX1004, [0302], which a POSITA would have recognized as *mechanically coupled to* apparatus of FIG. 23A supporting the dispensing system 3700.

125. Moreover, Warren describes that “the z-controller processor 3750 may be implemented with, e.g., a microprocessor,” which a POSITA would have known to include a constituent circuit (i.e., *a control circuit*) *in data communication with* z-controller step motor 3760 (i.e., *the one or more actuators*) *and* vibration sensor 3730 and transducer 3740 (i.e., *the one or more sensors*) so that z-controller

processor 3750 can receive signals and assert control over, e.g., z-controller step motor 3760. EX1004, [0302].

126. Warren makes clear that its feedback signal is used by “a z-controller processor 3750 to **control** the z positioning of the dispenser 3700 via a z-controller step motor 3760” (i.e., **the one or more actuators**) so as “to maintain a desire force contact [i.e., **a specified contact force**] between the dispenser 3700 [where **the one or more sensors** are located] and the substrate 3710 [included by **the separate structure**]”). *Id.*, [0302].

127. The language of the claim 11 “**to achieve a specified contact force between the one or more sensors and the separate structure**” literally requires the specified contact force be between the sensor and the separate structure. A POSITA would have understood Warren’s dispenser 3700 could also be considered part of the claimed **sensor** and the contact force to be “**between the [/sensors and the separate structure,**” because the dispenser 3700, due to its vibration, is an active component in Warren’s the vibrating force sensor. If it is argued that claim 11 does not require a specified contact force between the sensors and the separate structure, Warren also discloses achieving a specified contact force in a manner that parallels the ’381 patent specification by sensing contact force with the vibration sensor 3730 and transducer 3740 (the **one or more sensors**) attached to the dispenser 3700 and the substrate 3710 (included by **the separate structure**). EX1004, [0302]. Indeed,

Warren’s disclosure parallels the ’381 patent at 9:25-40 (“the contact force(s) between the fabrication tool and the separate structure may be calculated from the collection of sensor signals 302”).

128. Accordingly, Warren’s combined teachings render obvious claim 11.

K. Claim 12

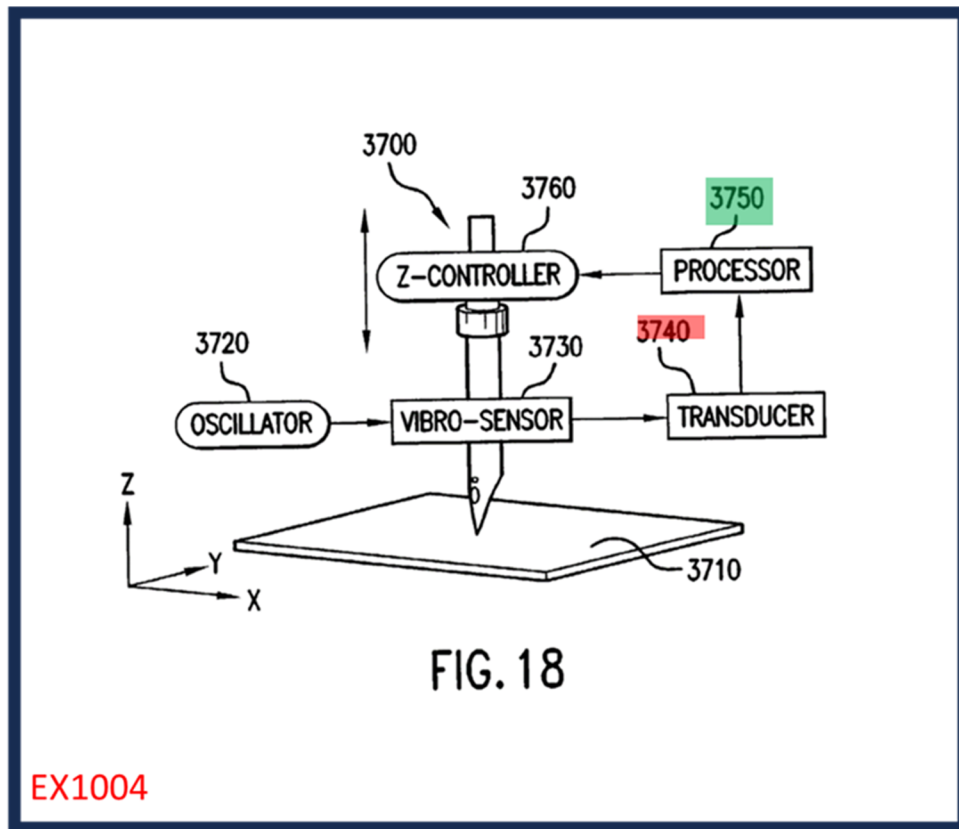
129. Claim 12 of the ’381 Patent recites:

12. The three-dimensional printer of claim 1, wherein the controller is further configured to adjust operation of the three-dimensional printer according to one or more of the signal from the one or more sensors and the calculated contact force.

130. Each and every element of claim 1 is obvious as explained above. As explained above in Sections VII.A & VIII.A as well as Elements [1.b]-[1.c], the *controller* (e.g., a “microprocessor” or “a personal computer (PC)”) operates responsive to *one or more of the signal from the one or more sensors* (e.g., “changed vibration signal” as detected by transducer 3740) *and the calculated contact force* (e.g., “the force of contact” calculated per Element [1.c]).

131. As annotated in FIG. 18 (below), Warren explains: “The vibration imposed on the dispenser 3700 is changed, e.g., modulated, by the contact of the 3700 [sic] dispenser with the substrate 3710” such that “[t]he transducer 3740 senses and transfers the changed vibration signal to an amplifier ... which then creates a

feedback signal” to drive a controller “to maintain a desired force of contact.” EX1004, [0302], [0309], [0313], [0316], FIG. 22A. A POSITA would have understood that processor 3750 is an example of the controller, which also controls other operations of the dispensing system. To the extent it is argued that the controller does not use the calculated contact force, a POSITA would have found it obvious to use the calculated contact force, for example, to facilitate comparison of the detected contact force to the “desired force of contact,” as well as for other advantages of the controller operating in a force, rather than sensor signal, domain.



132. In the above context, Warren’s combined teachings provide a *controller* (e.g., a “microprocessor” or “a personal computer (PC)”) that asserts

control *to adjust operation of operation of the three-dimensional printer* including, e.g., a z-axis position, a feed rate, a movement speed, and a temperature, as I explain in more detail below.

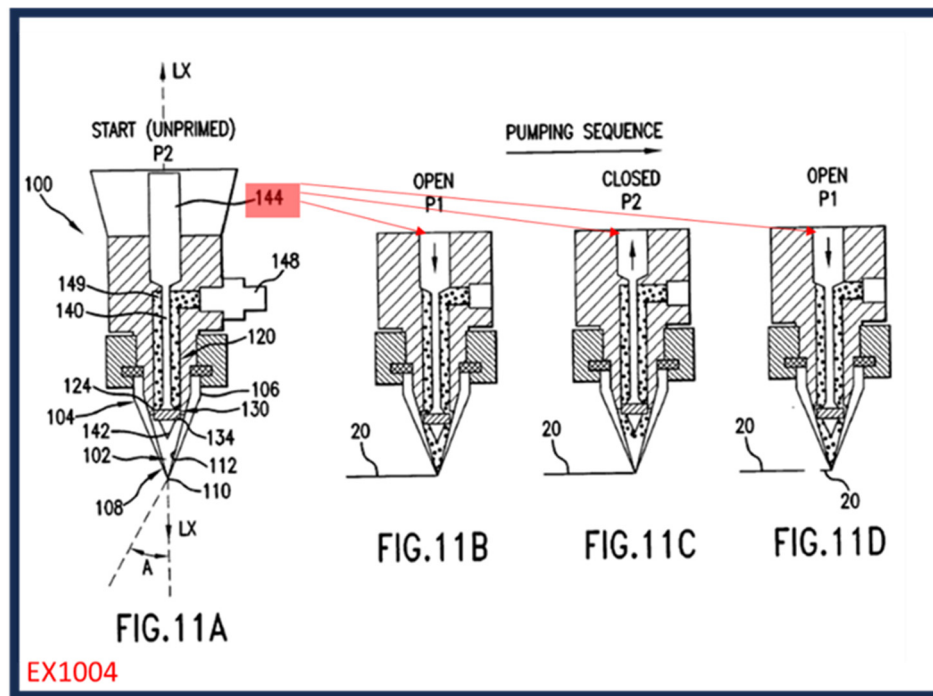
Z-axis Position

133. In the context of FIG. 18 (annotated above), Warren discloses: “The feedback signal [created by the amplifier] is used to control the position of the dispenser 3700 to maintain a desired force of contact between the dispenser 3700 and the substrate 3710.” *Id.* In one example, “the feedback signal may be used by a z-controller processor 3750 to control the z positioning of the dispenser 3700 via a z-controller step motor 3760.” *Id.*; *see also id.*, [0313] (varying “the position(s) of the dispenser and/or the substrate” depending on “whether the contact force is that which is desired” at steps 4106 and 4108 of FIG. 22A). “The z-controller [processor] 3750 may be implemented with, e.g., a microprocessor,” and, optionally, “[a] personal computer (PC) may be used in conjunction with z-controller [processor] 3750.” *Id.*, [0302-0303].

Feed Rate

134. In the through-nozzle dispenser design, “the flow of material is controlled by adjusting the open position P1 and closed position P2 of the valve 130.” EX1004, [0232]; *see also generally* [0230-0252], FIGS. 11A-11D (annotated below), 12A-12B. The “valve 130 includes a linear-actuated piston 140..., the piston being

operatively coupled to [the] miniature displacement pump 148.” *Id.*, [0242]. “[T]he linear actuator 144 [operating the valve piston 140] controls the material dispensing rate” through the nozzle tip orifice 110. *Id.*, [0243-0244], [0239] (“control the amount of material dispensed per second”).



Speed of Movement

135. In Warren’s through-nozzle design, Warren further teaches that the actuator-controlled “valving mechanism may be synchronized with the xyz motion of the dispenser.” EX1004, [0234]. Warren describes “choices available when synchronizing the valve with the substrate motion in xyz” to achieve desired material dispensing characteristics. *Id.*, [0234-0252]. In a “distance invariant” mode, Warrant teaches “open the valve independently before any xyz motion begins, then

finish opening the valve over a set xyz distance” so that “if xyz motion speed was increased the valve still opens completely at the same xyz location, albeit faster due to the faster xyz speed.” *Id.*, [0235]. A POSITA would, of course, understand that initially opening and finishing opening the valves affect the material feed rate through the dispenser. Warren also presents “[a] combination approach...to define the speed at which the dispenser should move, and then adjust with [valve positioning] techniques” in tandem. *Id.*, [0240].

136. Accordingly, it would have been apparent or obvious to a POSITA that Warren’s force feedback control scheme allows the controller to control (i) z-controller step motor for adjusting the z-position of the dispenser, (ii) the linear actuator to provide synchronous adjustments to the flow of material from the dispenser, and (iii) the xyz speed of the dispenser in tandem with valve position on the dispenser using the through-nozzle design.

