

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

ZEPP HEALTH CORPORATION

Petitioner

v.

UNIVERSITY OF CONNECTICUT

Patent Owner

Case No. IPR2025-00523
U.S. Patent No. 10,278,647

**DECLARATION OF DR. GEORGE E. YANULIS
IN SUPPORT OF PETITION FOR *INTER PARTES* REVIEW
OF U.S. PATENT NO. 10,278,647**

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Ex-1002	Declaration of Dr. George E. Yanulis
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Ex-1004	Prosecution History of the ‘647 Patent
Ex-1005	Po-Hsiang Lai et al., <i>Lightweight Wrist Photoplethysmography for Heavy Exercise: Motion Robust Heart Rate Monitoring Algorithm</i> , Healthcare Technology Letters, Volume 2, Issue 1, pp. 6-11 (February 24, 2015) (“Lai”)
Ex-1006	Zhilin Zhang et al., <i>TROIKA: A General Framework for Heart Rate Monitoring Using Wrist-Type Photoplethysmographic Signals During Intensive Physical Exercise</i> , IEEE Transactions on Biomedical Engineering, Volume 62, Issue 2, pp. 522-531 (September 19, 2014) (“TROIKA”)
Ex-1007	Declaration of Sylvia D. Hall-Ellis, Ph.D.
Ex-1008	Zepp Health Corporation’s Stipulation Regarding Invalidity Challenges
Ex-1009	Docket Control Order (Dkt. 58) in <i>Research Foundation for The State University of New York v. Xiaomi Corporation et al.</i> , No. 2:23-cv-00353-RWS-RSP (E.D. Tex.)
Ex-1010	Judge Robert W. Schroeder, III (E.D. Tex.) – Calendar Events Set for 2/17/2026
Ex-1011	Judge Robert W. Schroeder, III (E.D. Tex.) – Case Statistics
Ex-1012	Docket entries in <i>Research Foundation for The State University of New York v. Xiaomi Corporation et al.</i> , No. 2:23-cv-00353-RWS-RSP (E.D. Tex.)

¹ In this Declaration, 4-digit pin citations that begin with “0” refer to the branded numbers added by Petitioner in the bottom right corner of the exhibits. All other pin citations in this Declaration refer to original page, column, paragraph, or line numbers.

I, George E. Yanulis, declare as follows:

I. INTRODUCTION

A. Engagement

1. I have been retained by counsel for Petitioner Zepp Health Corporation (“Zepp” or “Petitioner”) as an expert witness for the above-captioned *inter partes* review (IPR) proceeding. I have been asked to consider the validity of claims 21-46 of U.S. Patent No. 10,278,647 (“the ‘647 Patent” or “the Patent”) in view of prior art, obviousness considerations, and the understanding of a person of ordinary skill in the art at the time of the invention as it relates to the ‘647 Patent. I have personal knowledge of the facts and opinions set forth in this declaration and believe them to be true. If called upon to do so, I would testify competently thereto.

B. Compensation

2. For my time working on this matter, I am being compensated at my standard hourly consulting rate. I do not have any personal or financial stake or interest in the outcome of the present proceeding, and the compensation is not dependent on the outcome of this IPR and in no way affects the substance of my statements in this Declaration. I do not have any expectation or promise of additional business with the Petitioner in exchange for the positions explained herein. 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.

C. Qualifications and Experience

3. I have over 35 years of experience in biomedical engineering and designing medical devices. Particularly, I have direct experience within the field of medical monitors that measure physiological parameters and provide statistical analyses relating to the parameters. My experience is related specifically to electrocardiograms, cardiac echo imaging, and cardiac pressure/volume analysis, which are closely related to pulse oximetry, oxygen saturation, and pulse rate. Through my experience, I have learned how to integrate medical monitoring technology into the medical profession.

4. I received my Bachelor of Arts in Pre-medicine degree in 1977 from Syracuse University, which included a minor in Chemistry. Originally, I planned to go to medical school, but I found that my interests aligned more closely to medical devices than practicing medicine. So, I pivoted to biomedical engineering, and I received a Master's degree in Biomedical Engineering from the University of Virginia in 1981. I closely studied medical devices while in graduate school at Virginia, including using preamplifiers to record evoked cortical signals to better understand the etiology of Epilepsy.

5. For approximately the next two decades, my professional experience included serving in the armed services as a 1st Lieutenant and Clinical Engineer for the Air Force (stationed at the Malcolm Grow Medical Center, Andrews Air Force Base), working as a Logistics Engineer for RCA, and conducting research within the education industry (at Syracuse, Alabama-Birmingham, Drexel, and the University of Pennsylvania). I was a Clinical Engineering Consultant involved with the Y2k Program at the Hospitals of the University of Pennsylvania from 1999-2000. I continued as a research assistant at the University of Pittsburgh, but in 2002, I decided to pursue a doctorate. Even though I was leaving, my mentor at Pitt awarded me a Master of Science in Bioengineering for my research work rather than leave without a degree. I studied medical devices at Pitt, but also implantable devices, such as using elastomeric polymers to design artificial diaphragm muscles.

6. Still continuing my education, I received a Doctor of Engineering (D.Eng.) from Cleveland State University in 2008. For my Doctorate, I focused on Applied Biomedical Engineering. It was during my Doctorate that I developed a specialty in cardiovascular medical devices and treatments, with a focus on treating atrial fibrillation. At Cleveland State, we studied electrical stimulation (i.e., coupled pacing applied near the end of the T-wave, which represents the repolarization of the ventricles in electrocardiography to prevent rapid ventricle

conduction during atrial fibrillation (AF)), and whether the benefits of coupled pacing could be used during persistent AF.

7. Since obtaining my D.Eng., I have taught the next generation of bright minds. From 2009-2013, I was an adjunct professor at the College of Staten Island teaching Engineering and Physics, and since 2015, I have been an Adjunct Professor at Temple University teaching Bioengineering.

8. In my career, I have had multiple research projects focusing on clinical assessment of medical devices and monitoring systems. For example, I am currently involved in the research and development of a heart rate monitoring system based on my earlier bench studies conducted related to my Doctoral research at the Cleveland Clinic (2005-2008) and now with Medical Device Consulting, LLC (2016-Present). I have consulted on heart bypass systems (2017-2018), and I served as a consultant on several cardiac pacemaker device related cases which involved monitoring heart rate, pulse rate, ECG. I was involved in reviewing critical monitoring systems as both a member and peer reviewer of submitted manuscripts of the association for the advancement of Medical Instrumentation (2012-present). At Cleveland State, I was involved in the research and design of critical care monitoring systems used for heart failure therapy patients both from 2005-2008, as part of my D.Eng. and since 2014, as part of my research and the development of a heart monitoring system. Further still, from

2015-2017, I was also involved in mentoring Temple bio-engineering students in the design of critical care monitoring systems for both cardiac systems courses and biomedical instrumentation design courses. Finally, I was involved in reviewing clinical care monitoring system as a clinical engineer with the USAF from 1987-1989.

9. I also have continued to study cardiovascular devices and other medical devices as a consultant. Particularly, I collaborated with Data Science Corporation to design a device that used a time elapsed interval between two consecutive R-waves of the QRS heart signal (R-R interval) to potentially use on heart failure therapy patients. I have assisted with 250 Cardiac Pacemaker Device Implants on dogs to develop pacing algorithms for heart failure therapy patients. Also, I have performed over 500 ECG signal detection sessions and cardiac pressure-volume analysis on dogs. Further still, I have intensely studied Heart Failure Cardiac Pressure/Flow Sensor Monitoring Systems.

10. Lastly, I have written six peer-reviewed articles in this area and other areas of medical device development. My publications from the last 10 years are listed in my CV where my CV is submitted as Ex-1003 to the Petition.

11. Thus, my background demonstrates an expertise and strong understanding of medical devices and how they can improve the health of patients.

D. Information Considered

12. In preparation for this declaration, I have considered the materials discussed in this declaration, including, for example, the '647 Patent, the references cited by the '647 Patent, the prosecution history of the '647 Patent (including the references cited therein), various background articles and materials referenced in this declaration, and the prior art references identified in this declaration. In addition, my opinions are further based on my education, training, experience, and knowledge in the relevant field.

II. PERSON OF ORDINARY SKILL IN THE ART

13. A person of ordinary skill in the art ("POSITA") at the time of the purported invention of the '647 Patent would have had a working knowledge of physiological monitoring technologies and/or signal processing as used in physiological monitoring technologies. The POSITA would have had a bachelor's degree in an academic discipline related to electrical, computer, software, optical, or biomedical technologies, in combination with two years of work experience related to the capture and processing of data or information signals, or designing and using biomedical sensors or systems, including but not limited to physiological monitoring technologies. Alternatively, a POSITA would have had a master's degree in one of the above academic disciplines with one year of work experience

as described above. Additional education can substitute work experience, and vice versa.

14. The proposed level of skill for the POSITA would not change if a different priority of the invention date is found.

III. LEGAL STANDARDS

15. I am not an attorney, and I have not been asked to offer any legal opinions. In preparing and expressing my opinions in this Declaration, I have applied the legal standards described below, which were explained to me by counsel for Petitioner.

A. Claim Construction

16. I do not believe that any claim term of the Patent requires explicit construction to resolve the issues presented in this Petition. I apply the plain and ordinary meaning to each claim term, as that plain and ordinary meaning would have been understood by a POSITA.

17. I reserve the right to offer opinions on any claim constructions proposed in this proceeding or to offer opinions on constructions in the district court litigation.

B. Obviousness (35 U.S.C. § 103 (AIA))

18. 35 U.S.C. § 103 (AIA), I understand that a patent claim is obvious if “the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains.” Relevant considerations for an obviousness determination include the level of ordinary skill in the art; the scope and content of the prior art; differences between the prior art and the claims at issue; and the so-called objective secondary factors of nonobviousness.

19. I understand that a claim can be found to be obvious if all the claimed elements were known in the prior art and that one skilled in the art could have combined the elements as claimed by known methods with no change in their respective functions, and the combination would have yielded nothing more than predictable results to one of ordinary skill in the art.

20. I understand that hindsight must not be used when comparing the prior art to the invention for obviousness. Thus, a conclusion of obviousness must be firmly based on knowledge and skill of a POSITA at the time the invention was made without the use of post-filing knowledge.

21. I understand that in order for a claimed invention to be considered obvious, there must be some motivation to combine the cited references as proposed.

22. I understand that obviousness may also be shown by demonstrating that it would have been obvious to modify what is taught in a single piece of prior art to create the patented invention. Obviousness may be shown by showing that it would have been obvious to combine the teachings of more than one item of prior art, with a reasonable expectation of success in doing so. In determining whether a piece of prior art could have been combined with other prior art or with other information within the knowledge of one of ordinary skill in the art, the following are examples of approaches and rationales that may be considered:

- (a) Combining prior art elements according to known methods to yield predictable results;
- (b) Simple substitution of one known element for another to obtain predictable results;
- (c) Use of a known technique to improve similar devices (methods, or products) in the same way;
- (d) Applying a known technique to a known device (method, or product) ready for improvement to yield predictable results;

(e) Applying a technique or approach that would have been “obvious to try” (choosing from a finite number of identified, predictable solutions, with a reasonable expectation of success);

(f) Known work in one field of endeavor may prompt variations of it for use in either the same field or a different one based on design incentives or other market forces if the variations would have been predictable to one of ordinary skill in the art; or

(g) Some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention.

23. I further understand that certain factors may support or rebut the obviousness of a claim. I understand that such secondary considerations include, among other things, commercial success of the patented invention, skepticism of those having ordinary skill in the art at the time of invention, unexpected results of the invention, any long-felt but unresolved need in the art that was satisfied by the alleged invention, the failure of others to make the alleged invention, praise of the alleged invention by those having ordinary skill in the art, and copying of the alleged invention by others in the field. I understand that there must be a nexus—a connection—between any such secondary considerations and the alleged invention (i.e., the features that are alleged to make the claim patentable).