Temperature

137. Warren’s combined teachings also provide “temperature control ... to enable the user to adjust viscosity of the constituent materials, to accelerate or decelerate setting of a scaffold material, or otherwise to provide a suitable environment for delicate or temperature-sensitive constituent materials.” EX1004, [0212]. While discussing its through-nozzle design, Warren teaches that the viscosity of its constituent material impacts the flow characteristics inside the nozzle.

Id., [0247-248] (citing Equation (1) where fluid dynamic viscosity impacts the shear force of the flowing constituent material). A POSITA, when reading Warren's through-nozzle design to accommodate a desired dispensing characteristic of the flowing constituent material, would have been alerted of this viscosity factor that is temperature-dependent. To wit, a POSITA would have recognized that providing temperature control abilities would have been advantageous for a combined dispenser system. *Id.* Indeed, a POSITA would have a reasonable expectation of success in the combination given that Warren's temperature control techniques were all known techniques, and the predictable use of such known techniques in Warren's dispenser system to obtain a conducive environment for "biological, tissue-engineering, and medical-process applications" would have been straightforward. EX1004, [0093].

138. Accordingly, it would have been obvious to a POSITA that, in the context of constructing a modeled structure for biological applications, Warren's force feedback control scheme also allows the controller to control a temperature on the dispenser.

L. Claim 13

139. Claim 13 of the '381 Patent recites:

13. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a feed rate of build material from the extruder in response to the calculated contact force.

140. Each and every element of claim 12 is obvious as explained above.

As I have explained with respect to claim 12, *supra*, Warren's combined teachings provide *the controller...configured to adjust a feed rate of build material from the extruder in response to the calculated contact force.*

M. Claim 14

141. Claim 14 of the '381 Patent recites:

14. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a z-axis position of the extruder in response to the calculated contact force.

142. Each and every element of claim 12 is obvious as explained above. As

I have explained with respect to claim 12, *supra*, Warren's combined teachings provide *the controller...configured to adjust a z-axis position of the extruder in response to the calculated contact force.*

N. Claim 15

143. Claim 15 of the '381 Patent recites:

15. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a speed of movement of the extruder in response to the calculated contact force.

144. Each and every element of claim 12 is obvious as explained above. As I have explained with respect to claim 12, *supra*, Warren's combined teachings provide *the controller...configured to adjust a speed of movement of the extruder in response to the calculated contact force*.

O. Claim 16

145. Claim 16 of the '381 Patent recites:

16. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a temperature of the extruder in response to the calculated contact force.

146. Each and every element of claim 12 is obvious as explained above. As I have explained with respect to claim 12, *supra*, Warren's combined teachings provide *the controller...configured to adjust a temperature of the extruder in response to the calculated contact force*.

IX. GROUND 1B: WARREN IN COMBINATION WITH DUNN WOULD HAVE RENDERED CLAIMS 3, 7 AND 8 OBVIOUS

A. Overview of the Combination and Reasons to Combine

147. As I have explained in Section VII.A, Warren discloses a 3D printing system incorporating force feedback control to maintain consistent contact force for successive layer-by-layer fabrication. While Warren shows a single-axis sensor configuration in its FIG. 18, Warren also states that “the invention is not limited to the specific embodiments, and that many modifications and other embodiments are intended to be included within the scope of the invention.” EX1004, [0572]. Here, Warren specifically discloses “xyz motion of the dispenser.” *Id.*, [0234].

148. In my opinion, a POSITA would have recognized the relevant portions of Warren suggested the desire for a multi-axis sensing capability to accommodate the xyz motion of its dispenser. In view of Dunn’s express example of a multi-axis sensor design, which I have explained in Section VII.B, a POSITA would have found it obvious to expand Warren’s single-axis example into a multi-axis configuration for contact force sensing along two or more non-parallel axes (e.g., the X and Y axes in addition to the Z axes) to improve the situational awareness of the resulting dispensing system during the xyz motion. A POSITA would have a reasonable expectation of success because doing so merely involves adding multi-axis sensing, as taught in Dunn, to Warren’s material dispensing system, which already has a single-axis example, to achieve predictable improvements (i.e., multi-dimensional) without impacting the operating principle of Warren’s dispenser system.

B. Claim 3

149. Claim 3 of the '381 Patent recites:

3. The three-dimensional printer of claim 1, wherein the contact force includes a deflection force exerted by the separate structure on a tip of the extruder.

150. Each and every element of claim 1 is obvious as explained above. I have additionally explained under Section VII.D (claim 3) that Warren experiences a deflection force due to friction from contact with the dispenser against the surface the material is being deposited on. The sensors of the Warren-Dunn combination are collectively operable to sense force in the x, y and z axis, and thus sense a deflection due to this friction.

151. Accordingly, the Warren-Dunn combination also renders obvious claim 3.

C. Claim 7

152. Claim 7 of the '381 Patent recites:

7. The three-dimensional printer of claim 1, wherein the one or more sensors are collectively operable to sense a force between the fabrication tool and the separate structure along two or more non-parallel axes.

153. Each and every element of claim 1 is obvious as explained above. As I have explained in Section IX.A, the Warren-Dunn combination provides *the one*

or more sensors collectively operable to sense a force between the fabrication tool and the separate structure along two or more non-parallel axes (e.g., the X or Y axes in addition to the Z-axis, as suggested by Dunn).

D. Claim 8

154. Claim 8 of the '381 Patent recites:

8. The three-dimensional printer of claim 7, wherein the one or more sensors are collectively operable to sense a force between the fabrication tool and the separate structure along three or more non-parallel axes.

155. Each and every element of claim 7 is obvious as explained above. In the context of claim 7, the Warren-Dunn combination provides *the one or more sensors collectively operable to sense a force between the fabrication tool and the separate structure along three or more non-parallel axes* (e.g., the X and Y axes in addition to the Z-axis, as suggested by Dunn).

X. GROUND 2A: CALDERON IN COMBINATION WITH REPRAP20208 WOULD HAVE RENDERED CLAIMS 1-6, AND 9-16 OBVIOUS

A. Overview of the Combination and Reasons to Combine

156. As I have explained in Section VII.C, Calderon describes auto-initialization of the z-axis of a three-dimensional printer where “the tip of nozzle 132 ... can be used as a plunging means to find z-axis positions of the platform,” where “[c]ontact between the tip of nozzle 132 and the substrate 128 is monitored by a

sensing means and the controller 116 electrically records the z-axis position of platform 134 at the time contact is detected.” EX1009, 9:63-10:23.

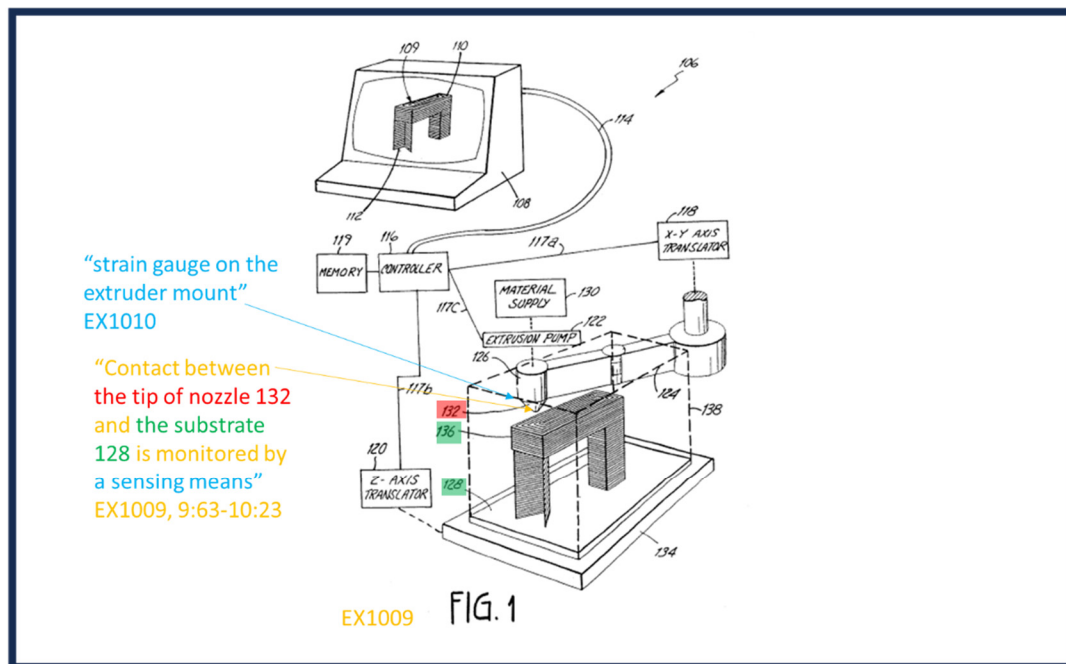
157. RepRap20208 complements Calderon’s disclosure with developers’ perspective of incorporating a force sensor, e.g., “[a] strain gauge on the extrusion mount,” which can be used “to calibrate the Z-axis.” EX1010, 13-14.

158. Based on my review, a POSITA would have found it obvious to use a “strain gauge on the extruder mount,” as suggested by RepRap20208, to provide “a sensing means,” as called for by Calderon to monitor “contact between the tip of the nozzle 132 and the substrate 128.” EX1010, 13-14; EX1009, 9:63-10:23. In view of the synergistic and complementary disclosures, a POSITA would have been motivated to (i) apply the force sensor example of RepRap20208, rather than relying on Calderon’s suggestion of “monitoring a change in the servo drive current,” and (ii) calculate the contact force based on measurements from the force sensor of RepRap20208.

159. Indeed, combining the strain gauge example of RepRap20208 with Calderon’s three-dimensional printer would have been nothing more than applying proven elements to a system ready for improvement. The fundamental operations of Calderon’s three-dimensional printer would remain intact, bolstered by the known advantages of RepRap’s strain gauge to arrive at the ’381 patent’s claimed invention with a reasonable expectation of success.

1. Apply the strain gauge example from RepRap20208

160. In my opinion, a POSITA would have been motivated to apply the strain gauge example from RepRap20208 to Calderon's three-dimensional printer so that the printer of the Calderon-RepRap20208 Combination is equipped with a strain gauge located on the extruder mount, where Calderon's extrusion head 126 mounts to the arm 124, to sense a contact force between nozzle 132, and substrate 128. The visual aid below demonstrates an exemplary three-dimensional printer embraced by the Calderon-RepRap20208 Combination where the strain gauge example of RepRap20208 is applied to Calderon's "sensing means." EX1009, 9:63-10:23. Multiple independent reasons would have prompted this combination.



161. As a *first* reason, the support frame of the extrusion head and the motors and associated drive, including those of Calderon (e.g., arm 124, x-y axis translator 118, z-axis translator 120 and servo drive motors), were known to have “slop/backlash” that would make it difficult to accurately and precisely identify when the nozzle contacted the substrate as is needed for Calderon’s Find-Z program. EX1010, 20. As Wade described, if “you’ve got a certain amount of backlash to take up before the sensor registers, [it] would prevent [one] from knowing exactly when the head touches.” *Id.* In other words, using the servo drive as a sensing means would give rise to a dampening effect on any force signal due to this “slop/backlash.” *Id.*

162. In contrast, the RepRap’s approach of using strain gauge on the extruder mount would not suffer the same degree of “slop/backlash,” in part because the strain gauge would measure force from a location closer to the nozzle – at the extrusion head mounting – which would alleviate the issue of “slop/backlash” in Calderon’s arm, x-y axis translator or its servo drive. In particular, it would provide an improved transient response avoiding delays or damping effects from the structures between the nozzle and the sensor.

163. Furthermore, Wade explains “There’s fair amount of give in the entire system when you’re looking at scales of less than a mm, so I was thinking a constant measurement of the force on the head (including it’s (sic) weight) would be useful.”

EX1010, 20. A POSITA would understand Wade's suggestion of constantly measuring the force acting on the extrusion head, including its weight, to be teaching detecting contact by sensing when the weight of the extrusion head carried by the extrusion head mounting is reduced by contact of the nozzle to the substrate. A POSITA would appreciate that this manner of identifying contact would not be influenced by slop/backlash, because it is not measuring in force relative to a reaction force affected by slop/backlash. A POSITA would appreciate that this manner of identifying contact would not be influenced by slop/backlash, because it is not measuring in force relative to a reaction force affected by slop/backlash. By comparison, if contact were recognized when a force measured at the extrusion head mount exceeded a certain reaction force, the slop/backlash in the system must be consumed before the reaction force at the extrusion head mount was experienced. Further, a strain gauge on the extrusion mount would allow the weight of the extrusion head to be constantly monitored during initialization. Thus, a POSITA would seek to use a strain gauge on the extrusion head mounting as a "sensing means" in Calderon to more precisely identify when the nozzle 132 has contacted the substrate 128 without the imprecision caused by slop/backlash.

164. As a *second* reason, a POSITA would have understood that the "monitoring a change in the servo drive current" measures the force of resistance to movement of the substrate 128 and platform 134 in the Z-axis, not just the contact

force between the substrate 128 and nozzle 132. The resistance to movement of the substrate 128 and platform 134 can be influenced by other factors like damage, wear or friction (e.g., due to dirt or need of maintenance) in the servo drive motors and drive system, as well as other factors. This resistance to movement can change over time, and so measurements made by “monitoring a change in the servo drive current” are both inaccurate and, over time, inconsistent. For example, a new, clean printer will require a certain amount of force to move the platform. As the drive mechanism wears, gets dirty, the lubrication dries up, etc., a higher force will be required to move the platform. The older or more used the printer, the more chance of wear, dirt, maintenance will increase the force needed to move the platform. Moreover, that force could change again, when the drive mechanism is cleaned and re-lubricated. This variation in the resistance to movement of the platform makes accurate force measurement difficult. A POSITA would have appreciated that the force measured by a strain gauge on the extrusion head mount would not be influenced by these other factors, because the extrusion head mount is not in a force chain of components that experience this type of damage, wear or friction. A strain gauge on the extrusion head mount measures the forces acting on the extrusion head, itself, which during Calderon’s initialization is largely the contact force between the nozzle 132 and substrate 128. Thus, a POSITA would seek to implement RepRap20208’s strain gauge on the extrusion head as a “sensing means” in

Calderon's system to produce more accurate and consistent force measurements by which to sense contact of the nozzle 132 to the substrate 128.

165. As a *third* reason, Calderon teaches that different substrates, including “rigid substrates” and “foam substrates,” can be used in its 3D modeling process and that those substrates can have greatly different compression strength. EX1009; 2:15-53 (e.g., a polystyrene foam with a very low “compression strength of 30 psi” versus a metal “magnetic material.” – e.g., compression strength of steel is 25,000 psi or more). A POSITA would understand that the contact force between the nozzle 132 and substrate 128 must be controlled to prevent damaging the substrate 128 during initialization, especially with low compression strength foam substrates, and that there is also a risk of damaging the nozzle 132 on rigid substrates. For example, if the nozzle were impacted into the substrate too hard on a low compression strength substrate, the substrate would crush, leaving a dent in the substrate that could subsequently affect the print. Similarly, if the nozzle were impacted into the substrate too hard on a rigid substrate, the nozzle could be crushed and prevent the nozzle from working properly (or at all). Strain gauges are very common, off-the-shelf devices and are commonly used for force sensing and have been used for force sensing long before the '381 patent. Thus, a POSITA would be motivated to use a strain gauge as a convenient, well understood manner of measuring force that would allow the contact force, and thus contact pressure of the nozzle 132 on the substrate

128 to be sensed with sufficient precision to control the contact force or contact pressure to an amount that would not damage the nozzle on the “rigid substrates” and not to damage “foam substrates.” EX1009, 2:36-53.

166. As a *fourth* reason, strain gauges were commonly used for force measurement of the type described in Calderon long before the '381 patent. It is rudimentary engineering to convert the signal from a strain gauge to a force measurement. In fact, the '381 patent admits that “[s]train gauges are one common sensor used for such [contact force] measurements.” EX1001, 9:16-24. The predictable inclusion of a strain gauge amounts to nothing more than supplementing Calderon with a strain gauge on the extrusion head mount, which would not have disturbed the other aspects of the system, and would have produced substantially similar functionality to what Calderon described.

167. A POSITA would have reasonably expected success in the above-discussed combination. Strain gauges and the use of strain gauges to sense force were commonplace at the time of the '381 patent in 2012, and had been successfully demonstrated in the real-world by then. For example, a well-known textbook explains that a strain gauge is commonly used in a Wheatstone configuration. EX1018, 302-304, 284-290. Thus, the result of the Combination would have been predictable to a POSITA, and the POSITA would have expected it to work.

168. Accordingly, my opinion is that a POSITA would have found it obvious to apply a “strain gauge on the extruder mount” from RepRap20208 as the “sensing means” of Calderon, rather than following Calderon’s suggestion of “monitoring a change in the servo drive current,” (EX1009, 10:1-8).

2. Calculate the contact force

169. In my opinion, a POSITA would have been further motivated to calculate the contact force from the strain gauge in the Calderon-RepRap20208 Combination using Calderon’s controller 116 or another controller associated with the system. The following independent reasons, taken separately or collectively, support the motivation.

170. A POSITA would have understood RepRap20208 to teach calculating contact force from the strain gauge signal when Wade explains “I was thinking a constant measurement of the force on the head (including it’s [sic] weight) would be useful,” because Wade is indicating he seeks a force “measurement” and a “weight,” not simply a sensor signal. EX1010, 17. This disclosure at least invites a POSITA to use the strain gauge to calculate contact force. As I have discussed above, a POSITA would have configured the 3D printer of the Calderon-RepRap20208 Combination to control the contact force between the nozzle 132 and substrate 128 during initialization to prevent damaging the substrate 128, especially with low compression strength foam substrates, and to prevent damaging the nozzle 132, for

example on rigid substrates. Thus, the controller of the Calderon-RepRap20208 Combination would be programmed with a maximum contact pressure, either coded into the software or input by a user, that that was related to the compression strengths of the substrate 128 and nozzle 132. Compression strength is expressed in units of force per unit area, e.g., pounds per square inch (psi) or newtons per square meter (pascals). Yet, the output of a strain gauge in the Calderon-RepRap20208 Combination would be a signal indicative of displacement or strain at the extruder mount, not directly the contact pressure (e.g., at the nozzle/substrate interface).

171. A POSITA would have been motivated to program the controller to calculate the contact force at the nozzle 132/substrate 128 interface from the signal output by the strain gauge so that the contact pressure, in turn, could be calculated and be directly comparable to the compression strength of the substrate. *Id.* For example, the strain gauge outputs a signal related to the geometric distortion of the gauge which is caused by forces acting on the gauge. In the most common configuration, these forces represent the deflection of the substrate or surface that the strain gauge is connected to. Knowing the geometry of the extruder mount at this location, one can measure and calculate the stress and force at this location. Thereafter, by knowing the material properties of the nozzle, one could calculate the force exerted on the nozzle through the contact with the substrate. And, knowing the geometry of the nozzle where it contacts the substrate, one could calculate the

contact pressure. In fact, RepRap 20208 taught to “measure upwards pressure from a calibration touch down.” EX1010, 19.

172. The controller calculating the contact force, and then the contact pressure, would facilitate programming the controller to a maximum contact pressure setpoint related to the compression strength of the substrate and nozzle because the setpoint and the compression strength would be in the same units (force per unit area). Or, if the controller were configured to allow a user to change the setpoint, such as to allow the printer to be adapted to different substrate materials, calculating contact force and contact pressure would facilitate a user’s interaction with the controller. The controller’s settings values could more readily be set, adjusted or displayed in meaningful (to a user) force-based units rather than in values of strain at the extrusion head mounting. Thus, for example, the Calderon-RepRap20208 Combination would accommodate a variety of substrate materials by enabling a user to input a contact strength limit based on a specification sheet for the substrate material. Moreover, as evidenced by RepRap20208, a POSITA would have perceived the contact sensing in terms of force. EX1010, 17 (“we’d *like* three forces”), 17 (“here’s a force sensor”), 20 (“a constant measurement of force”). As such, the strain/deflection measured by the strain gauge would have required a user to know the material properties and geometry of the strain gauge at the mounting in order to make sense of the measured strain.

173. In my opinion, a POSITA would have reasonably expected success in calculating, with a controller, the contact force from the strain gauge of the combination. Calculating contact force, and then contact pressure, with a controller from a sensor intended to produce a signal related to force, and particularly a strain gauge, was rudimentary engineering and commonplace long before the '381 patent and 2012. For example, a well-known textbook explains that a strain gauge is commonly used in a Wheatstone configuration. EX1018, 302-304, 284-290. Thus, these calculations would have been predictable to a POSITA, who would have expected it to work.

174. For the reasons above, my opinion is that a POSITA would have found it obvious to calculate the contact force at the nozzle/substrate interface with a controller using output from the strain gauge on the extrusion head mount in the Calderon-RepRap20208 Combination.