IV. OVERVIEW OF THE ‘647 PATENT

A. Brief Summary of the ‘647 Patent (Ex-1001)

24. The ‘647 Patent describes method and apparatus for heart rate monitoring and oxygen saturation estimation during intensive physical activity. Ex-0001, 6:34-38. The time-frequency spectra (TFS) of a heart-related signal (e.g., photoplethysmography signal) and a motion (accelerometer) TFS are computed from pre-processed (filtered and down-sampled) signals. Movement is classified as corrupted by motion artifacts if the accelerometer data exceeds a modulation threshold. If so, the movement is further classified as pseudo-periodic, periodic, or random motion. Based on the classification, the system discards spectral peaks or uses prior estimates to reconstruct the heart-related signal. *Id.*, Table 1.

B. Summary of Claims

25. Independent Claims 1, 35, and their dependent claims 2-34, 36-68, and independent Claims 69 of the ‘647 Patent are directed to a method, an apparatus, and a non-transitory computer-readable medium, respectively. Independent method Claims 70, 71, and 72 and their counterpart apparatus claims, Claims 73-75, all include elements [1A]-[1F] and [1H] of Claim 1 and various additional claim elements selected from the method dependent claims, Claims 2-34 and apparatus dependent claims, Claims 36-68.

26. Claim 1 is representative for all independent claims and reproduced here:

1. A method for reconstructing a heart-related signal output by a biomedical sensor, the method comprising:

[1A] reconstructing a representation of the heart-related signal to produce a reconstructed representation of the heart-related signal,

[1B] the reconstructing based on (i) a time-varying spectral analysis of the heart-related signal and a motion signal,

[1C] the motion signal output by a motion sensor and representative of motion artifacts in the heart-related signal,

[1D] the motion artifacts being signal artifacts produced by movement of the biomedical sensor relative to a sensing location, and

[1E] (ii) a classification of the movement,

[1F] wherein the time-varying spectral analysis includes pre-processing the heart-related signal to produce a pre-processed heart-related signal, pre-processing the motion signal to produce a preprocessed motion signal,

[1G] and computing a first time-frequency spectrum (TFS) of the heart-related signal using the preprocessed heart-related signal and a second TFS of the motion signal using the pre-processed motion signal; and

[1H] outputting the reconstructed representation of the heart-related signal.

C. Prosecution History of the ‘647 Patent

27. I understand that the ‘647 Patent was filed as Application No. 15/178,089 (“the ‘089 Application”) and issued on May 7, 2019. Ex-1001, 1.

28. I further understand that the ‘647 Patent Prosecution History has been submitted as Ex-1004. The ‘089 Application was filed on Jun. 9, 2016, claiming priority to U.S. Provisional application No. 62/299,944, filed on Feb. 25, 2016, and U.S. Provisional application No. 62/172,862, filed on Jun. 9, 2015.

29. During prosecution of, the Examiner found that prior art Grundlehner et al. includes (1) “**reconstructing a representation of a heart-related** signal for output using spectral analysis of an acquired biopotential signal (i.e., and ECG or even an EEG or EMG) **and** a secondary signal pertaining to **a motion signal**. The secondary signal pertaining to motion is obtained **from** a motion sensor such as **an accelerometer** which senses the motion artifacts resulting from the movement of recording electrodes, cables, or acquisition system with respect to the user’s skin and environment;” (2) “a **motion classification module** 110 configured to extract

motion artifact and determine the type of motion causing the artifact and communication setting for artifact removal from the biopotential signal ... provid[ing] as output the cleaned, reconstructed biopotential signal which is free from motion artifact ... such that the **motion artifact is suppressed from the reconstructed signal;**” (3) “before conducting the spectral analysis, the signals are **pre-processed** by removing powerline noise and resampling;” (4) “the preprocessing determines the **type of motion artifact** and communicates optimal settings for artifact removal;” (5) “the pre-processing includes **filtering** the signal for noise;” and (6) all of which “may [sic] employed in **real-time or non-real time.**” Ex-1004 (0933-0934), 2018-04-18 Office Action, at 3-4 (emphasis added).

30. Examiner also found that the prior art Venkatraman et al. teaches (1) “a wearable heart rate sensor that **combines sensors for heart-related signals with motion sensors** for removing motion artifacts from the heart-related signal;” (2) “during processing of the biopotential signals determines to modify or **reduce the sampling rate** when the device determines that a user’s motion is below a threshold;” (3) “signal processing for reconstruction includes **real-time windowed segments** wherein the heart rate information is measured with in a time window segment;” (4) “a PPG [photoplethysmography] sensor utilizing **LED sources;**” (5) “[o]ne of ordinary skill in the art is considered to possess the knowledge to determine a **representation of heart rate estimate** from the heart rate sensor

and/or ECG;” (6) that “to **downsample** the sampling rate is considered obvious;” and (7) that “[m]easurement of **oxygen saturation** from the sensors employed by Venkatraman et al. is a well-known function;” (8) “[u]se of windows is considered routine in spectral analysis as **windowing** is a known technique for breaking down large datasets into smaller, more easily handled subsets;” and (9) “[t]hree-dimensional **spectra** is also considered to be within routine skill in the art.” Ex-1004 (0935-0938) (emphasis added).

31. Regarding the subject matter of claim 6 (“*wherein the time-varying spectral analysis includes: **computing a first time-frequency spectrum (TFS) of the heart-related signal; and computing a second TFS of the motion signal***”), the Examiner further found that “Chon et al. ‘employ computation of time-frequency spectrum analysis of the signals’ and ‘demonstrates that this is a **suitable technique for removing artifacts from a heart related signal**. Modification is considered to comprise application of a known technique to a known process to yield a predictable result.’” Ex-1004, 0938 (emphasis added).

32. The Patent Owner did not refute any of these findings. Instead, to distinguish independent claims 1, 35, and 69 from the prior art, the Patent Owner added the subject matter of claim 6 (found to be prior art) into all independent claims and incorporated the subject matter of claim 18 (“*wherein the time-varying spectral analysis further includes **preprocessing the heart-related signal and the***”).

motion signal ...”), which depends from claim 6 and was found allowable. *Id.* (emphasis added). The Patent Owner further added new independent claims 70-75 combining various claim elements from Claims 9-34 that were allowed. Response to Non-Final Office Action dated 7/16/18, at 17-21 (Ex-1004 at 0980-0984).

33. As explained in detail below, the ‘647 Patent’s claims would have been obvious in view of the prior art. As an example, since the Examiner found that the prior art disclosed both the subject matter of claim 6 and the “preprocessing” steps recited in claim 18, which depends on claim 6, logic dictates that claim 18 also should have been found not allowable.

34. Thus, the Examiner clearly erred by allowing, at the least, claims 1, 35, and 69, which rely on the subject matter of claim 18.

35. Further, the prior art for the invalidity ground in this Petition was not presented during the prosecution of the ‘647 Patent.

36. Also, the arguments for the invalidity ground in this Petition were not presented during the prosecution of the ‘647 Patent.

D. Priority Date

37. I understand that the earliest possible priority date that the patent owner may claim for the ‘647 Patent is based on provisional application No. 62/172,862’s filing date of June 9, 2015. I do not concede that any claim of the Patent is entitled to that priority date. I further understand the prior art asserted in

my declaration was published before that earliest possible priority date, and thus qualifies as prior art under AIA 35 U.S.C. §§ 102(a)(1) and 103.

E. Claim Interpretation

38. I have been informed and understand that in an IPR proceeding, claims are to be interpreted according to the *Phillips* claim construction standard. I understand that under this standard, the meaning of claim terms is considered from the viewpoint of a POSITA at the time of the alleged invention. I have been informed and understand that claim construction is a matter of law and that the final claim constructions for this proceeding will be determined by the Patent Trial and Appeal Board (“PTAB”).

39. I have been informed that claim terms are generally given their ordinary and customary meaning as understood by one of ordinary skill in the art in light of the specification and the prosecution history pertaining to the patent. I understand, however, that claim terms are generally not limited by the embodiments described in the specification.

40. I understand that in addition to the claims, specification, and prosecution history, other evidence may be considered to ascertain the meaning of claim terms, including textbooks, encyclopedias, articles, and dictionaries. I have been informed that this other evidence is often less significant and less reliable than the claims, specification, and prosecution history.

V. TECHNOLOGY BACKGROUND

41. The ‘647 Patent specifically incorporates by reference numerous prior art documents that confirm that time-frequency spectral techniques for mitigating motion artifacts were routine and well-known to a POSITA before the effective filing date of the ‘647 Patent. For example, the ‘647 Patent acknowledges that “[t]he first TFS computed may be a first time-varying power spectral density (PSD) and the second TFS computed may be a second time-varying PSD. A time-frequency technique, such as a variable frequency complex demodulation (VFCDM), ... may be used for computing the first TFS (308), that is, a TFS of the accelerometer signal. However, it should be understood that any suitable time-frequency technique may be used, such as a smoothed pseudo Wigner-Ville method, or a wavelet-based method.” Ex-1001, 14:60-15:4.

42. The ‘647 Patent further states that “embodiments disclosed herein ... may decompose the PPG signal into many frequency bands using a VFCDM method ... or any other suitable time-frequency technique, such as a wavelet analysis.” Ex-1001, 39:62-40:3.

43. These statements confirm that techniques for computing TFSs of heart-related and motion signals were routine and widely used in the field. A POSITA would understand that methods such as VFCDM, PSD, wavelet analysis,

and smoothed pseudo Wigner-Ville were commonly used to isolate cardiac frequency components and suppress motion-induced artifacts.

44. Regarding both the “pre-processing” and “filtering” steps analyzed in respective Sections A.7 and B.3 below, TROIKA (Ex-1006), which is prior art and expressly incorporated by reference into the ‘647 Patent, emphasizes the importance of (bandpass) filtering raw PPG and accelerometer signals as a pre-process step in removing noise and motion artifacts, particularly during “complicated intensive hand movements.” Ex-1006, 5 (“When complicated intensive hand movements occur” operations such as “the preprocessing procedures including bandpass filtering ... are important”); *see also id.*, 3 (“Before TROIKA starts, the raw PPG signal and the acceleration signal in a given time window are first bandpass filtered from 0.4 Hz and 5 Hz. This preprocessing removes noise and motion artifacts outside of the frequency band of interest, which also sparsifies the spectra”). This confirms that both pre-processing and filtering steps, including bandpass filtering of PPG and accelerometer signals, are routine and well-known in the field, as can be seen from TROIKA, which was published on September 19, 2014 and is thus prior art to the Patent under AIA 35 U.S.C. §§ 102(a)(1) and 103. *See* Ex-1007, 30 (showing that TROIKA was published on September 19, 2014).

45. Regarding the “prior reconstructed representation” steps, TROIKA discloses such fallback mechanisms, noting that “the frequency location index of HR estimated in the previous time window” is used when the signal is interrupted. Ex-1006, 6. This confirms that such fallback mechanisms are routine and well-known in the field.

46. Regarding the “retaining, discarding” steps, Troika discloses that spectral peaks corresponding to motion artifacts can be identified and removed by aligning them with acceleration spectra, underscoring the common and routine nature of such comparisons. *Id.*, 6.

47. Regarding the “discarded by second discarding” steps, Troika discloses that “[t]he frequency location index of HR estimated in the previous time window” is used if no peaks are found, based on the observation that the spectral peak associated with HR often keeps the same location in two successive time windows. *Id.*, 6. Further, Troika emphasizes thresholds for identifying and discarding implausible HR estimates. *Id.* (“The change of BPM values in two successive time windows rarely exceeds 10 BPM”). This confirms that the second discarding process that removes peaks deviating beyond a threshold from prior reconstructed values is routine and well-known in the field.

48. Regarding the “closest frequency” steps, Troika highlights that the spectral peak associated with HR “often keeps the same location in two successive

time windows,” underscoring the need to select peaks based on their alignment with prior reconstructed frequencies. *Id.*, 6. This confirms that selecting the peak closest to a prior reconstructed frequency is routine and well-known in the field.

49. Regarding the “largest power/amplitude” steps, Troika emphasizes the use of dominant peaks in the motion spectrum, noting that the motion signals often contain “dominant quasi-periodic signals” caused by rhythmic hand swings or repetitive motions. *Id.*, 1. This confirms that dominant peaks, defined by their largest amplitude or power values, are routinely used to align with PPG peaks during artifact suppression.