B. Independent Claim 1

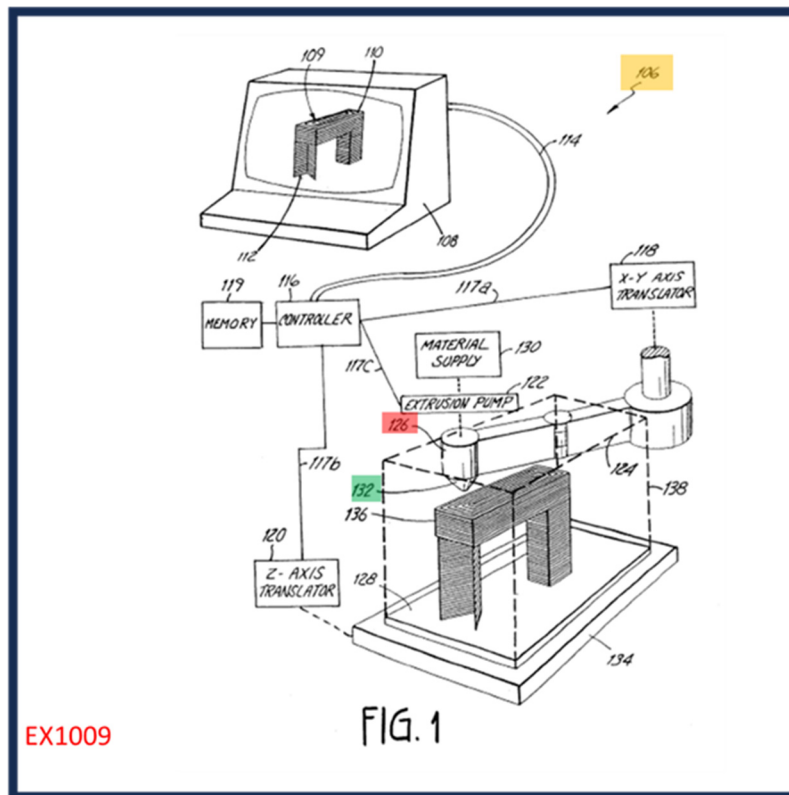
175. Independent claim 1 of the '381 Patent recites:

1. A three-dimensional printer comprising:
 - a fabrication tool including an extruder configured to extrude build material to fabricate an object during a build process;
 - one or more sensors mechanically coupled to the extruder, wherein the one or more sensors are collectively operable to sense a contact force between the extruder and a separate structure distinct from the fabrication tool; and
 - a controller configured to receive a signal from the one or more sensors on the extruder and to calculate the contact force between the extruder and the separate structure.

176. As I explain in more detail below through my element-by-element analysis, the combination of Calderon with RepRap20208 renders claim 1 obvious.

[1.pre]: A three-dimensional printer comprising:

177. To the extent that the preamble is treated as a limitation, the Calderon-RepRap20208 Combination renders obvious a three-dimensional printer. *See e.g.*, EX1009, 4:20-5:10 (discussing “extrusion-based layered modeling system 106” as depicted in FIG. 1 (below)).



[1.a]: a fabrication tool including an extruder configured to extrude build material to fabricate an object during a build process;

178. In the Calderon-RepRap20208 Combination, Calderon provides *a fabrication tool* including, e.g., “an xy axis translator 118, a z-axis translator 120 and an extrusion pump 122” as well as “an extrusion head 126.” EX1009, 4:34-65, FIG. 1 (above). Specifically, “extrusion head 126 terminates in a nozzle 132 through which the modeling material is extruded ... onto the substrate 128 ... to build up a model 136 layer-by-layer on the substrate 128.” *Id.* A POSITA would have understood that these features of Calderon provide *an extruder* similar to the one disclosed in the '381 patent. EX1001, 2:28-52 (“The extruder 106 may also or

instead include a motor 128 or the like to push the build material into the chamber 122 and/or through the extrusion tip 124”).

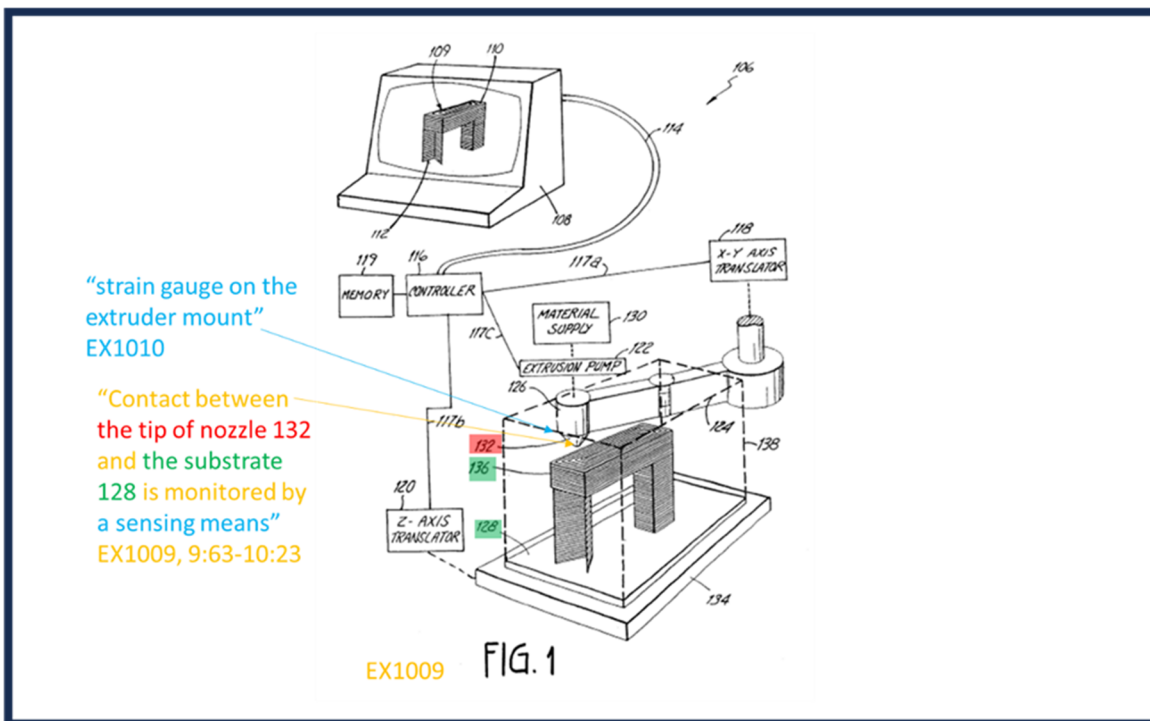
179. Therefore, the Calderon-RepRap20208 Combination provides Element [1a].

[1.b]: one or more sensors mechanically coupled to the extruder, wherein the one or more sensors are collectively operable to sense a contact force between the extruder and a separate structure distinct from the fabrication tool; and

180. The Calderon-RepRap20208 Combination renders obvious the ***claimed one or more sensors***. As I have explained above §VII.D, RepRap20208 provides “[a] strain gauge on the extruder mount,” which would be ***mechanically coupled to the extruder*** consistent with the ’381 specification. EX1010, 13; EX1001, 9:17-23 (“Strain gauges are one common sensor used for such [contact force] measurements, and may be suitably adapted ... by affixing one or more strain gauges to an extruder or other location along a mechanical chain that supports an extruder in an intended position during fabrication.”).

181. As I have explained above under Section X.A, a POSITA would have found it obvious to use the strain gauge example from RepRap20208 (e.g., “strain gauge on the extruder mount”) in the Calderon-RepRap20208 Combination to “measure upwards pressure from a calibration touch” and to provide a “measurement of the force on the head” during calibration. EX1010, 13, 19-20; EX1009, FIG. 1 (below). A POSITA would have understood that a strain gauge at the extrusion head

mount would sense *a contact force between the extruder and a separate structure* by sensing the displacement, or strain, at the extrusion head mount and that strain could be used to calculate the contact force.



182. According to RepRap20208, "[t]he extruder mount could use a pair of bolts with strain gauges, and you could watch the change in bolt tension when you run into something," (EX1010, 14), evidencing that the strain gauges are "affix[ed] to an extruder or other location along a mechanical chain that supports an extruder in an intended position during fabrication," as disclosed by the '381 patent. EX1001, 9:17-23. Thus, the one or more strain gauges of the Calderon-RepRap20208 Combination operate to *sense the contact force between the extruder and a separate*

structure, such as the modeling platform 134 where substrate 128 is mounted, or the model 136 being built in a layer-by-layer manner.

183. As I have explained above under Section X.A, a POSITA would have been motivated to use the strain gauge example from RepRap20208 on grounds of detection sensitivity while pursuing known improvements (e.g., no “slop/backlash in the support frame/stepper motors.”) and implementing proven elements (e.g., “conductive-plastic fiber ... well matched the plastic [used in the bolts]”), thereby arriving at the predictable result with reasonable expectation of success (e.g., strain gauge “has high intrinsic resistance (compared to foil gauges)” and “develops a larger signal, with minimal resistive heating”). EX1010, 16-17.

184. Accordingly, the Calderon-RepRap20208 Combination provides Element [1b].

[1.c]: a controller configured to receive a signal from the one or more sensors on the extruder and to calculate the contact force between the extruder and the separate structure.

185. In my opinion, the Calderon-RepRap20208 Combination renders obvious the claimed **controller**. In Calderon’s Example 3, Calderon describes: “Contact between the tip of nozzle 132 and the substrate 128 is monitored by a sensing means and the **controller** 116 electrically records the z-axis position of platform 134 at the time contact is detected.” EX1009, 9:63-10:8 (“the tip of nozzle 132 (shown in FIG. 1) can be used as a plunging means to find Z-axis positions of

the platform”). As I have explained under Section X.A and Element [1.b], it would have been obvious to use the strain gauge example of RepRap20208 as the “sensing means” of Calderon.

186. In the above context, a POSITA would have found it obvious for the controller 116 in the Calderon-RepRap20208 Combination to *receive a signal from the one or more sensors on the extruder* (e.g., one or more strain gauges on the extruder mount as detailed in RepRap20208) so that the controller 116 can continue to “electrically record[] the z-axis position of platform 134,” as intended by Calderon’s initialization routine to determine the correct z-start positions. EX1009, 9:63-10:8, 2:54-3:3 (“incorrect z-start position can result in failure in forming a model” such as “‘modeling in air’ or ... too much ‘plowing’ by the tip”), FIG. 1 (below), EX1010, 13.

187. As I have further explained under Section X.A, a POSITA would have found it obvious for the controller 116 in the Calderon-RepRap20208 Combination to *calculate the contact force between the extruder and the separate structure* (e.g., based on the signal received from the one or more strain gauges on the extruder mount, as suggested by RepRap20208) so that a “measurement of the force on the head” can be provided. EX1010, 20. As discussed above, a POSITA would have been prompted to have the controller of the Calderon-RepRap20208 Combination *calculate the contact force* (e.g., based on the signal received from the “strain gauge

on the extruder mount,” as suggested by RepRap20208) and monitor the “[c]ontact between tip of nozzle 132 and the substrate 128” accordingly (e.g., so as not to damage a foam substrate or the nozzle), as provided by Calderon. EX1010, 13; EX1009, 10:1-8.

188. Accordingly, my opinion is that the Calderon-RepRap20208 Combination renders obvious all limitations of claim 1.

C. Claim 2

189. Claim 2 of the '381 Patent recites:

2. The three-dimensional printer of claim 1, wherein the contact force is a force along an extrusion axis of the extruder.

190. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. Additionally, in the Calderon-RepRap20208 Combination, ***the contact force is a force*** that acts on the tip of nozzle 132 of extruder 126. EX1009, 10:1-5 (“Contact between the tip of nozzle 132 and the substrate 128 is monitored by a sensing means”). When the top surface of substrate is generally orthogonal to the tip (the desired orientation), the contact force is ***along*** the vertical axis (i.e., ***the extrusion axis of the extruder 126***). *Id.*, FIG. 1. Moreover, even if the substrate 128 were not precisely orthogonal to the tip of nozzle 132, a POSITA would have understood that there to be a force component from the

contact directed along the extrusion axis and that this force component is a contact force.

D. Claim 5

191. Claim 5 of the '381 Patent recites:

5. The three-dimensional printer of claim 1, wherein the separate structure includes a build platform of the three-dimensional printer.

192. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. In the context of claim 1, the “strain gauge on the extruder mount” would sense a contact force between the tip of nozzle 132 and “the substrate 128 ... mounted onto a modeling platform 134.” EX1009, 4:53-65, 10:1-5, FIG. 1; EX1010, 13. A POSITA would have recognized that this scenario is similar to the '381 specification where, as illustrated in FIG. 3, “sensor 302 may be operable to sense a contact force between the fabrication tool 300 and a separate structure, such as ... the build platform 306” EX1001, 8:55-64.

193. Accordingly, my opinion is that the Calderon-RepRap20208 combination renders obvious that *the separate structure includes* the modeling platform 134 (i.e., *a build platform of the three-dimensional printer*). EX1009, 4:62-63, FIG. 1.

E. Claim 6

194. Claim 6 of the '381 Patent recites:

6. The three-dimensional printer of claim 1, wherein the contact force is a force normal to a surface of the separate structure.

195. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. In the Calderon-RepRap20208 Combination, *the contact force is a force* that acts on the tip of nozzle 132 of extruder 126. EX1009, 10:1-5 (“Contact between the tip of nozzle 132 and the substrate 128 is monitored by a sensing means”). When the top surface of the substrate 128 is generally orthogonal to the tip of nozzle 132, the force is *normal to the surface of the separate structure*. *Id.*, FIG. 1. Moreover, even if the substrate 128 were not precisely orthogonal to the tip of nozzle 132, a POSITA would have understood that there would have been a force component from the contact directed normal to the substrate and that this force component would have been a contact force.

196. Accordingly, my opinion is that the Calderon-RepRap20208 Combination renders obvious claim 6.

F. Claim 9

197. Claim 9 of the '381 Patent recites:

9. The three-dimensional printer of claim 1, wherein each of the one or more sensors are selected from the group consisting of: capacitive sensors, electromagnetic sensors, optical sensors, potentiometric sensors, and piezoelectric sensors.

198. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. A POSITA would have understood the phrase “potentiometric sensor” as used in this claim to refer to a sensor that can make a measurement in terms of a voltage or a resistance ratio. Based on my experience, a strain gauge is a potentiometric sensor because it was general knowledge to use a strain gauge in a Wheatstone bridge configuration with a readout voltage (e.g., a differential voltage between two parallel voltage dividers), which renders the configuration a potentiometric sensor. *See e.g.*, EX1018, 302-304 (“... the output of a Wheatstone bridge is the difference between the midpoints of two parallel voltage dividers, so interpreting the output of the bridge involves amplifying small differential voltages with large common mode DC offsets”), 284-290 (details of the Wheatstone bridge configuration). Alternatively, a simpler, but less sensitive voltage measurement can be made by simply using the well-known Ohm’s law to measure a voltage from a strain gauge by sending a fixed current through the device.

199. Additionally, my opinion is that a POSITA would have found it obvious to use one or more piezoelectric, or capacitive strain sensors on the extruder mount

of the Calderon-RepRap20208 Combination to measure strain. In my experience, such types of strain sensors were commonly used to measure mechanical pressure/strain. *See e.g.*, EX1019, Abstract (“Strain measurements from piezoceramic (PZT) and piezofilm (PVDF) sensors are compared with strains from a conventional foil strain gage and the advantages of each type of sensor are discussed, along with their limitations.”), Conclusions (“It has been found that the performance of piezoelectric sensors surpasses that of conventional foil type strain gages, with much less signal conditioning required, especially in applications involving low strain levels, and high noise levels.”). Calderon, even, advocates a capacitive sensor for sensing displacement. EX1009. 6:38-47. A POSITA would have been motivated to employ a piezoelectric or capacitive strain sensor in the Calderon-RepRap20208 Combination because such sensors were readily available off-the shelf type devices, well understood, and a convenient sensor designed for the very purpose of measuring strain and force. *See e.g.*, EX1020. The predictable inclusion of a piezoelectric strain sensor follows the familiar pattern of merely substituting one element (a common piezoelectric or capacitive strain sensor) for another known in the field (RepRap20208’s broad teaching of a “strain gauge”) to obtain predictable results. Supplementing the Calderon-RepRap20208 Combination with a piezoelectric or capacitive strain sensor would not have disturbed the other

aspects of the system, and it would have produced substantially similar functionality to what RepRap20208 described.

200. Moreover, the claim's list of "capacitive sensors, electromagnetic sensors, optical sensors, potentiometric sensors, and piezoelectric sensors" encompasses nearly all common types of strain sensors. The specification of the '381 Patent reveals nothing more than what was already known about these sensors. A POSITA would have found it obvious to incorporate any common type of strain sensor based on RepRap20208's general teaching of a "strain gauge."

G. Claim 10

201. Claim 10 of the '381 Patent recites:

10. The three-dimensional printer of claim 1, wherein the one or more sensors include one or more strain gauges.

202. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As I have explained under Sections VII.D, X.A and claim 1, the one or more sensors on the three-dimensional printer of the Calderon-RepRap20208 Combination include *one or more strain gauges* (e.g., "strain gauge on extruder mount"). EX1010, 13.

203. Accordingly, the Calderon-RepRap20208 Combination renders obvious claim 10.

H. Claim 11

204. Claim 11 of the '381 Patent recites:

11. The three-dimensional printer of claim 1, further comprising:
one or more actuators mechanically coupled to the fabrication tool, and a control circuit in data communication with the one or more actuators and the one or more sensors, the control circuit configured to control the one or more actuators to achieve a specified contact force between the one or more sensors and the separate structure.

205. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. The Calderon-RepRap20208 Combination provides x-y axis translator 118 and z-axis translator 120 (i.e., *the one or more actuators*) *coupled to the fabrication tool* (including, e.g., extrusion head 126 carried by robotic arm 124). EX1009, 4:41-52, FIG. 1. The Calderon-RepRap20208 Combination also provides controller 116 and associated memory 119 (i.e., *a control circuit*) *in data communication with* x-y axis translator 118 and z-axis translator 120 and “strain gauge on extruder mount” (i.e., *the one or more sensors*). *Id.*, 4:41-52, FIG. 1 (below); EX1010, 13.

206. As I have explained under Sections VII.C&D, X.A and claim 1, controller 116 sends control signals to the z-axis translator (i.e., *controls the one or more actuators*) to achieve a contact force sufficient for measurement but does not exceed a force limit to be damaging (i.e., *a specified contact force*) *between* the

“strain gauge on extruder mount” (i.e., *one or more sensors*) and the modeling platform 134 (i.e., *separate structure*).

207. Accordingly, my opinion is that The Calderon-RepRap20208 Combination renders obvious claim 11.

I. Claim 12

208. Claim 12 of the '381 Patent recites:

12. The three-dimensional printer of claim 1, wherein the controller is further configured to adjust operation of the three-dimensional printer according to one or more of the signal from the one or more sensors and the calculated contact force.

209. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. Calderon teaches “using the plurality of recorded z-axis positions to calculate a z-start position of the platform” and “then automatically position the platform at the calculated z-start position, without operator intervention.” EX1001, 3:27-30. Calderon further teaches “a ‘Find-Z’ software program loaded into controller 116,” which “uses the recorded z-axis positions to calculate a z-start position.” EX1009, 7:63-63, 8:11-37, 10:9-15. As I have explained under Section VII.C, Calderon teaches: “Contact between the tip of nozzle 132 and the substrate 128 is monitored by a sensing means and the

controller 116 electrically records the z-axis position of platform 134 at the time contact is detected.” *Id.*, 10:1-5.

210. A POSITA, when reading the above, would have readily recognized that the controller of the Calderon-RepRap20208 Combination would “automatically position the platform” (i.e., *adjust operation of the three-dimensional printer*) “at the calculated z-start position” calculated using the recorded z-axis position, which was recorded at the time instant of a sufficient contact (i.e., according to *one or more of the signal from the one or more sensors and the calculated contact force* that indicate the time of each recorded contact). EX1001, 3:27-30.

211. Accordingly, my opinion is that the Calderon-RepRap20208 Combination renders obvious claim 12.

J. Claim 14

212. Claim 14 of the '381 Patent recites:

14. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a z-axis position of the extruder in response to the calculated contact force.

213. Each and every element of claim 12 is obvious in light of the Calderon-RepRap20208 Combination as explained above. In the context of claim 12, a POSITA would have found it obvious that the controller of the Calderon-

RepRap20208 Combination *adjusts a z-axis position of the extruder* because Calderon make clear that “in a modeling system having a dispensing head movable along the z-axis,” the same relative distance between the dispensing head and the platform can be achieved “by lowering the dispensing head instead of raising the modeling platform.” EX1009, 11:6-11. Moreover, adjusting the z-axis position of the extruder is based on the calculated z-start position calculated using the recorded z-axis position, which was recorded at the time instant of a sufficient contact (i.e., in response to the calculated contact force that indicate the sufficient contact). EX1001, 3:27-30.

Implement collision detection after initialization

214. Further to my earlier explanations under Section X.A, my opinion is that a POSITA also would have found it obvious to implement collision detection in Calderon’s controller or another controller, as described by RepRap20208, using the “strain gauge on extruder mount” from RepRap20208 whenever the extrusion head or platform is moving. Upon detecting a collision, the controller in the Calderon-RepRap20208 Combination would shut the three-dimensional printer down. My opinion is supported by at least the following reasons.

215. First, a POSITA would have been prompted by the express indication that “[c]ollision detection is a nice side affect [sic]” for its force sensor configuration. EX1010, 19. As developer Wade explains: “The extruder mount could use a pair of

bolts with strain gauges, and you could watch the change in bolt tension when you run into something.” *Id.*, 14. A POSITA would have been inspired to use the suggested strain gauge on extruder mount for real-time collision detection after system initialization because the feature would have used the same sensor configuration without requiring more. There is no reason to stop the strain gauge after initialization.

216. Second, a POSITA would have been reminded of the benefits collision detection. As explained by developer Wade: “I’d have the machine shut down and flag me if it [i.e., collision] happens, as opposed to breaking something.” EX1010, 19. Developer Wade further explains “a tangled plastic filament feed, which has wrecked a few builds of mine, ... would probably just trigger the head collision detection.” *Id.*, 20. A POSITA would have been motivated to shut down the three-dimensional printer upon collision detection to conserve energy, minimize damage, and avoid material waste.

K. Claim 3

217. Claim 3 of the ’381 Patent recites:

3. The three-dimensional printer of claim 1, wherein the contact force includes a deflection force exerted by the separate structure on a tip of the extruder.

218. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As I have explained under Section X.A, in the Calderon-RepRap20208 Combination implementing collision detection, the collision detection operates whenever the extrusion head is moving. Here, Calderon's extrusion head 126 moves in the x-y plane. EX1009, 4:45-48. When a nozzle tip collides into a separate structure while the extrusion head is moving in the x-y plane, the resulting contact force includes a deflection force. The strain gauge on the extrusion head mount would measure that deflection force, because the force would cause a deflection to the strain gauge on the extrusion head mount.

219. Accordingly, the Calderon-RepRap20208 Combination renders obvious claim 3.

L. Claim 4

220. Claim 4 of the '381 Patent recites:

4. The three-dimensional printer of claim 1, wherein the separate structure includes an object being fabricated by the three-dimensional printer.

221. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. In the above context, when the three-dimensional printer is depositing modeling material "to build up a model 136 layer-by-layer on the substrate 128," the "strain gauge on the extruder mount" would

sense a contact force between the tip of nozzle 132 and the top surface of model 136. EX1009, 4:62-63, FIG. 1; EX1010, 13. A POSITA would understand this scenario is aligned with the '381 specification. EX1001, 8:55-64 (“Each sensor 302 ... to sense a contact force between the fabrication tool 300 and a separate structure, such as the object 304”), FIG. 3.

222. Accordingly, my opinion is that the Calderon-RepRap20208 combination renders obvious that *the separate structure includes* the model 136 (i.e., *an object being fabricated by the three-dimensional printer*). EX1009, 4:62-63, FIG. 1.

M. Claim 13

223. Claim 13 of the '381 Patent recites:

13. The three-dimensional printer of claim 12, wherein the controller is configured to adjust a feed rate of build material from the extruder in response to the calculated contact force.

224. Each and every element of claim 12 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As I have explained above and earlier under Section X.A, it would have been obvious to apply the strain gauge example of RepRap20208 to “provide a constant measurement of the force on the head” and implement collision detection on the three-dimensional printer of the Calderon-RepRap20208 Combination. EX1010, 13. According to Wade: “I'd have

the machine shut down and flag me if it [i.e., a collision] happens, as opposed to breaking something.” *Id.*, 19. “That saved my machine once already.” *Id.* Wade further observed: “It could also pick up on a tangled plastic filament feed, which has wrecked a few builds of mine in the past as well. That would probably just trigger the head collision detection, due to the upward force on the extruder.” *Id.*, 20.

225. A POSITA would have recognized that RepRap20208 suggests stopping the feed of additional build material (i.e., ***adjusting a feed rate of build material from the extruder***) ***in response to the calculated contact force*** (e.g., when “the upward force on the extruder” indicates a collision has occurred). At a minimum, a POSITA would have found it obvious to stop the feed of additional build material (i.e., ***adjust a feed rate of build material from the extruder***) ***in response to the calculated contact force*** indicating that a collision has just occurred. In fact, it was general knowledge in the field of 3D printing to “stop[] production of an object” when “a collision has occurred.” *See e.g.*, US20070179656A1 (“Eshed”) at [0180]. To save the machine and avoid material waste, a POSITA would have known to stop feeding of additional build material, and hence ***adjust a feed rate of build material from the extruder***.

226. Accordingly, my opinion is that the Calderon-RepRap20208 combination renders obvious claim 13.

N. Claim 15

227. Claim 15 of the '381 Patent recites:

15. The three-dimensional printer of claim 12, wherein the controller is configured to adjust a speed of movement of the extruder in response to the calculated contact force.

228. Each and every element of claim 12 is obvious in light of the Calderon-RepRap20208 Combination as explained above. Like the feed rate of claim 13, a POSITA would have recognized that RepRap20208's statement on shutting down the machine suggested stopping the movement of the extruder (i.e., *adjusting a speed of movement of the extruder*) *in response to the calculated contact force* (e.g., when "the upward force on the extruder" indicates a collision has occurred). EX1010, 20; *supra* §X.A.

229. At a minimum, a POSITA would have found it obvious to stop the movement of the extruder (i.e., *adjust a speed of movement of the extruder*) *in response to the calculated contact force* indicating that a collision has just occurred. Because it was general knowledge in the field of 3D printing to "stop[] production of an object" when "a collision has occurred," a POSITA would have known to stop the movement of the extruder, and hence *adjust a speed of movement of the extruder* to save the machine and conserve energy. *See e.g.*, US20070179656A1 ("Eshed") at [0180].

O. Claim 16

230. Claim 16 of the '381 Patent recites:

16. The three-dimensional printer of claim **12**, wherein the controller is configured to adjust a temperature of the extruder in response to the calculated contact force.

231. Each and every element of claim 12 is obvious in light of the Calderon-RepRap20208 Combination as explained above. Like the feed rate of claim 13 and extruder movement of claim 15, a POSITA would have recognized that RepRap20208's statement on shutting down the machine suggested shutting down the heater on the extruder (i.e., *adjusting a temperature of the extruder*) *in response to the calculated force contact force* (e.g., when "the upward force on the extruder" indicates a collision has occurred). EX1010, 20; *supra* §X.A.

232. At a minimum, a POSITA would have found it obvious to turn off the heater of the extruder (i.e., *adjust a temperature of the extruder*) *in response to the calculated contact force* indicating that a collision has just occurred. Because it was general knowledge in the field of 3D printing to "stop[] production of an object" when "a collision has occurred," a POSITA would have known to turn off the heater of the extruder, and hence *adjust a temperature of the extruder* to save the machine and conserve energy. *See e.g.*, US20070179656A1 ("Eshed") at [0180]. Indeed,

there would be no reason to keep the heaters going if the print has stopped due to a collision.

XI. GROUND 2B: CALDERON AND REPRAP20208 FURTHER IN VIEW OF DUNN WOULD HAVE RENDERED CLAIMS 3, 7-8 OBVIOUS

A. Overview of the Combination and Reasons to Combine

233. As I have explained earlier under Section VII.B, Dunn discloses “multi-axis sensor assembly” with “the capability of sensing surfaces in the X and Y directions” in addition to “sensing surfaces in the Z-direction.” EX1007, [0069-70], FIG. 9.

234. Calderon already describes defining a lateral range for its z-axis initialization routine by, e.g., “moving extrusion head 142 in the x-direction so as to drive actuator 154 against a first stationary block 190 located outside of the modeling envelope 138 to the right of extrusion head 142,” as depicted in FIGS. 7A-7B, and later “moving the extrusion head 142 in the x-direction towards a second stationary block 192 located outside of the modeling envelope 138, to the left of extrusion head 147,” as depicted in FIGS 8A-8B. EX1009, 7:16-23, 53-61.

235. A POSITA would have found it obvious to provide multiple strain gauges in the extrusion head mount of the Calderon-RepRap20208 Combination oriented to measure in multiple axis, in accordance with the “multi-axis sensor assembly” of Dunn, so that the three-dimensional printer of the Calderon-RepRap20208-Dunn Combination has “the capability of sensing surfaces in the X

and Y directions” in addition to “sensing surfaces in the Z-direction.” EX1007, [0069-70].

236. Here, measuring force in multiple axis, like Dunn’s multi-axis sensor assembly, would have allowed the three-dimensional printer to efficiently identify the surfaces of first and second stationary blocks in the x-direction, thereby improving the efficiency of Calderon’s z-axis initialization routine. *Id.* EX1009, 7:16-23, 53-61. Moreover, a POSITA would have recognized the predictable improvement of the Calderon-RepRap20208-Dunn Combination is not limited to the x-direction, but rather includes the y-direction. *Id.* Indeed, a POSITA would have enjoyed a reasonable expectation of success by combining known elements to arrive at the predicable improvement.

B. Claim 3

237. Claim 3 of the ’381 Patent recites:

3. The three-dimensional printer of claim 1, wherein the contact force includes a deflection force exerted by the separate structure on a tip of the extruder.

238. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As discussed under Section X.D (claim 3), Calderon’s extrusion head would experience a deflection force due to collision while moving in the x-y plane. The sensors of the Calderon-RepRap20208-

Dunn combination are collectively operable to sense a deflection force acting in the x-y axes.

C. Claim 7

239. Claim 7 of the '381 Patent recites:

7. The three-dimensional printer of claim 1, wherein the one or more sensors are collectively operable to sense a force between the fabrication tool and the separate structure along two or more non-parallel axes.

240. Each and every element of claim 1 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As I have explained earlier under Section XI.A, *the one or more sensors* of the Calderon-RepRap20208-Dunn combination (adapting the strain gauge example of RepRap20208 to be multi-axis like the multi-axis sensor assembly of Dunn to improve Calderon's routine) are collectively operable to sense a force between the fabrication tool and the separate structure *along two or more non-parallel axes* (e.g., the x or y axes in addition to the z-axis, as suggested by Dunn).

D. Claim 8

241. Claim 8 of the '381 Patent recites:

8. The three-dimensional printer of claim 7, wherein the one or more sensors are collectively operable to sense a force between the fabrication tool and the separate structure along three or more non-parallel axes.

242. Each and every element of claim 7 is obvious in light of the Calderon-RepRap20208 Combination as explained above. As I have explained earlier under Section XI.A, *the one or more sensors* of the Calderon-RepRap20208-Dunn combination (adapting the strain gauge example of RepRap20208 to be multi-axis like the multi-axis sensor assembly of Dunn to improve Calderon's routine) are collectively operable to sense a force between the fabrication tool and the separate structure *along three or more non-parallel axes* (e.g., the x and y axes in addition to the z-axis, as suggested by Dunn).

XII. SECONDARY CONSIDERATIONS OF NON-OBVIOUSNESS.

243. I have considered the impact of secondary considerations of non-obviousness. I am not aware of any evidence of the existence of any secondary considerations of non-obviousness regarding the Challenged Claims that would alter the opinions expressed above. In the event patent owner asserts any such evidence, I reserve the right to address it.

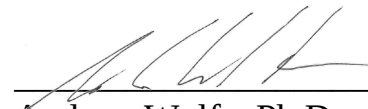
XIII. ADDITIONAL REMARKS

244. In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross examination in the case and that cross examination will take place within the United States. If cross examination is required of me, I will appear for cross examination within the United States during the time as mutually agreed between the parties.

245. I currently hold the opinions expressed in this declaration. But my analysis may continue, and I may acquire additional information and/or attain supplemental insights that may result in added observations. Therefore, I reserve the right to revise, supplement, and/or amend my opinions stated herein based on new information that becomes available to me and on my continuing analysis of the materials already provided.

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

2/3/2025
Date


Andrew Wolfe, Ph.D.

Appendix A

Andrew Wolfe Ph.D.

2005 De La Cruz Blvd STE 142
Santa Clara, CA 95050
(408) 394-1096 (mobile)
Email: awolfe@awolfe.org

Education:

Ph.D. in Electrical and Computer Engineering, Carnegie Mellon University, 1992
Visiting Graduate Student, Center for Reliable Computing, Stanford University, 1988-1989
M.S. in Electrical and Computer Engineering, Carnegie Mellon University, 1987
B.S.E.E. in Electrical Engineering and Computer Science, The Johns Hopkins University, 1985

Recent Employment:

Lecturer, Asst. Teaching Professor [September 2013-present]
Santa Clara University

Teaching graduate and undergraduate courses on embedded computing, mechatronics, real-time systems, computer architecture, design, and community service. Faculty Senate President 2023-24.

Consultant, [October 2002-present]
Wolfe Consulting

Consultant on processor technology, computer systems, consumer electronics, software, design tools, and intellectual property issues. Testifying and consulting expert for IP and other technology-related litigation matters.