50. Regarding the “amplitude modulation” steps, Troika confirms that the use of thresholds to remove irrelevant or fluctuating spectral components during the classification process is routine and well-known in the field. (“In each search range, we select no more than three highest peaks with amplitude no less than a threshold η . In our experiments η was set to 30% of the highest peak amplitude in R_0 . This setting is helpful to remove spectral fluctuations”). *Id.*, 6.

51. Regarding the “concurrently” steps, Troika describes “a single-channel PPG signal and simultaneously recorded acceleration data.” *Id.*, 3. This confirms that concurrent production and analysis of the heart-related and motion signals is standard practice in the field and necessary for motion artifact suppression in real-time applications

52. Regarding the “real-time” steps, Troika discloses that “these devices estimate HR in real time using photoplethysmographic (PPG) signals recorded from wearers’ wrist.” *Id.*, 1. Troika further describes a sliding time window approach, where “a time window of T seconds is sliding on the signals with incremental step of S seconds,” showing synchronized processing of the input data in real time. *Id.*, 3. This confirms that configuring the reconstruction and output units to operate in real time with respect to signal production are routine and well-known in the field.

53. Overall, Lai’s teaching of STFT-based motion artifact mitigation, combined with the admissions and prior art incorporated by reference into the ‘647 Patent itself, demonstrate that the claims of the ‘647 Patent are obvious in light of the prior art.

VI. BRIEF DESCRIPTION OF THE APPLIED PRIOR ART

54. In my opinion, and as explained in further detail below, the claims of the ‘647 Patent do not identify anything new or significantly different from what was already known to those skilled in the art prior to the filing of the ‘647 Patent.

55. Lai (Ex-1005) notes that removing or mitigating motion artifacts was a known challenge and a major research topic in PPG-based heart rate monitoring, and highlights the challenges of motion artifacts in wearable devices like smartwatches, where high arm mobility increases the susceptibility of PPG signals

to motion distortion. Ex-1005, 6 (“PPG is susceptible to motion artefacts, which have to be mitigated for accurate heart rate estimation. Motion artefacts are particularly apparent for wrist devices, for example, a smart watch, because of the high mobility of the arms”).

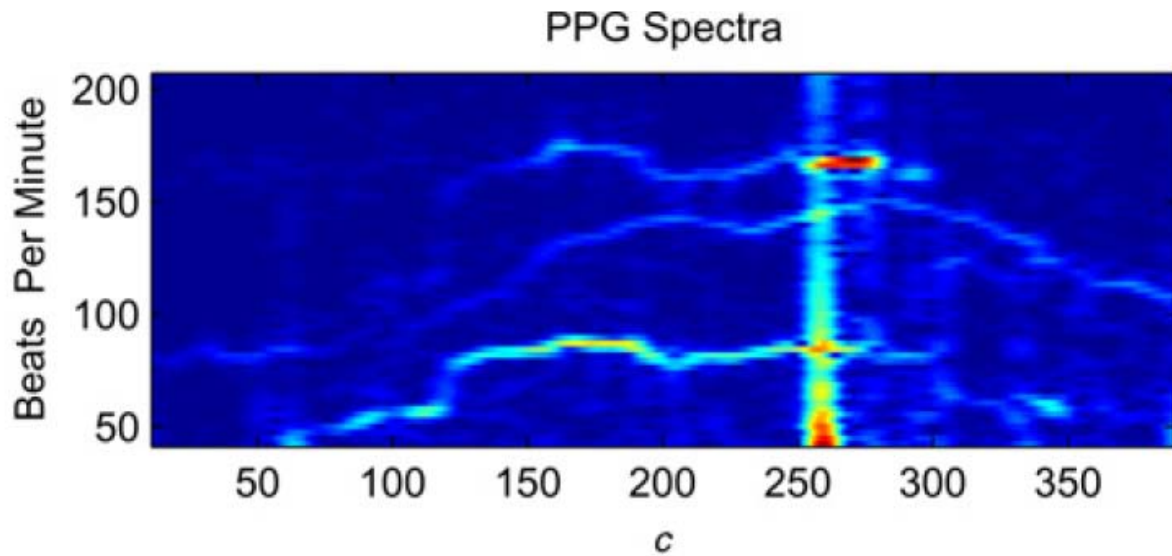
56. Lai discloses a method for mitigating motion artifacts in physiological signals, such as PPG signals, which employs Short-Time Fourier Transform (“STFT”). STFT is only one example of the many well-known time-frequency spectrum analysis techniques in the field that the ‘647 Patent itself acknowledges, including Power Spectral Density (PSD), Variable Frequency Complex Demodulation (VFCDM), wavelet analysis, and smoothed pseudo Wigner-Ville methods. Ex-1001, 14:60-15:4, 19:57-64; *see also* Ex-1006, 1 (“MA-removal techniques include electronic processing methodology [10], time-frequency analysis [11], wavelet denoising [12], and empirical mode decomposition [13], to name” including “a few techniques [] proposed for HR monitoring in fitness”).

57. Lai (Ex-1005) was published on February 24, 2015, is thus prior art to the ‘647 Patent under AIA 35 U.S.C. §§ 102(a)(1) and 103. *See* Ex-1007, 29 (showing that Lai was published on February 24, 2015). This demonstrates that combining accelerometers with time-frequency spectrum techniques to mitigate unwanted artifacts caused by movement was well-established and widely known in

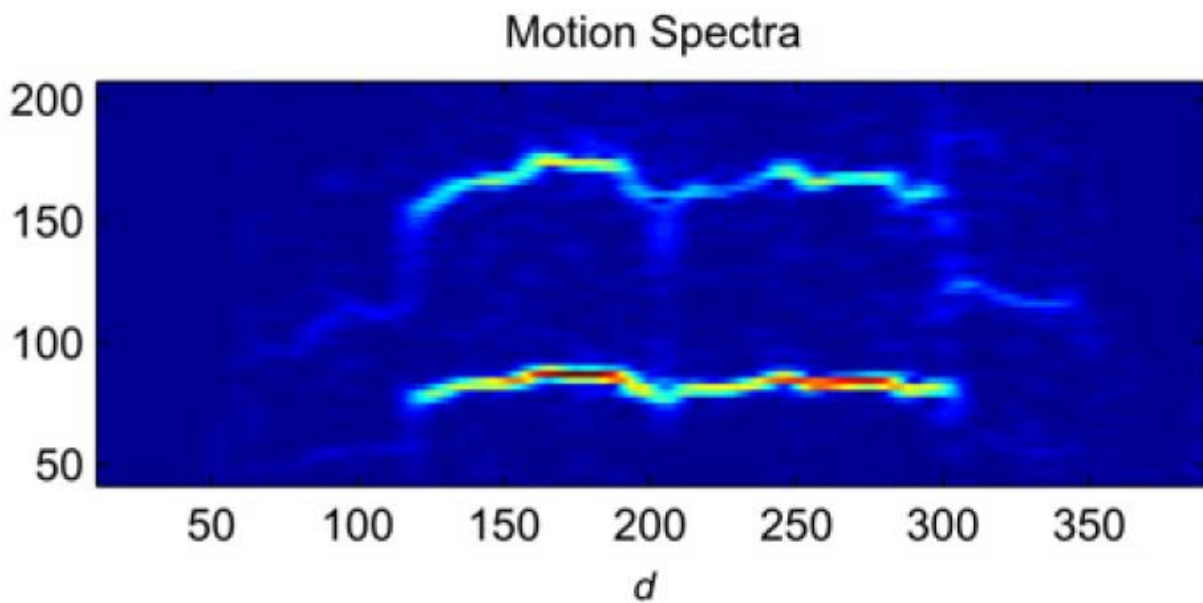
the field prior to the earliest possible priority date (June 9, 2015) of the ‘647 Patent.

58. Lai, titled “Lightweight wrist photoplethysmography for heavy exercise: motion robust heart rate monitoring algorithm,” describes a method for processing streaming PPG and accelerometer signals to mitigate motion artifacts and extract heart rate estimates. Ex-1005, 6 (“The algorithm takes streaming PPG and accelerometer data as inputs ... [and] outputs a raw heart rate estimate, which contains a few errors due to motion artefacts”).

59. Using STFT for perform time-frequency spectral analysis, Lai analyzes PPG signals and motion signals segment by segment to detect significant peaks, including motion peaks that correspond to repetitive activities such as footsteps or arm movements. Motion artifacts are suppressed by separating cardiac components from unwanted motion-induced noise. For example, Figure 2c shows a PPG spectrum, where cardiac components are contaminated by motion artifacts, while Figure 2d shows the motion spectrum derived from accelerometer data. Ex-1005, 8 (Figs. 2c and 2d). These spectra are used to identify and suppress motion peaks. *Id.*



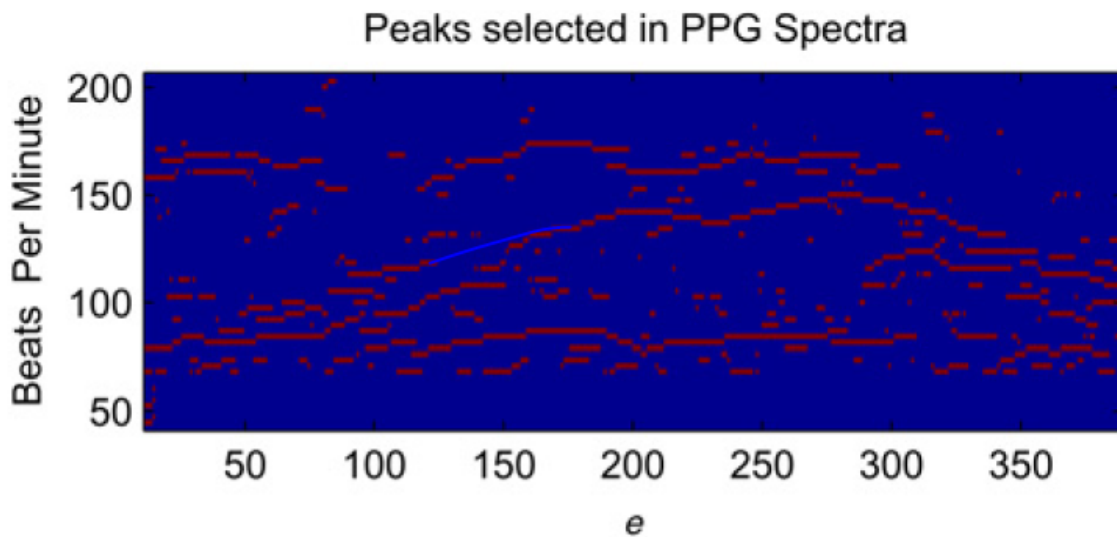
(Ex-1005, Fig. 2c)



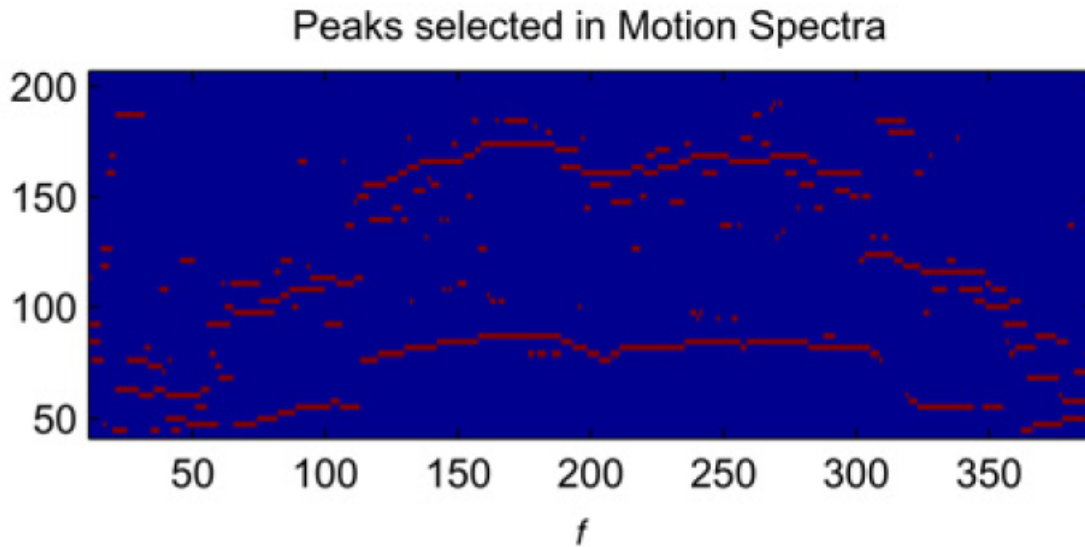
(Ex-1005, Fig. 2d)

60. Lai describes how motion artifacts, such as those caused by periodic movements, can be identified and mitigated by comparing the PPG spectrum with the motion spectrum. Ex-1005, 6-7. For example, the PPG and motion spectra in

respective figures 2e and 2f show the detection of five peaks with the highest energy in their spectrum. These peaks are then ranked based on a scoring mechanism that considers their energy and proximity to motion frequencies. The ranking mechanism uses a scoring system, where peaks consistent with prior heart rate estimates are favored. This ranking ensures that the cardiac frequency is selected from the PPG peaks while suppressing motion-induced artifacts. Ex-1005, 6-7; Figs. 2e-2f.



(Ex-1005, Fig. 2e)



(Ex-1005, Fig. 2f)

61. The steps disclosed in Lai transform a noisy, raw signal into a clean and usable representation of the heart-related physiological parameter—heart rate—free from motion induced distortions. Ex-1005, 7.

VII. THE ‘647 PATENT CLAIMS ARE OBVIOUS IN VIEW OF LAI (EX-1005) UNDER AIA 35 U.S.C. § 103

62. In my opinion, claims 1-75 of the ‘647 Patent are obvious in view of Lai (Ex-1005) under AIA 35 U.S.C. § 103.

63. As discussed below, Lai either discloses the elements of claims 1-75 of the ‘647 Patent or renders them obvious in light of the common knowledge in the art.

A. Independent Claims 1, 35, 69 and 70-75 are obvious in view of Lai

1. Preamble

[1pre], [70pre], [71pre], [72pre] A method for reconstructing a heart-related signal output by a biomedical sensor, the method comprising:	[35pre], [73pre], [74pre], [75pre] An apparatus for reconstructing a heart-related signal output by a biomedical sensor, the apparatus comprising:	[69pre] A non-transitory computer-readable medium having encoded thereon a sequence of instructions which, when loaded and executed by a processor, causes the processor to reconstruct a heart-related signal output by a biomedical sensor, the processor reconstructing the heart-related signal by:
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64. To the extent that each preamble is limiting, Lai (Ex-1005) discloses each preamble. For example, Lai describes devices and methods for heart-related signal reconstruction, including wrist-based devices having PPG sensors and integrated accelerometers. Ex-1005, 6 (“With the recent introduction of PPG-equipped wearable devices, such as smart watches, continuous heart rate monitoring has become feasible”). Lai further describes these devices as incorporating biomedical PPG sensors and accelerometers to process and reconstruct heart-related signals. Ex-1005, Fig. 5b (depicting a biomedical PPG sensor of a “wrist device” having three built-in accelerometers designed to capture both heart-related and motion signals).

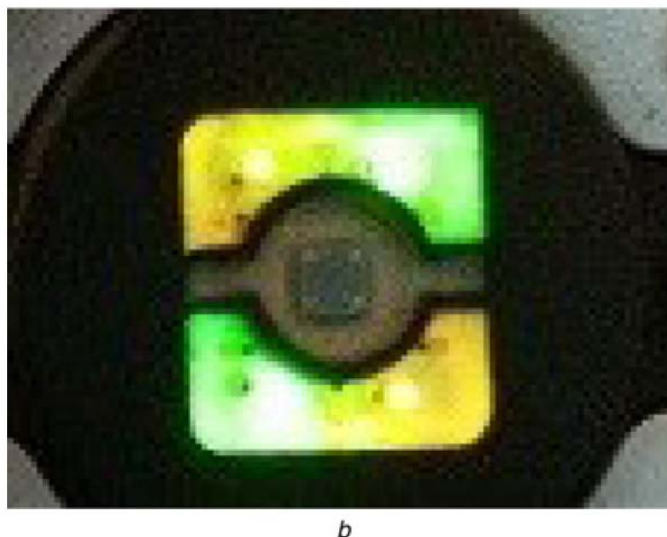


Figure 5 *Wrist devices used*

a Watch type form factor devices used in the experiment, see the main text for specifications

b LED sources and sensor of the devices

(Ex-1005, Fig. 5b)

65. A POSITA would recognize that such apparatuses facilitate the reconstruction of heart-related signals by integrating the biomedical sensor outputs (PPG and motion data) into a signal processing pipeline for noise removal and physiological signal reconstruction.

66. The reconstruction functionality of this apparatus is further detailed in Lai's description of its processing methodology. Lai describes pre-processing the raw biomedical sensor data (PPG and motion signals) through bandpass filtering and applying spectral analysis techniques, such as STFT, to isolate cardiac components and produce a robust reconstructed signal suitable for physiological monitoring. Ex-1005, 6 ("The algorithm takes streaming PPG and accelerometer

data as inputs, applies preprocessing and spectral analysis, and outputs robust physiological estimates based on reconstructed signals”); Figs. 1 and 2a-i.

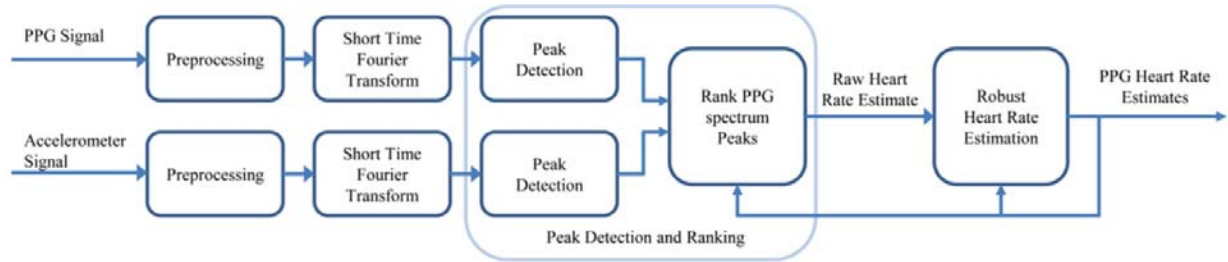
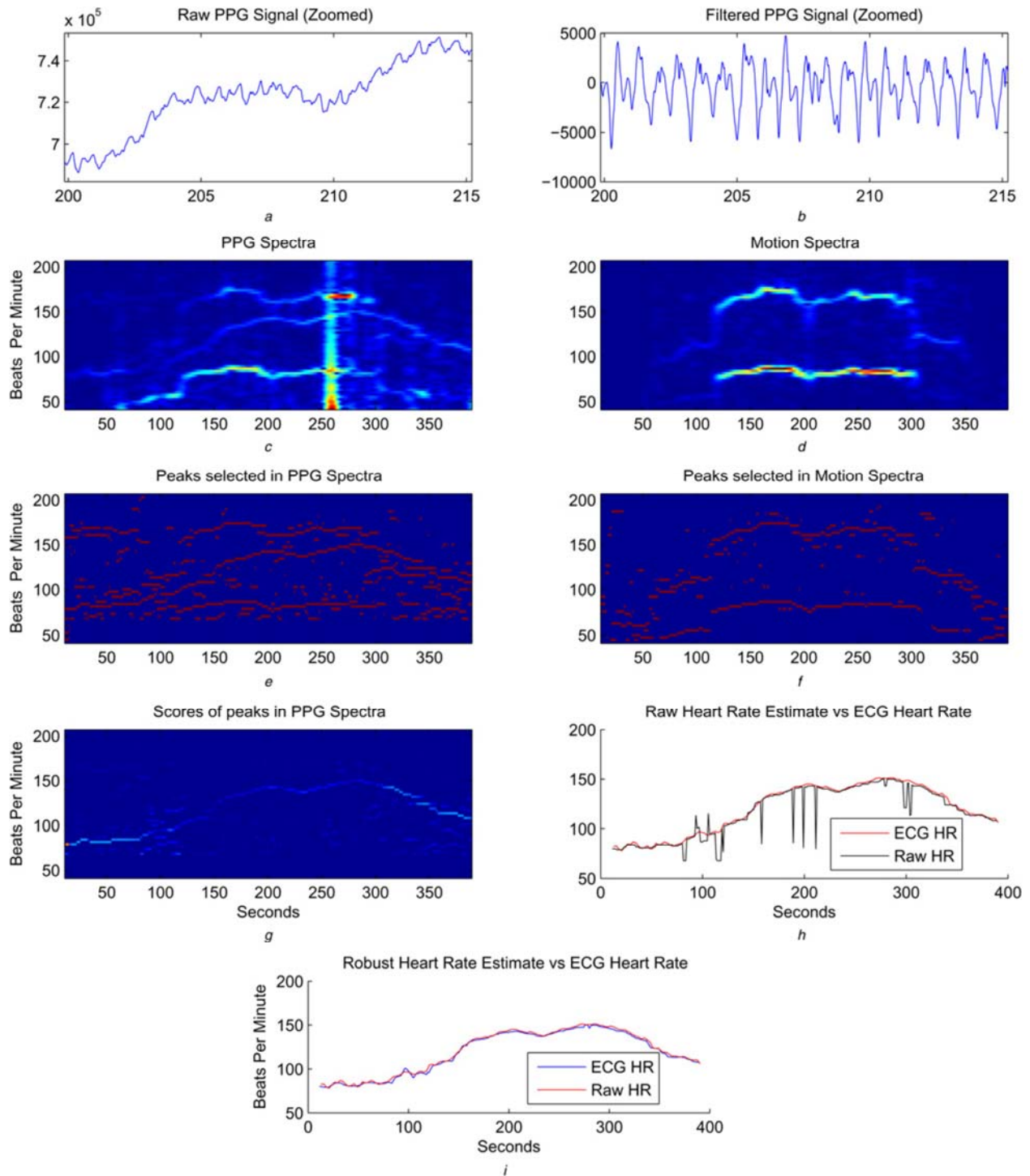


Figure 1 *System diagram of proposed method*

The proposed method contains four components: preprocessing, signal representation using short-time Fourier transform, detection of PPG and motion peak and rank PPG peaks as potential cardiac signal which outputs a raw heart rate estimate, and the Robust heart rate estimation

(Ex-1005, Fig. 1)



(Ex-1005, Fig. 2a-i)

67. Thus, Lai discloses these preambles.

68. Additionally, the ‘647 Patent confirms that such apparatuses, which include biomedical sensors and reconstruction units, were well known in the field. Ex-1001, 6:54-60 (acknowledging that a “pulse oximeter signal contains not only the blood oxygen saturation and heart rate (HR) data, but also other vital physiological information”) (internal citations omitted).

69. The ‘647 Patent also describes integrated wearable devices capable of reconstructing heart-related signals for HR and rhythm monitoring. Ex-1001, 7:7-10 (“Utilizing a pulse oximeter as a multi-purpose vital sign monitor has clinical appeal, since it is familiar to the clinician and comfortable for the patient”) (internal citations omitted).

2. “reconstructing” / “reconstruction unit”

[1A], [69A], [70A], [71A], [72A] reconstructing a representation of the heart-related signal to produce a reconstructed representation of the heart-related signal	[35A], [73A], [74A], [75A] a reconstruction unit configured to reconstruct a representation of the heart-related signal to produce a reconstructed representation of the heart-related signal
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70. Lai describes a process for reconstructing a representation of a PPG signal by combining and processing both raw PPG and accelerometer data to output a robust heart rate estimate. Ex-1005, 7 (“[t]he algorithm takes streaming

PPG and accelerometer data as inputs, as illustrated Fig. 1” and “outputs a raw heart rate estimate, and the Robust heart rate estimation”). By mitigating motion artifacts through preprocessing and spectral analysis, Lai reconstructs a usable representation of the heart-related signal, which is then used for robust physiological monitoring.