Sample clients include:

Google	Apple	Samsung
Sony	Huawei	HTC
AT&T	Verizon Mobile	T-Mobile
IBM	Motorola/Lenovo	Nintendo
Activision	AMD	Western Digital
Sonos	Qualcomm	LG
Netflix	Roku	Tivo
Synaptics	Sawstop	3M
Medigus	TCL	ZTE
Egnyte	Acer	Waymo

Chief Technical Officer, [1999-2002]; Sr. VP of Business Development, [2001-2002]; VP, Systems Integration, S3 Fellow, [1998 – 1999]; Director of Technology, S3 Fellow, [1997 - 1998]
SONIC|blue, Inc., Santa Clara, CA (formerly S3 Inc.)

Strategic Business Development:

Developed and implemented strategy to reposition S3 from PC graphics into the leading networked consumer electronics company.

- Acquired Diamond Multimedia and coordinated integration of communications, Rio digital music, and workstation graphics divisions into S3.
- Identified and negotiated acquisitions to grow digital media businesses including Empeg, ReplayTV, and Sensory Science.
- Identified and negotiated strategic investments including Comsilica, Intellon, KBGear Interactive, Entridia, DataPlay and others.

- Developed strategy for integrated graphics/core-logic products and established a joint venture with Via Technologies to design and market these products.
- Negotiated divestiture of graphics chip business to Via and the workstation graphics division to ATI.

Product Planning and Development:

- Drove roadmap development within SONICblue product divisions.
- Managed Business Development for all product lines.
- Led New Product Development and Corporate Vision processes.
- Acting co-General Manager of Rio digital music business in 2nd half of 2001. Responsible for all areas of product development, business development, and cost management.
- Managed development of the Savage/MX and Savage/IX mobile 3D graphics accelerators and Savage/NB system logic products.

Public Relations, Public Policy and Investor Relations:

- Present company products and strategy at industry events such as CES, Comdex, and Microprocessor Forum.
- Discuss new products and initiatives with the press.
- Promote issues of interest to SONICblue to industry groups and in Washington.
- Brief analysts, and investors on company progress. Participate in quarterly conference calls.

IP Management and Licensing:

- Negotiated and managed partnership agreements including a critical cross-licensing agreement with Intel.
- Renegotiated technology-licensing agreements with IBM for workstation graphics products.
- Evaluated outside technology opportunities, managed video research and development, and managed corporate IP strategy with legal staff including patent filings, cross licensing, and litigation.

Consulting Professor, [1999-2002]

Stanford University, Stanford, CA

Teaching computer architecture and microprocessor design.

Assistant Professor [1991 - 1997]

Princeton University, Princeton, NJ

Teaching and research in the Electrical Engineering department. Research in embedded computing systems, multimedia, video signal processors, compiler optimization, and high performance computer architecture. Principal investigator or project manager for ~\$6M in funded research.

Visiting Assistant Professor, [1992]

Carnegie Mellon University, Pittsburgh, PA

Research and preparation of teaching materials on advanced microprocessor designs including new superscalar and superpipelined processor architectures.

Founder and Vice President and Consultant, [1989 - 1995]

The Graphics Technology Company, Inc., Austin, TX

Founded company to develop touch-sensitive components and systems for the first generation of PDA devices and interactive public systems. Obtained financing from Gunze Corp., Osaka, Japan. Company is now part of 3M.

Senior Electrical Engineer, [1989]

ESL - TRW, Advanced Technology Division, Sunnyvale, CA

Designed the architecture for an Intel i860-based multiple-processor digital signal processing system for advanced military applications. Designed several FPGA interface chips for VME-bus systems.

Design Consultant, [1986 -1987]

Carroll Touch Division, AMP Inc., Round Rock, TX

Developed several new technologies for touch-screen systems. Designed the first ASIC produced for AMP, a mixed-signal interface chip for controlling touch-screen sensors. Developed the system electronics, system firmware, and customer utility software for numerous products including those based on the new ASIC.

Senior Design Engineer, [1983 -1985]

Touch Technology Inc., Annapolis, MD

Advisory Boards:

Director, Turtle Beach Corporation (NASDAQ:HEAR) (formerly Parametric Sound Corporation), KBGear Interactive, Inc., Comsilica, Inc., Rioport.com, various S3 subsidiaries.

Technical Advisory Boards, Ageia, Inc., Intellon, Inc., Comsilica, Inc., Entridia, Inc., Siroyan, Ltd., BOPS, Inc, Quester Venture Funds

Carnegie Mellon University Silicon Valley Advisory Board; Johns Hopkins University Tech Transfer Advisory Board

Awards:

IEEE Fellow - for contributions in hardware code compression of embedded software, power consumption analysis, and optimization, 2022
IEEE Computer Society Distinguished Contributor - 2021
Micro Test-of-Time Award (in recognition of one of the ten most influential papers of the first 25 years of the symposium), 2014
Business 2.0 “20 Young Executives You Need to Know”, 2002
Walter C. Johnson Prize for Teaching Excellence, 1997.
Princeton University Engineering Council Excellence in Teaching Award, Spring 1996
AT&T/Lucent Foundation Research Award, 1996.
Walter C. Johnson Prize for Teaching Excellence, 1995
IEEE Certificate of Appreciation, 1995, 2001.
AT&T Foundation Research Award, 1993.
Semiconductor Research Corporation Fellow, 1986 - 1991.
Burroughs Corporation Fellowship in Engineering, 1985 - 1986.

Professional Activities:

Program Chair: Micro-24, 1991, Hot Chips 13, 2001.
General Chair: Micro-26, 1993, Micro-33, 2000.
Associate Editor: IEEE Computer Architecture Letters; ACM Transactions in Embedded Computing Systems
Speaker at CES, WinHec, Comdex, Intel Dev. Forum, Digital Media Summit, Microprocessor Forum, etc.
Keynote speaker at Micro-34, ICME 2002
IEEE B. Ramakrishna Rau Award committee – 2012-2016
IEEE Computer Society Awards Committee – 2015
Director – IEEE Consultants Network of Silicon Valley – 2022-present
CES Awards Judge – 2016
Entrepreneurship Mentor – Draper University

Over 50 refereed publications.**Publications since January 2006:**

Wolfe, A., “Retrospective on Code Compression and a Fresh Approach to Embedded Systems”, IEEE MICRO, July/Aug. 2016, Invited paper.

Michael Kreienkamp, Olivia McConaghy, Sally L. Wood, Andrew Wolfe, Julia A. Scott, 2024 NYC Neuromodulation Conference, Transcranial Photobiomodulation Control System Compatible with EEG, abstract and poster. June 2024 <https://neuromodec.org/nyc-neuromodulation-2024/poster-list.html#A83D>

Patents:

- U.S. Pat. 5,041,701 – *Edge Linearization Device for a Contact Input System*, Aug. 20, 1991.
- U.S. Pat. 5,438,168 – *Touch Panel*, Aug. 1, 1995.
- U.S. Pat. 5,736,688 – *Curvilinear Linearization Device for Touch Systems*, Apr. 7, 1998.
- U.S. Pat. 6,037,930 – *Multimodal touch sensitive peripheral device*, March 14, 2000.
- U.S. Pat. 6,408,421 – *High-speed asynchronous decoder circuit for variable-length coded data*, June 18, 2002.
- U.S. Pat. 6,865,668 – *Variable-length, high-speed, asynchronous decoder circuit*, March 8, 2005
- U.S. Pat. 7,079,133 – *Superscalar 3D Graphics Engine*, July 18, 2006
- EP 1 661 131 B1 – *PORTABLE ENTERTAINMENT APPARATUS*, Jan. 21, 2009
- U.S. Pat. 7,555,006 – *Method and system for adaptive transcoding and transrating in a video network*, June 30, 2009
- U.S. Pat. 7,996,595 – *Interrupt Arbitration for Multiprocessors*, Aug. 9, 2011
- EP 2 241 979 B1 – *Interrupt Arbitration for Multiprocessors*, Oct. 10, 2011
- U.S. Pat. 8,131,970 – *Compiler Based Cache Allocation*, March 6, 2012
- U.S. Pat. 8,180,963 – *Hierarchical read-combining local memories*, May 15, 2012
- U.S. Pat. 8,193,941 – *Snoring Treatment*, June 5, 2012
- U.S. Pat. 8,203,541 – *OLED display and sensor*, June 19, 2012
- U.S. Pat. 8,243,045 – *Touch-sensitive display device and method*, August 14, 2012
- U.S. Pat. 8,244,982 – *Allocating processor cores with cache memory associativity*, August 14, 2012
- U.S. Pat. 8,260,996 – *Interrupt Optimization for Multiprocessors*, Sept. 4, 2012
- 101185761 (KR) – *Noise Cancellation for Phone Conversation*, Sept. 19, 2012
- 101200740 (KR) – *OLED display and sensor*, November 7, 2012
- 101200741 (KR) – *Touch-sensitive display device and method*, November 7, 2012
- U.S. Pat. 8,321,614 – *Dynamic scheduling interrupt controller for multiprocessors*, Nov. 27, 2012
- U.S. Pat. 8,352,679 – *Selectively securing data and/or erasing secure data caches responsive to security compromising conditions*, Jan. 8, 2013
- U.S. Pat. 8,355,541 – *Texture Sensing*, Jan. 15, 2013
- U.S. Pat. 8,370,307 – *Cloud Data Backup Storage Manager*, Feb. 5, 2013
- U.S. Pat. 8,398,451 – *Tactile Input Interaction*, March. 19, 2013
- JP 5241032 B2 – *Routing Across Multicore Network Using Real World or Modeled Data*, April 13, 2013
- ZL201010124820.3 – *Interrupt Optimization for Multiprocessors*, April 17, 2013
- U.S. Pat. 8,428,438 – *Apparatus for Viewing Television with Pause Capability*, April 23, 2013
- JP 5266197 B2 – *Data Centers Task Mapping*, May 10, 2013
- U.S. Pat. 8,508,498 – *Direction and Force Sensing Input Device*, August 13, 2013
- U.S. Pat. 8,547,457 – *Camera Flash Mitigation*, October 1, 2013
- U.S. Pat. 8,549,339 – *Processor core communication in multi-core processor*, October 1, 2013
- 101319048 (KR) – *Camera Flash Mitigation*, October 10, 2013
- U.S. Pat. 8,628,478 – *Microphone for remote health sensing*, January 14, 2014
- 101362017 (KR) – *Thread Shift: Allocating Threads to Cores*, Feb. 5, 2014
- 101361928 (KR) – *Cache Prefill on Thread Migration*, Feb. 5, 2014
- 101361945 (KR) – *Mapping Of Computer Threads onto Heterogeneous Resources*, Feb. 5, 2014
- JP 5487307 B2 – *Mapping Of Computer Threads onto Heterogeneous Resources*, Feb. 28, 2014
- JP 5484580 B2 – *Task Scheduling Based on Financial Impact*, Feb. 28, 2014
- JP 5487306 B2 – *Cache Prefill on Thread Migration*, Feb. 28, 2014
- 101372623 (KR) – *Power Management for Processor*, March. 4, 2014
- 101373925 (KR) – *Allocating Processor Cores with Cache Memory Associativity*, March 6, 2014
- U.S. Pat. 8,676,668 – *Method for the determination of a time, location, and quantity of goods to be made available based on mapped population activity*, March 18, 2014
- U.S. Pat. 8,687,533 – *Energy Reservation in Power Limited Networks*, April 1, 2014
- 101388735 (KR) – *Routing Across Multicore Networks Using Real World or Modeled Data*, April 17, 2014
- U.S. Pat. 8,725,697 – *Cloud Data Backup Storage*, May 13, 2014
- U.S. Pat. 8,726,043 – *Securing Backing Storage Data Passed Through a Network*, May 13, 2014
- ZL201010124826.0 – *Dynamic scheduling interrupt controller for multiprocessors*, May 14, 2014
- JP 5547820 B2 – *Processor core communication in multi-core processor*, May 23, 2014
- U.S. Pat. 8,738,949 – *Power Management for Processor*, May 27, 2014