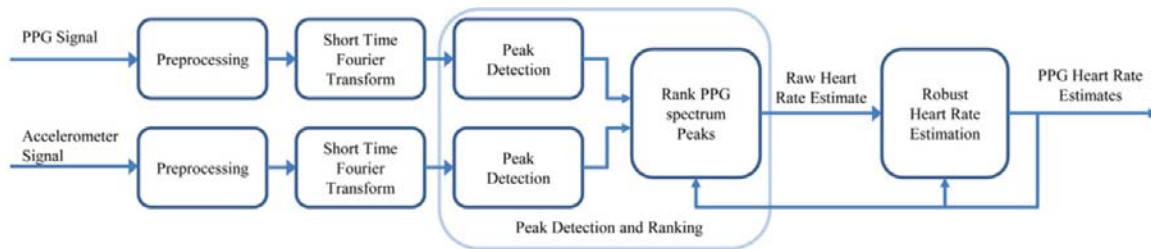
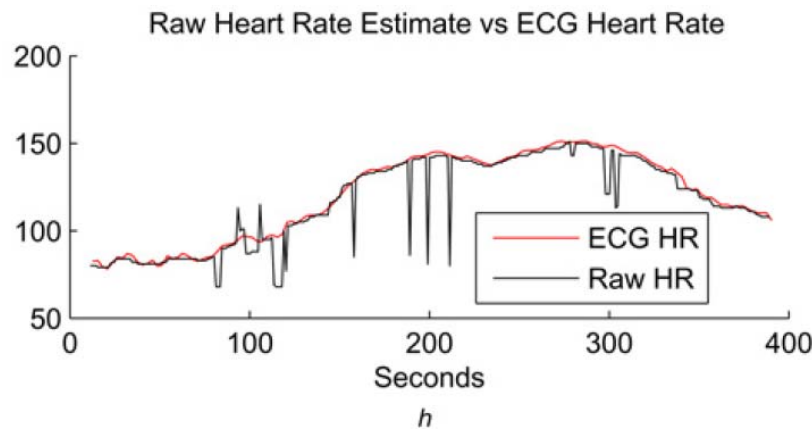


Figure 1 System diagram of proposed method

The proposed method contains four components: preprocessing, signal representation using short-time Fourier transform, detection of PPG and motion peak and rank PPG peaks as potential cardiac signal which outputs a raw heart rate estimate, and the Robust heart rate estimation

(Ex-1005, Fig. 1)



(Ex-1005, Fig. 2h)

71. Thus, Lai discloses these elements.

72. Further, while Lai does not label any particular component as a “reconstruction unit,” a POSITA would recognize that Lai’s algorithm performs the

functionality of such a unit. Specifically, Lai discloses receiving raw input signals from both PPG and accelerometer sensors, applying preprocessing steps such as removing baseline drift and DC components, and performing spectral analysis using STFT to isolate cardiac components from motion artifacts. This iterative combination of preprocessing and spectral analysis reconstructs a representation of the heart-related signal suitable for further analysis.

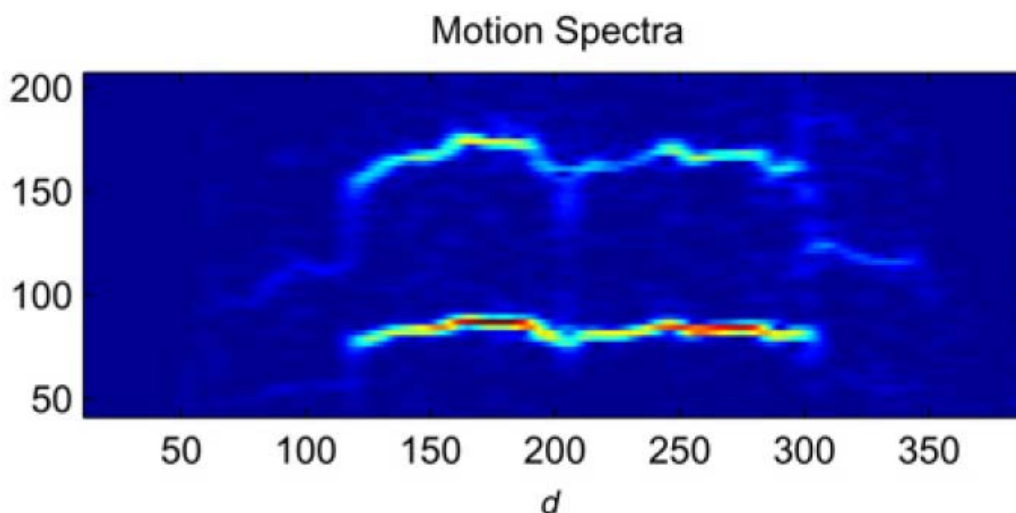
73. A POSITA would understand that these reconstruction steps directly corresponds to the claimed functionality of “reconstruction unit.” The reconstruction process not only filters and analyzes signals but also produces a refined representation that serves as the basis for calculating heart rate and other physiological parameters. This functionality could be implemented through software, hardware, or a combination of the two, as is typical for such systems. As a result, Lai’s algorithm inherently performs the functions needed to process raw signals and generate a reconstructed representation of the heart-related signal, which serves as a basis for calculating a heart rate. Therefore, Lai also renders these elements obvious in light of the common knowledge in the art.

3. “based on time-varying spectral analysis”

[1B], [35B], [69B], [70B], [71B], [72B], [73B], [74B], [75B] the reconstructing based on (i) a time-varying spectral analysis of the heart-related signal and a motion signal

74. Lai discloses that reconstruction of the heart-related signal and motion signal is based on time-varying spectral analysis through the use of STFT (Short-Time Fourier Transform). Ex-1005, 6-7 (“[s]ignal representation using short-time Fourier transform: The filtered signal is then processed segment by segment. For each segment, the Fourier spectrum is computed”).

75. Lai applies STFT to both the heart-related signal (PPG) and the motion signal (accelerometer) to generate time-varying spectra for these signals. Figures 2c and 2d illustrate how Lai compares the motion spectrum with the PPG spectrum to identify motion artifacts and isolate cardiac components, thereby mitigating motion-induced distortions. Ex-1005, 6-7, Fig. 2c and 2d. This reconstruction process is explicitly based on the time-varying spectral analysis of both signals. *Id.*



(Ex-1005, Fig. 2d)

76. Thus, Lai discloses this element.

77. A POSITA further recognize that STFT is a widely known and established method for performing time-varying spectral analysis in signal processing, which captures dynamic changes in frequency content over time.

78. While Lai primarily describes STFT, the ‘647 Patent itself also acknowledges that various time-frequency techniques, including VFCDM, smoothed pseudo Wigner-Ville, and wavelet-based methods, were standard approaches in the field for mitigating motion artifacts and reconstructing PPG signals. Ex-1001, 14:62-15:4 (“a time-frequency technique, such as a variable frequency complex demodulation (VFCDM), disclosed in U.S. Pat. No. 8,388,543 B2, incorporated herein in its entirety by reference, may be used for computing the first TFS (308), that is, a TFS of the accelerometer signal. However, it should be

understood that any suitable time-frequency technique may be used, such as a smoothed pseudo wigner-ville method, or a wavelet-based method”).

4. “motion sensor”

[1C], [35C], [69C], [70C], [71C], [72C], [73C], [74C], [75C] the motion signal output by a motion sensor and representative of motion artifacts in the heart-related signal

79. Lai describes the use of an accelerometer as a motion sensor to detect motion signals that contribute to motion artifacts in PPG-based heart-related signals. Lai describes an algorithm that processes streaming PPG and accelerometer data, enabling the detection and mitigation of motion artifacts caused by user movements. Ex-1005, 6; Figs. 1 and 2 (“[t]he algorithm takes streaming PPG and accelerometer data as inputs, as illustrated Fig. 1, and an example of step-by-step results is shown in Fig. 2”).

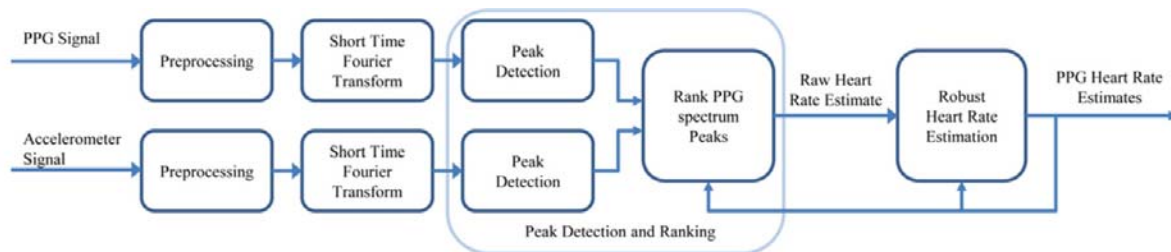
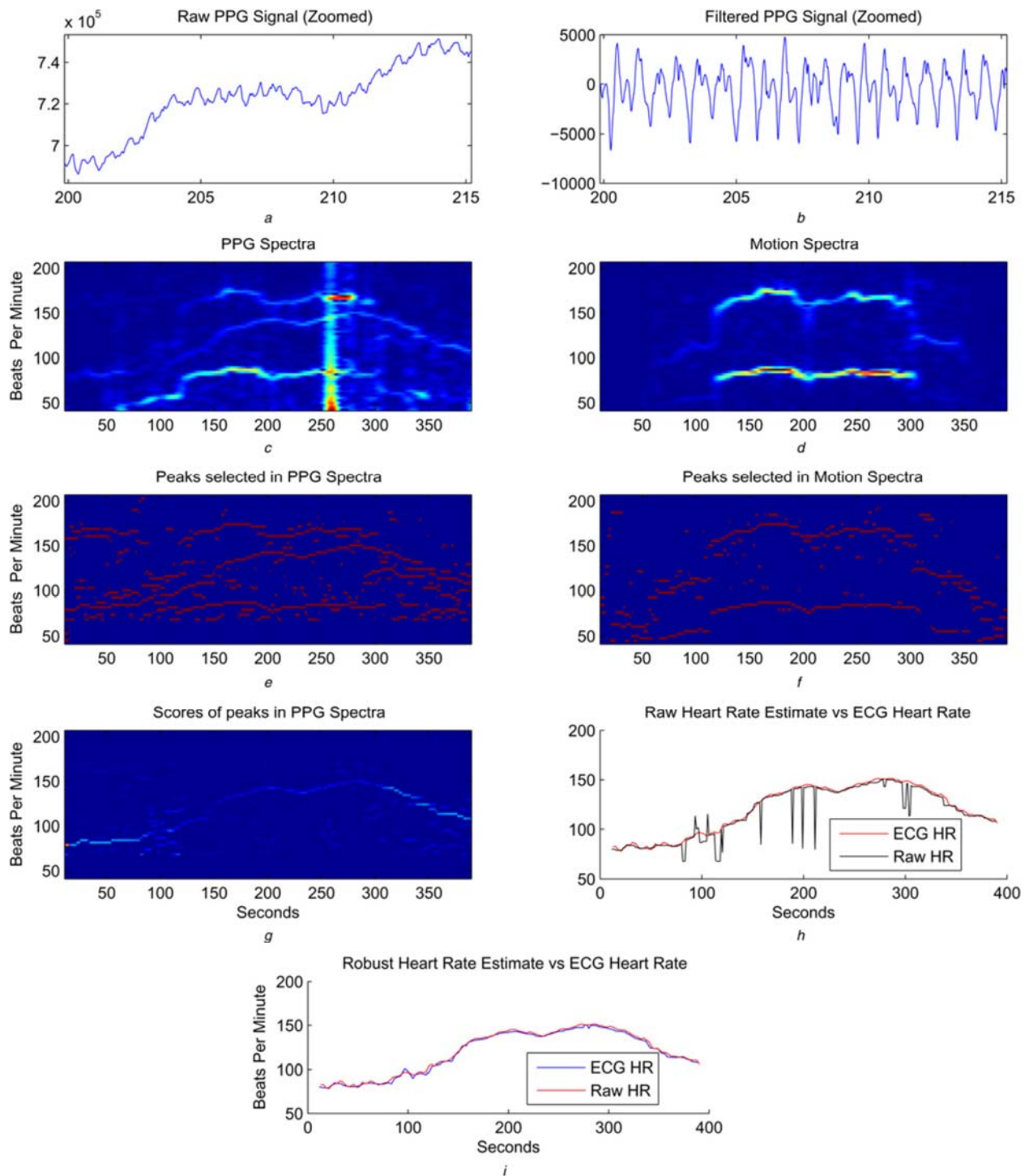


Figure 1 *System diagram of proposed method*

The proposed method contains four components: preprocessing, signal representation using short-time Fourier transform, detection of PPG and motion peak and rank PPG peaks as potential cardiac signal which outputs a raw heart rate estimate, and the Robust heart rate estimation

(Ex-1005, Fig. 1)



(Ex-1005, Fig. 2)

80. Lai's hardware configuration includes "[t]hree accelerometers," which are used to generate motion signals that characterize motion-induced distortions in PPG signals for removal. Ex-1005, 10.

81. The '647 Patent acknowledges that accelerometer-based motion signals are widely used to detect and mitigate motion artifacts in PPG signals. It states: "Acceleration data are also shown to be helpful to remove MA [motion artifacts]" and describes prior art techniques, which use accelerometer data to filter motion artifacts from PPG signals. Ex-1001, 9:10-22.

82. A POSITA would readily recognize that accelerometers function as motion sensors that output motion signals representative of motion artifacts in the heart-related signal. This understanding is consistent with Lai's disclosures of using accelerometer data to process and remove motion artifacts.

83. Thus, Lai discloses this element.

5. “artifacts produced by movement”

[1D], [35D], [69D], [70D], [71D], [72D], [73D], [74D], [75D] the motion artifacts being signal artifacts produced by movement of the biomedical sensor relative to a sensing location

84. Lai discusses the susceptibility of PPG signals to motion artifacts caused by the movement of a wrist-worn biomedical sensor relative to the sensing location on the user’s skin, explaining that such movement introduces significant distortions in heart rate estimation due to the high mobility of the user’s arm. Ex-1005, 6 (“PPG is susceptible to motion artefacts, which have to be mitigated for accurate heart rate estimation. Motion artefacts are particularly apparent for wrist devices, for example, a smart watch, because of the high mobility of the arms”)

85. This clearly identifies that the motion artifacts arise from the relative motion of the biomedical sensor (e.g., a smart watch) against the skin’s surface, leading to interference in the recorded PPG signal. Additionally, Lai connects these motion artifacts to specific user activities, such as periodic arm movements, which can introduce noise in the PPG signal. Ex-1005, 6-7. (“Motion artefacts corresponding to periodic footsteps and arm movements with harmonics can be recognised by comparing the resulting PPG spectrum and the motion spectrum”). A POSITA would know that Lai’s reference to motion artifacts caused by the mobility of wrist-worn devices describes motion artifacts as signal distortions

resulting from the movement of the sensor relative to its sensing location, i.e., the point of contact between the sensor and the user's skin. Such relative motion is a well-recognized source of noise in PPG signals, requiring methods to mitigate its effects for accurate heart rate estimation.

86. Thus, Lai discloses this element.

6. “classification”

[1E], [35E], [69E], [70E], [71E], [72E], [73E], [74E], [75E] (ii) a classification of the movement
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87. Lai discloses processes for detecting, analyzing, and ranking components in both the PPG signal and the motion signal, which can reasonably be interpreted “classification of the movement.” While Lai does not explicitly state that the classification concerns the movement of the biomedical sensor relative to a sensing location, such motion is inherently described in Lai's discussion of motion artifacts caused by the movement of a wrist-worn device relative to the user's skin. Lai states, “PPG is susceptible to motion artefacts, which have to be mitigated for accurate heart rate estimation. Motion artefacts are particularly apparent for wrist devices, for example, a smart watch, because of the high mobility of the arms.” Ex-1005, 6. These motion artifacts arise from the relative motion of the sensor against the sensing location (i.e., the point of contact between the sensor and the user's

skin), and Lai's algorithm is designed to detect and mitigate such artifacts, thereby implicitly addressing the relative motion of the biomedical sensor.

88. Beyond addressing relative motion, Lai describes a broader process for detecting and classifying the movement that causes motion artifacts. Specifically, Lai discloses “[d]etection and ranking of potential cardiac and motion components,” which involves distinguishing cardiac signals from motion artifacts by analyzing spectral characteristics of both the PPG signal and accelerometer data. Ex-1005, 6-7. Motion artifacts are identified by comparing the motion spectrum (derived from the accelerometer) with the PPG spectrum. Overlapping frequencies, particularly those exhibiting periodic harmonic patterns, are treated as motion-induced artifacts. For example, Lai states, “Motion artefacts corresponding to periodic footsteps and arm movements with harmonics can be recognised by comparing the resulting PPG spectrum and the motion spectrum.” Ex-1005, 6-7. This artifact detection step establishes whether motion is interfering with the heart-related signal and forms the first part of the classification process.

89. In addition to detecting artifacts, Lai evaluates the spectral characteristics of the motion signal to infer the nature of the movement causing the artifacts. Periodic motion, such as rhythmic arm swings or footsteps, is recognized by the presence of harmonics or recurring patterns in the motion spectrum. Ex-1005, 6-7; Fig. 2d and 2f. While Lai does not explicitly describe pseudo-periodic

or random motion, a POSITA would understand that the absence of harmonics (broadband noise) corresponds to random motion, while non-perfect harmonics exhibiting variability in their patterns indicate pseudo-periodic motion.

90. Thus, a POSITA would understand Lai’s detection and ranking process as a classification process that fulfills two key objectives: (1) determining whether motion artifacts are present (artifact detection) and (2) evaluating the characteristics of the movement (periodic, pseudo-periodic, or random). These steps allow the algorithm to adapt its artifact mitigation strategies based on the nature of the movement, such as focusing on suppressing harmonics for periodic motion or applying fallback methods (discussed below in Section B.9) for random motion.

91. Thus, Lai discloses this element.

7. “pre-processing”

[1F], [35F], [69F] wherein the time-varying spectral analysis includes pre-processing the heart-related signal to produce a pre-processed heart-related signal, pre-processing the motion signal to produce a preprocessed motion signal
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92. Lai’s preprocessing and signal representation steps, including STFT, reconstruct the heart-related signal by isolating cardiac signals from motion artifacts. Ex-1005, 7. (“The proposed method contains four components:

preprocessing, signal representation using short-time Fourier transform, detection of PPG and motion peak and rank PPG peaks as potential cardiac signal which outputs a raw heart rate estimate, and the Robust heart rate estimation”).

93. Pre-processing steps in Lai’s algorithm include filtering both raw PPG signals (heart-related signals) and accelerometer signals (motion signals) to produce preprocessed heart-related and motion signals prior to spectral analysis by STFT. Ex-1005, 6; Fig. 1, 2a-2d (“Both can be removed continuously by applying an infinite impulse response bandpass filter. Examples of such filters are Butterworth filters with an order of <10 with a passband from 0.5 to 30 Hz”). As stated in ¶44 above, pre-processing steps, including bandpass filtering of PPG and accelerometer signals, are routine and well-known in the field. A POSITA would recognize that Lai’s algorithm follows these well-established techniques to produce preprocessed heart-related and motion signals for spectral analysis.

94. Thus, Lai discloses this element.

8. “computing TFS”

[1G], [35G], [69G] computing a first time-frequency spectrum (TFS) of the heart-related signal using the preprocessed heart-related signal and a second TFS of the motion signal using the pre-processed motion signal	[70F], [71F], [72F], [73F], [74F], [75F] wherein the time-varying spectral analysis includes computing a first time-frequency spectrum (TFS) of the heart-related signal and computing a second TFS of the motion signal
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95. Lai discloses that the application of STFT to preprocessed PPG (heart-related) and accelerometer (motion) signals, shown in Figure 1, produces time-dependent frequency representations of the signals yield a first TFS of the heart-related signal (PPG) and a second TFS of the motion signal (accelerometer). The first TFS isolates cardiac frequency components, while the second TFS characterizes motion-induced frequency components. Ex-1005 6-7; Fig. 1, 2c, 2d (“Signal representation using short-time Fourier transform: The filtered signal is then processed segment by segment....”). A POSITA would recognize these time-frequency representations as TFS because STFT inherently computes time-varying frequency content.

96. As detailed in Section A.7 above, Lai’s pre-processing steps filter raw PPG and accelerometer signals to produce refined inputs for spectral analysis. By applying STFT to these preprocessed signals, Lai computes the time-varying frequency content of each signal. A POSITA would recognize that the resulting time-frequency representations constitute the claimed TFSs, as these are standard outputs of time-varying spectral analysis techniques like STFT.

97. The ‘647 Patent acknowledges that time-varying spectral analysis inherently involves computing TFSs for heart-related and motion signals. Ex-1001, 39:54-62 (“[t]he first TFS computed may be a first time-varying power spectral

density (PSD) and the second TFS computed may be a second time-varying PSD. A time-frequency technique, such as a variable frequency complex demodulation (VFCDM), disclosed in U.S. Pat. No. 8,388,543 B2, incorporated herein in its entirety by reference, may be used for computing the first TFS (308), that is, a TFS of the accelerometer signal. However, it should be understood that any suitable time-frequency technique may be used, such as a smoothed pseudo Wigner-Ville method, or a wavelet-based method”).

98. This confirms that standard time-frequency techniques, such as VFCDM, smoothed pseudo Wigner-Ville, and wavelet analysis, are routinely applied to compute TFSs for both PPG (heart-related signals) and accelerometer (motion) signals. A POSITA would recognize that the resulting time-frequency representations constitute the claimed TFSs, as these are standard outputs of time-varying spectral analysis techniques like STFT. See Ex-1004 (0938), 2018-04-18 Office Action, pg. 8. (“Chon et al. employ computation of time-frequency spectrum analysis of the signals” and “demonstrates that this is a suitable technique for removing artifacts from a heart related signal. Modification is considered to comprise application of a known technique to a known process to yield a predictable result”). Moreover, the reference to both heart-related and motion signals in the context of these techniques underscores that TFS computation is an expected outcome of applying time-varying spectral analysis to these types of data.

99. Thus, Lai discloses these elements.

9. “outputting” / “output unit”

[1H], [69H], [70F], [71G], [72F] outputting the reconstructed representation of the heart-related signal.	[35H], [73G], [74G], [75H] an output unit configured to output the reconstructed representation of the heart-related signal
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100. Lai outputs “raw heart rate estimate” and “PPG heart rate estimates,” derived from processing PPG data, which constitute representations of reconstructed heart-related signals obtained after Lai’s algorithm processes the PPG and motion signals. For example, Figure 1 depicts these outputs as the result of an algorithm that takes streaming PPG and accelerometer signals as inputs. Ex-1005, 7-8; Fig. 1 (“The proposed method ... outputs a raw heart rate estimate” and “Frequency, in beats per minute, of peak with highest score is selected as raw heart rate estimate, which contains a few errors”).

101. Lai further discloses the ability to transmit data to external devices, such as mobile devices or laptops. These external devices function as output units by displaying, storing, or processing the reconstructed heart-related signals. Ex-1005, 10 (“the data collected by the wrist device can be transmitted to a recording mobile device or a laptop”). A POSITA would recognize such common established hardware components in physical monitoring systems as functional equivalents to

an “output unit” capable of outputting results like heart rate estimates after motion artifact removal by Lai’s algorithm.

102. Thus, Lai discloses these elements.

B. Dependent Claims 2-34 and 36-68 are Obvious in View of Lai

1. “artifacts are suppressed”

[2] The method of claim 1, wherein the motion artifacts are suppressed in the reconstructed representation of the heart-related signal.	[36] The apparatus of claim 35, wherein the motion artifacts are suppressed in the reconstructed representation of the heart-related signal.
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103. Lai discusses suppression of motion artifacts during signal reconstruction through both preprocessing steps and time-varying spectral analysis. As detailed in Section A.2 above, Lai’s algorithm filters raw PPG signals to remove baseline drift and DC components and uses STFT to separate cardiac frequencies from motion-induced components. Ex-1005, Fig. 2a-2i (illustrating the reconstruction process).

104. Figures 2c and 2d demonstrate the identification of motion artifacts in the spectral domain by comparing PPG and accelerometer data, and suppressing these artifacts through frequency-domain separation. This process ensures that the

cardiac frequency components remain dominant in the final representation of the heart-related signal. Ex-1005, 6.

105. A POSITA would understand the final output of Lai’s algorithm, described as a “robust heart rate estimate,” as being derived from raw PPG signals that have been processed to suppress motion artifacts and isolate physiologically relevant cardiac components reflecting the claimed reconstructed representation of the heart-related signal.