U.S. Pat. 8,751,854 – *Processor Core Clock Rate Selection*, June 10, 2014
 JP 5559891 B2 – *Thermal Management in Multi-Core Processor*, June 13, 2014
 101414033 (KR) – *Dynamic Computation Allocation*, June 25, 2014
 JP 5571184 B2 – *Dynamic Computation Allocation*, July 4, 2014
 101426341 (KR) – *Processor core communication in multi-core processor*, May 23, 2014
 U.S. Pat. 8,799,671 – *Techniques for Detecting Encrypted Data*, Aug 5, 2014
 101433485 (KR) – *Task Scheduling Based on Financial Impact*, Aug. 18, 2014
 U.S. Pat. 8,824,666 – *Noise Cancellation for Phone Conversation*, Sept. 2, 2014
 U.S. Pat. 8,836,516 – *Snoring Treatment*, Sept. 16, 2014
 U.S. Pat. 8,838,370 – *Traffic flow model to provide traffic flow information*, Sept. 16, 2014
 U.S. Pat. 8,838,797 – *Dynamic Computation Allocation*, Sept. 16, 2014
 U.S. Pat. 8,854,379 – *Routing Across Multicore Networks Using Real World or Modeled Data*, Oct. 7, 2014
 JP 5615361 B2 – *Thread Shift: Allocating Threads to Cores*, Oct. 15, 2014
 U.S. Pat. 8,866,621 – *Sudden infant death prevention clothing*, Oct. 21, 2014
 U.S. Pat. 8,881,157 – *Allocating threads to cores based on threads falling behind threads*, Nov. 4, 2014
 ZL201080024755.5 – *Camera Flash Mitigation*, Nov 5, 2014
 U.S. Pat. 8,882,677 – *Microphone for remote health sensing*, Nov. 11, 2014
 U.S. Pat. 8,924,743 – *Securing Data Cache through Encryption*, December 30, 2014
 U.S. Pat. 8,994,857 – *Camera Flash Mitigation*, March 31, 2015
 JP 5699140 B2 – *Camera Flash Mitigation*, April 8, 2015
 ZL201080035189.8 – *Thread Shift: Allocating Threads to Cores*, June 10, 2015
 ZL201180005030.6 – *Processor core communication in multi-core processor*, June 10, 2015
 U.S. Pat. 9,143,814 – *Method and system for adaptive transcoding and transrating in a video network*, Sept 22, 2015
 ZL201080035177.5 – *Mapping Of Computer Threads onto Heterogeneous Resources*, Oct. 14, 2015
 U.S. Pat. 9,178,694 – *Securing Backing Storage Data Passed Through a Network*, November 3, 2015
 U.S. Pat. 9,189,282 – *Thread-to-core mapping based on thread deadline, thread demand, and hardware characteristics data collected by a performance counter*, November 17, 2015
 U.S. Pat. 9,189,448 – *Routing image data across on-chip networks*, November 17, 2015
 U.S. Pat. 9,208,093 – *Allocation of memory space to individual processor cores*, December 8, 2015
 U.S. Pat. 9,239,994 – *Data Centers Task Mapping*, January 19, 2016
 ZL201080036611.1 – *Allocating Processor Cores with Cache Memory Associativity*, January 20, 2016
 EP2228779 B1 – *Traffic flow model to provide traffic flow information*, Jan. 27, 2016
 U.S. Pat. 9,262,628 – *Operating System Sandbox*, February 16, 2016
 GB2485682 – *Mapping Of Computer Threads onto Heterogeneous Resources*, Sept. 28, 2016
 U.S. Pat. 9,330,137 – *Cloud Data Backup Storage Manager*, May. 3, 2016
 ZL201080035185.X – *Cache Prefill on Thread Migration*, Aug. 24, 2016
 U.S. Pat. 9,519,305 – *Processor Core Clock Rate Selection*, December 13, 2016
 U.S. Pat. 9,569,270 – *Mapping thread phases onto heterogeneous cores based on execution characteristics and cache line eviction count*, February 14, 2017
 GB2485683 – *Thread Shift: Allocating Threads to Cores*, Oct. 18, 2017
 U.S. Pat. 9,852,435 – *Telemetrics based location and tracking*, December 26, 2017.
 U.S. Pat. 9,915,994 – *Power management for processor*, March 13, 2018
 U.S. Pat. 9,927,254 – *Traffic flow model to provide traffic flow information*, March 27, 2018
 EP2254048 B1 – *Thread Mapping in Multi-Core Processors*, August 29, 2018
 U.S. Pat. 10,860,432 – *Cloud Data Backup Storage Manager*, December 8, 2020

Expert testimony by deposition or at trial – April 15, 2018 - -present

Case	Venue	Case Number
Joe Andrew Salazar v HTC Corporation	E.D. Texas	2:16-cv-010986-JRG-RSP
Hitachi Maxell, Ltd. v. ZTE Corporation and ZTE (USA), Inc.	E.D. Texas	5:16-cv-00179 5:16-cv-00178
INTER PARTES REVIEW OF U.S. PATENT NO. 7,663,506 (Mediatek v AMD)	PTAB	IPR2017-00101 IPR2017-00102
Papst Licensing GmbH & Co. KG v. Samsung Electronics Co.,Ltd. and Samsung Electronics America, Inc.	E.D. Texas	6:15-CV-1102
HTC Corporation v. Telefonaktiebolaget LM Ericsson	E.D. Texas	6: 18-cv-00243-JRG
Seven Networks, LLC v ZTE (USA) Inc and ZTE Corporation	N. D. Texas - Dallas	3:17-CV-1495
AGIS Software Development, LLC v. HTC Corporation	E. D. Texas	2:17-cv-514
Barbaro Technologies, LLC v. Niantic, Inc	N.D. CA	3:18-cv-02955-RS
Immersion Corp. v. Samsung Electronics America, Inc. et al	E.D. Texas	2:17-cv-00572
INTER PARTES REVIEW OF U.S. PATENT NO. 7,171,526 (Northstar Innovations – Micron)	PTAB	IPR2018-01004 IPR2018-01005
CISCO SYSTEMS, INC., vs. UNILOC USA, INC., UNILOC 2017 LLC and UNILOC LICENSING USA LLC	N.D. CA	3:18-cv-04991-SI
INTER PARTES REVIEW OF U.S. PATENT NO. 8,020,014 (Intel/VLSI)	PTAB	IPR2018-01661 IPR2018-01312
INTER PARTES REVIEW OF U.S. PATENT NO Patent 9,294,799 (Comcast/Rovi)	PTAB	IPR2019-00299
Inter Partes Review of U.S. Patent No 7720929 (Unified Patents v Datascope)	PTAB	IPR2019-01115
Solas OLED Ltd., v. Samsung Display Co., Ltd., Samsung Electronics Co, Ltd., and Samsung Electronics America, Inc.,	PTAB	IPR2019-01668
INTER PARTES REVIEW OF U.S. PATENT NO Patent 8,973,069 (Comcast/Rovi)	PTAB	IPR2019-01434
U.S. Patent No. 8,448,215 IPR (Comcast v Rovi)	PTAB	IPR2019-01353
U.S. PATENT NO. 8,847,898 IPR filing (Samsung v Neodron)	PTAB	IPR2020-00234
U.S. PATENT NO. 8,610,009 IPR filing (Samsung v Neodron)	PTAB	IPR2020-00225
U.S. PATENT NO. 10,365,747 IPR filing (Samsung v Neodron)	PTAB	IPR2020-00308

AGIS Software Development LLC v. Google LLC, AGIS Software Development LLC v. WAZE Mobile Limited, and AGIS Software Development LLC v. Samsung Elecs. Co., Ltd. et al	E.D. Texas	2:19-cv-00361- JRG 2:19-cv-00359- JRG 2:19-cv-00362- JRG
Inter Partes Review of U.S. Patent No 8,112,670 (Sony)	PTAB	IPR2020-00726
U.S. Patent 8,819,505 IPR (Intel v PACT)	PTAB	IPR2020-00525
Inter Partes Review of U.S. Patent No 8,078,540 (Sony)	PTAB	IPR2020-00922
Inter Partes Review of U.S. Patent No 9,037,807 (Intel v PACT)	PTAB	IPR2020-00540
HONG KONG UCLOUDLINK NETWORK TECHNOLOGY LIMITED AND UCLOUDLINK (AMERICA), LTD., vs. SIMO HOLDINGS INC. AND SKYROAM, INC.,	N.D. CA	3:18-cv-05031- EMC
Joe Andrew Salazar v AT&T Mobility, LLC et al.	E.D. Texas	2:20-cv-00004- JRG
Innovative Memory Solutions Inc. v Micron, Inc	Delaware	14-1480 RGA
Inter Partes Review of U.S. Patent No. 6,411,941	PTAB	IPR2021-01338 IPR2021-01406
Maxell, Ltd. et al v. VIZIO, Inc	C.D. CA	2-21-cv-06758
Inter Partes Review of U.S. Patent No. 7,619,912	PTAB	IPR2022-00615
Inter Partes Review of U.S. Patent Nos. 11,016,918 and 11,232,054	PTAB	IPR2022-00996 IPR2022-00999
In the Matter of Certain Smart Televisions, - Maxell, Ltd. et al v. VIZIO, Inc	ITC	337-TA-1338
INTER PARTES REVIEW OF U.S. PATENT NOS. 8,787,060 and 9,318,160	PTAB	IPR2022-01427 IPR2022-01428
Sweat Equity Partners, LLC vs. Swoop Search, LLC, et al.,	San Francisco Superior Court	CGC-21-591702
Walter Kidde Portable Equipment, Inc. v. First Alert, Inc. and BRK Brands	W.D. Texas	6:22-cv-566-ADA
INTER PARTES REVIEW OF U.S. PATENT NO. 11,093,417	PTAB	IPR2023-00454
INTER PARTES REVIEW OF U.S. PATENT NO. 9,858,215	PTAB	IPR2023-00455
INTER PARTES REVIEW OF U.S. PATENTS NOS. 9,369,081 and 9,941,830	PTAB	IPR2023-00992 IPR2023-00993
FlatFrog Laboratories AB v. Chemtronics Co., Ltd.	E.D. Texas	2:23-cv-00306
INTER PARTES REVIEW OF U.S. PATENT NOS. 8,624,844	PTAB	IPR2024-00404
Topia Technology, Inc. v. Egnyte, Inc.	District of Delaware	1-21-cv-01821- CJB