106. Thus, Lai discloses these elements.

2. “average of peak-to-peak intervals”

[3] The method of claim 1, wherein: in an event the classification indicates that the movement does not rise to a level causing the motion artifacts, the reconstructed representation is based on an average value of peak-to-peak intervals in the pre-processed heart-related signal.	[37] The apparatus of claim 35, wherein: in an event the classification indicates that the movement does not rise to a level causing the motion artifacts, the reconstructed representation is based on an average value of peak-to-peak intervals in the pre-processed heart-related signal.
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107. As explained in Section A.6 above, Lai’s algorithm involves classifying the movement by detecting motion artifacts and assessing the nature of the motion. For movements that do not rise to a level causing motion artifacts, Lai describes scenarios where the PPG spectra show no “apparent motion artefacts”

Ex-1005, 6. In such instances, a POSITA would recognize that the periodicity of the cardiac waveform, where each peak in the PPG signal corresponds to a heartbeat, is intact. This periodicity enables the use of peak-to-peak interval averaging as a computationally efficient and well-known time-domain method for reconstructing the heart-related signal and calculating heart rate.

108. The ‘647 Patent further acknowledges that averaging techniques, including peak-to-peak interval averaging, are widely understood and applied in the field as fallback strategies for signal reconstruction. Ex-1001, 26:50-51 (“simply us[ing] a moving average of several past HR beats or some other variant”). This acknowledgment demonstrates that averaging techniques, particularly for scenarios where the signal remains undistorted by motion artifacts, were well-established and routinely implemented for accurate signal reconstruction.

109. When Lai’s classification process is viewed in light of the foregoing common knowledge in the art, these elements are rendered obvious.

110. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

3. “filtering”

[4], [38] wherein the pre-processing includes filtering the heart-related signal to produce a filtered heart-related signal, the filtered heart-related signal being the preprocessed heart-related signal	[17] [51] wherein the pre-processing includes filtering the heart-related signal and the motion signal to produce a filtered heart-related signal and a filtered motion signal, respectively, the filtered heart-related signal being the pre-processed heart-related signal and the filtered motion signal being the pre-processed motion signal
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111. As detailed in Section A.7, Lai’s pre-processing steps include filtering both the heart-related signal (PPG) and the motion signal (accelerometer) to produce respective filtered signals. Ex-1005, 6. Lai describes the use of an infinite impulse response bandpass filter, such as a Butterworth filter with an order of <10 and a passband from 0.5 to 30 Hz, to continuously remove baseline drift, DC components, and noise from the raw signals. These filtering steps directly correspond to the claimed filtered heart-related signal being the pre-processed heart-related signal and the filtered motion signal being the pre-processed motion signal.

112. As stated in ¶44, filtering of PPG and accelerometer signals is routine and well-known in the field. A POSITA would recognize that Lai’s algorithm

aligns with these well-established techniques and discloses that filtering the heart-related and motion signals during pre-processing produces filtered signals that are then used for subsequent spectral analysis.

113. Thus, Lai discloses these elements.

4. “down-sampling”

[5], [18], [39], [52] wherein the pre-processing further includes down-sampling the filtered heart-related signal, the down-sampling being at a sampling rate less than an original sampling rate

114. Lai describes down-sampling as part of a preprocessing pipeline that, as detailed in Section A.7, applies a bandpass filter to the raw PPG signal to remove baseline drift and noise. Following this, the sampling rate of the filtered signal is reduced by factors of 5 and 10 to optimize computational efficiency. Ex-1005, 6. (highlighting that this process achieves mean absolute error rates of 2.76% and 4.72%, demonstrating its effectiveness in preserving signal accuracy.)

115. A POSITA would recognize down-sampling the heart-related signal at a rate less than the original sampling rate is a widely-practiced and routine step in digital signal processing that is commonly used for efficiency and signal integrity purposes (e.g., anti-aliasing). See Ex-1004 (0935-0936), 2018-04-18 Office Action, at 5-6 (“to downsample the sampling rate is considered obvious”).

116. Thus, Lai discloses this element.

5. “3-dimensional spectra”

[6], [40] wherein the first TFS computed and the second TFS computed are 3-dimensional spectra, the first TFS computed and the second TFS computed each including a respective time-varying amplitude or power distribution with respect to time and frequency

117. As detailed in Section A.8, Lai’s TFS analysis involves using STFT to compute first and second time-frequency representations of respective filtered PPG (heart-related signal) and accelerometer (motion) signals. Ex-1005, 6. Figure 2c in Lai shows the TFS of the PPG signal, while Figure 2d depicts the TFS of the motion signal. Both spectra are plotted with respect to time and frequency, with varying intensities (visualized as colors) that represent amplitude (or power) at specific time-frequency coordinates. *Id.*; Fig. 2c, 2d.

118. A POSITA would recognize these plots as 3-dimensional spectra, where the three axes (time, frequency, and amplitude or power) are simultaneously represented. See Ex-1004 (0938), 2018-04-18 Office Action, at 8 (“[t]hree-dimensional spectra is also considered to be within routine skill in the art”).

119. Thus, Lai discloses this element.

6. “TFS being PSD”

[7] The method of claim 1, wherein the first TFS computed is a first time-varying power spectral density (PSD) and the second TFS computed is a second time-varying PSD.	[41] The apparatus of claim 35, wherein the first TFS computed is a first time-varying power spectral density (PSD) and the second TFS computed is a second time-varying PSD.
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120. In Lai, PPG and motion spectra, plotted with respect to time and frequency, use color intensity to represent amplitude or energy at specific time-frequency coordinates. Ex-1005, Fig. 2c, 2d. A POSITA would recognize that while Lai refers to these visualizations as “energy” distributions, energy and power are directly related in signal processing. Accordingly, a POSITA would recognize them as 3-dimensional spectra where the axes represent time, frequency, and power and, thus, displays of time-varying power distributions that directly correspond to the claimed first and second TFSs as time-varying PSDs.

121. Further, the ‘647 Patent itself confirms that TFSs are computed using well-known time-frequency techniques, such as VFCDM, smoothed pseudo Wigner-Ville, or wavelet-based methods. Ex-1001, 15:1-4. The same techniques were also standard in producing PSDs and known in the art. *Id.*, 19:57-64 (“computing a window-segmented power spectral density of both PPG and

accelerometer signals in real-time”); *see also* Ex-1006, 2 (“A natural approach is to estimate HR is using power spectrum estimation”). This further reinforces that time-varying power distributions, such as those demonstrated in Lai’s Figures 2c and 2d, are expected outputs of these techniques.

122. Thus, Lai discloses these elements.

7. “pseudo-periodic, periodic, random movement”

[8A], [70H] wherein the reconstructed representation is a current reconstructed representation and wherein, based on the classification indicating that the movement does rise to a level causing the motion artifacts and is a pseudo-periodic movement or a periodic movement	[21], [55] wherein, in an event the result indicates that the movement does rise to the level causing the motion artifacts, classifying the classification of the movement further includes determining whether the movement is either a pseudo-periodic movement or a periodic movement, versus a random movement.	[42A], [73H] wherein the reconstructed representation is a current reconstructed representation and wherein, based on the classification indicating that the movement does rise to a level causing the motion artifacts and is a pseudo-periodic movement or a periodic movement
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123. Lai explains that “motion artefacts corresponding to periodic footsteps and arm movements with harmonics can be recognised by comparing the resulting

PPG spectrum and the motion spectrum” and describes a process for separating cardiac components from motion artifacts based on signal characteristics derived from the spectral analysis of PPG and accelerometer data. Ex-1005, 6-7; Fig. 2c, 2d.

124. As discussed in A.6, Lai’s detection and ranking process serves as a classification of the movement. A POSITA would recognize that the structured harmonic patterns in the accelerometer spectrum, such as those caused by rhythmic steps or swings, correspond to periodic motion. Similarly, motion with approximately structured but irregular harmonic patterns would be understood as pseudo-periodic motion, while the absence of harmonics or structured patterns would suggest random motion, which the ‘647 Patent defines as “non-periodic movements.” Ex-1001, 17:24-26. Thus, the classification distinguishes periodic or pseudo-periodic movements that cause significant motion artifacts from random movements, which are less likely to interfere with the heart-related signal.

125. Lai further describes reconstructing the heart-related signal based on this classification. For movements classified as periodic or pseudo-periodic, the algorithm mitigates motion artifacts by isolating cardiac components in the PPG spectrum while suppressing motion-correlated peaks identified in the accelerometer spectrum. Ex-1005, 6-7; Fig. 1, 2i. This reconstruction process dynamically updates the current representation of the heart-related signal,

producing what Lai refers to as a “robust heart rate estimate,” free from motion-induced distortions.

126. A POSITA would understand that Lai’s algorithm applies this classification of motion patterns during the reconstruction process by analyzing TFS derived from the PPG and accelerometer signals. A comparison of spectral characteristics allows the system to identify and categorize motion-induced components, suppressing those corresponding to periodic or pseudo-periodic movements to produce a “current reconstructed representation” of the heart-related signal, consistent with the claim language.

127. Thus, Lai discloses these elements.

8. “peak’s corresponding frequency in TFS”

[8B], [70I] the reconstructing includes: determining whether at least one spectral peak is present having a corresponding frequency within a given frequency range at a point in time in the first TFS computed, the current reconstructed representation being reconstructed for the point in time	[42B], [73I] to reconstruct the representation includes: determining whether at least one spectral peak is present having a corresponding frequency within a given frequency range at a point in time in the first TFS computed, the current reconstructed representation being reconstructed for the point in time
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128. Figure 2c in Lai illustrates the TFS of the PPG signal, showing spectral peaks at specific points in time and frequency that correspond to a heart rate frequency range chosen based on human heart rates (e.g., 0.5-3 Hz). This TFS directly corresponds to the claimed “first TFS computed” and the claim’s requirement to determine whether a “spectral peak is present.” A POSITA would understand that Lai’s analysis inherently determines whether at least one spectral peak is present within this frequency range for each time segment of the TFS.

129. While Lai’s use of spectral peaks is a segment-wise analysis, a POSITA would understand that each identified peak corresponds to a specific time point within the TFS. For instance, when a spectral peak is identified as corresponding to a heart rate frequency, Lai’s algorithm reconstructs the signal for that point in time, yielding its robust heart rate estimate. Thus, Lai discloses the claimed elements of determining spectral peaks in the first TFS computed and reconstructing a representation for the corresponding point in time.

130. Thus, Lai discloses these elements.

9. “prior reconstructed representation”

[8C], [70J] wherein, based on a determination that the at least one spectral peak is not present, the current reconstructed representation is based	[42C] [73J] wherein, based on a determination that the at least one spectral peak is not present, the reconstructed current representation is
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on a prior reconstructed representation, the prior reconstructed representation associated with a previous point in time in the first TFS computed	based on a prior reconstructed representation, the prior reconstructed representation associated with a previous point in time in the first TFS computed
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131. As the ‘647 Patent states, “where HR is not detectable in the window ... embodiments disclosed herein may take a previous window’s HR value as the current HR (or simply use a moving average of several past HR beats or some other variant).” Ex-1001, 26:44-51. This acknowledgment of interchangeable fallback methods, including referencing prior HR values or applying moving averages to ensure signal continuity and accuracy, especially in cases where no valid spectral peaks are detected for a current time window, reflects a widely accepted practice in the field of physiological signal reconstruction; *see also* ¶45 (confirming that fallback mechanisms, such as basing the current reconstructed representation on a prior reconstructed representation, are routine and well-known in the field).

132. A POSITA would recognize that Lai’s reconstruction process inherently supports such fallback mechanisms. For example, if no spectral peaks are identified in the PPG spectrum at a given time segment, the reconstruction process logically reverts to the most recent valid heart rate estimate or a derived

prior representation to maintain signal continuity. This reliance on prior reconstructed representations is consistent with standard practices in physiological monitoring systems, where interpolation, extrapolation, or averaging techniques are routinely employed to handle gaps in valid data due to transient noise or lack of detectable cardiac components.

133. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

10. “0.5-3 Hz”

[9], [11], [43], [45] wherein the given frequency range is 0.5 Hz to 3 Hz.
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134. As detailed in Section A.8, Lai discloses detecting spectral peaks within a known physiological heart rate frequency range, focusing on “the frequency range within which human heart rate falls.” Ex-1005, 6. A POSITA would interpret this range to correspond to the cardiac frequency range of 0.5-3 Hz, as it encompasses the physiological limits of heart rates, from bradycardia (slow heart rates, ~30 bpm or 0.5 Hz) to tachycardia during intense exercise (fast heart rates, ~180 bpm or 3Hz). This interpretation is further supported by Lai’s use of a bandpass filter with a passband from 0.5 Hz to 30 Hz, which includes the narrower, physiologically relevant cardiac frequency range. Ex-1005, 6.

135. Further, the ‘647 Patent acknowledges that “defined HR range (30-180 bpm)” of “0.5 Hz to 3 Hz ... is typically the HR frequency range accounting for both normal and elevated heart rates.” Ex-1001, 25:61-62; 36:25-28.

136. The ‘647 Patent explicitly states that this frequency range “takes into account both at rest and high HR due to either tachycardia or exercise scenarios” and confirms that “for HR estimation, the strategy is to eliminate frequencies that are outside of this HR frequency range as they are most likely due to motion artifacts or harmonics of the FIR [sic HR] frequency.” Ex-1001, 36:25-33. These admissions reinforce that a POSITA would recognize the 0.5-3 Hz range as the physiologically relevant frequency range for HR estimation and would consider narrowing the frequency range to this range as a known and effective approach for eliminating irrelevant noise.

137. A POSITA would understand that narrowing the frequency range to 0.5-3 Hz represents a well-known design choice aimed at optimizing computational efficiency, as this approach filters out irrelevant frequencies, while retaining only those spectral peaks most relevant to heart rate detection and estimation. This also aligns with Lai’s disclosure of isolating cardiac spectral peaks for robust heart rate estimation, which focuses on physiologically relevant HR frequencies. Ex-1005, 6.

138. Thus, Lai renders this element obvious in light of the common knowledge in the art.

11. “retaining, discarding”

[10], [44], [71H], [74H] wherein the reconstructing includes: retaining up to a pre-determined number of candidate spectral peaks located at a first point in time in the first TFS computed, the candidate spectral peaks retained based on having corresponding frequencies within a given frequency range and highest amplitude or power values relative to other spectral peaks located at the first point in time, the other spectral peaks having respective frequencies within the given frequency range; and discarding each of the candidate spectral peaks retained that is associated with a same frequency as a dominant spectral peak located at a second point in time in the second TFS computed, the first point in time and the second point in time having same time values.

139. Lai describes comparing peaks retained in the PPG spectrum (first TFS) with peaks in the motion spectrum (second TFS) to identify and suppress motion artifacts. Ex-1005, 6-7; Fig. 2. For each time point, Lai’s process involves identifying spectral peaks in the PPG spectrum with the highest amplitude or power values relative to other peaks within the cardiac frequency range. A POSITA would understand that these retained peaks are most likely to represent cardiac components. The retention ensures that only the most relevant spectral peaks are preserved for further analysis.

140. The comparison involves identifying dominant motion-induced peaks in the accelerometer spectrum (second TFS), which are defined by their largest amplitude or power values in the motion spectrum. Peaks in the PPG spectrum that coincide in frequency with these dominant motion-induced peaks are discarded as motion artifacts. Ex-1005, 6-7. Figure 2 shows “three motion peaks with highest peak” in the motion spectrum, illustrating how these dominant peaks, caused by periodic movements, are compared to the PPG spectrum to identify and remove motion artifacts. This comparison enables time-matched evaluation, facilitating the removal of motion artifacts by discarding PPG peaks that align with dominant motion-induced peaks at the same time point. *Id.*, Fig. 2f.

141. As stated in ¶46, identifying and removing spectral peaks corresponding to motion artifacts by aligning them with acceleration spectra, is routine and well-known in the field.

142. A POSITA would recognize that this process equally applies to methods for discarding motion-induced peaks to isolate cardiac components and, thus, corresponds to the claim requirement of retaining spectral peaks in the PPG spectrum based on their amplitude or power and, subsequently, discarding peaks that match dominant motion-induced peaks in the motion spectrum. Motion-induced dominant peaks, which have the largest amplitude or power values, are

prioritized for suppression because they represent the most significant contributors to motion artifacts.

143. Thus, Lai renders this element obvious in light of the common knowledge in the art.

12. “prior reconstructed representation”

[12] The method of claim 10, wherein the representation is a current representation, wherein the reconstructed representation is a current reconstructed representation, and wherein, in an event the discarding discards each of the candidate spectral peaks retained, reconstructing the current representation is based on a prior reconstructed representation, the prior reconstructed representation associated with a previous point in time in the first TFS computed, the previous point in time being an earlier point in time with respect to the first point in time.	[46] The apparatus of claim 44, wherein the representation is a current representation, wherein the reconstructed representation is a current reconstructed representation, and wherein, in an event the discarding discards each of the candidate spectral peaks retained, reconstructing the current representation is based on a prior reconstructed representation, the prior reconstructed representation associated with a previous point in time in the first TFS computed, the previous point in time being an earlier point in time with respect to the first point in time.
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144. As previously analyzed, Lai's PPG spectrum corresponds to the claimed "first TFS computed" and Lai discloses both "wherein the reconstructed representation is a current reconstructed representation" and basing a current reconstructed representation on a prior reconstructed representation associated with an earlier time point. *See* Sections A.7-A.9, B.7-B.9.

145. In instances where all candidate spectral peaks in the PPG spectrum are discarded due to noise or motion artifacts, a POSITA would reasonably interpret Lai's reconstruction to fall back on prior reconstructed representations associated with earlier time windows in the first TFS computed (i.e., the PPG spectrum) to ensure signal continuity when generating its robust heart rate estimation. This fallback involves reverting to the most recent prior reconstructed representation (i.e., a signal derived from a previous point in time relative to the current point being processed in the first TFS), as supported by the '647 Patent and well-established practices recognized by a POSITA. *See* Sections B.2 and B.9 above ('647 Patent suggesting "simply us[ing]" available fallback strategies as alternatives).

146. This corresponds to using a prior reconstructed representation associated with an earlier point in time relative to the current time point being processed in the TFS.

147. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

13. “second discarding”

[13] The method of claim 10, wherein the discarding is a first discarding and wherein the representation is a current representation and, wherein, in an event the first discarding results in at least one remaining candidate spectral peak retained, reconstructing the current representation further includes: second discarding, wherein the second discarding discards remaining candidate spectral peaks, of the at least one remaining candidate spectral peak retained, based on whether a corresponding frequency of the at least one remaining candidate spectral peak retained is distanced by at least a frequency difference threshold from a prior reconstructed representation's frequency, the prior reconstructed representation associated with a previous point in time in the first TFS computed, the previous point in time	[47] The apparatus of claim 44, wherein the discarding is a first discarding and wherein the representation is a current representation and, wherein, in an event the first discarding results in at least one remaining candidate spectral peak retained, reconstructing the current representation further includes: second discarding, wherein the second discarding discards remaining candidate spectral peaks, of the at least one remaining candidate spectral peak retained, based on whether a corresponding frequency of the at least one remaining candidate spectral peak retained is distanced by at least a frequency difference threshold from a prior reconstructed representation's frequency, the prior reconstructed representation associated with a previous point in time in the first TFS
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being an earlier point in time with respect to the first point in time.	computed, the previous point in time being an earlier point in time with respect to the first point in time.
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148. A POSITA would recognize that Lai’s “first discarding” corresponds to the discarding detailed in Sections B.11 and B.12 above, where motion-induced artifacts are removed from cardiac-relevant spectral peaks by comparing candidate peaks in the PPG spectrum (first TFS) against dominant peaks in the accelerometer spectrum (second TFS). As discussed, this comparison ensures that motion-correlated peaks, such as those caused by periodic footsteps or arm movements, are identified and discarded by isolating cardiac-relevant components in the PPG spectrum, thus, achieving a refined set of candidate peaks for further analysis. Ex-1005, 6-7. This process directly corresponds to the claim’s description of first discarding.

149. A POSITA would recognize that this comparison step directly corresponds to the claim’s description of first discarding by eliminating peaks associated with motion-induced frequencies and refining the retained set.

150. Regarding the “second discarding” mechanism, Lai further supports a refinement process that ensures temporal consistency across reconstructed representations. A POSITA would understand that abrupt changes in heart rate are physiologically implausible under normal conditions and likely indicate noise or artifacts. Thus, discarding candidate peaks that deviate beyond a defined threshold

from prior reconstructed HR values ensures that outlier peaks caused by noise or artifacts are excluded.

151. The ‘647 Patent acknowledges the use of prior reconstructed representations or averages as fallback methods. Ex-1001, 26:47-51; 61-67; 27:1-3 (even in cases where a HR spectral peak is detectable, but “the difference between its value and that of the previous HR is more than 10 bpm” that HR may be replaced “by the most recent HR value from a previous window segment (or a moving average of several past HR beats or some other variant”).

152. By equating these methods—relying on the most recent HR data or a calculating moving average—the ‘647 Patent confirms that such interchangeable options represent routine and well-known fallback strategies in the field for ensuring robust HR reconstruction.

153. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

14. “discarded by second discarding”

[14A] The method of claim 13, wherein: based on each of the at least one remaining candidate spectral peak retained having been discarded by the second discarding, reconstructing the	[48A] The apparatus of claim 47, wherein: based on each of the at least one remaining candidate spectral peak retained having been discarded by the second discarding, reconstructing the
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current representation is based on the prior reconstructed representation	current representation is based on the prior reconstructed representation
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154. The fallback mechanisms detailed in Sections B.12 and B.13, where the reconstructed representation uses a prior reconstructed representation when no valid spectral peaks remain, directly apply here. A POSITA would understand that a second discarding process, which removes peaks deviating beyond a threshold from prior reconstructed values, can result in all remaining candidate spectral peaks (i.e., each of the at least one remaining candidate spectral peak [sic]) being discarded.

155. Further, as stated in ¶47, discarding processes that remove peaks deviating beyond a threshold from prior reconstructed values are routine and well-known in the field.

156. A POSITA would therefore understand that when no valid peaks remain after the second discarding—similar to after the first discarding—Lai’s reconstruction process can ensure continuity and robustness by referring to prior data, using the same fallback strategies described in Section B.12.

157. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

15. “closest frequency”

[14B], [48B] based on at least one last candidate spectral peak remaining, the at least one last candidate spectral peak remaining not discarded by the second discarding, reconstructing the current representation is based on a selected candidate spectral peak selected from amongst the at least one last candidate spectral peak remaining having a closest corresponding frequency to the prior reconstructed representation’s frequency relative to respective frequencies of each of the at least one last candidate spectral peak remaining.

158. The ‘647 Patent confirms that “an accurate HR may be estimated by selecting the components that match closest to the actual HR frequency,” which demonstrates that estimating and selecting the appropriate candidate peak based on proximity to prior reconstructed values was a well-understood practice in the field. Ex-1001, 36:32-33.

159. Further, as detailed in Sections B.12 to B.14, Lai shows that fallback mechanisms that address situations where no valid spectral peaks remain after the second discarding process were known in the art. These mechanisms rely on prior reconstructed representations to ensure signal continuity and maintain physiologically plausible outputs. Ex-1005, 6-7.

160. As stated in ¶48, selecting the peak closest to a prior reconstructed frequency is routine and well-known in the field. A POSITA would understand that, for any “remaining” candidate peaks—those non-distant peaks that fall within the

threshold frequency range—selecting the peak closest to a prior reconstructed frequency is a logical and routine approach for ensuring signal continuity and robustness of the reconstructed representation.

161. Thus, Lai renders this element obvious in light of the common knowledge in the art.

16. “largest power/amplitude”

[15] The method of claim 10, wherein the dominant spectral peak has a largest power or amplitude value relative to other peaks located at the second point in time in the second TFS.	[49] The apparatus of claim 44, wherein the dominant spectral peak has a largest power or amplitude value relative to other peaks located at the second point in time in the second TFS.
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162. Lai explains that motion-induced components, such as those from periodic footsteps or arm movements, are identifiable in the motion spectrum, where prominent peaks corresponding to these periodic movements are compared against the PPG spectrum for artifact suppression. Ex-1005, 6-7 (“Motion artefacts corresponding to periodic footsteps and arm movements with harmonics can be recognised by comparing the resulting PPG spectrum and the motion spectrum”).

163. While Lai does not explicitly state that these peaks are the largest in amplitude or power, a POSITA would recognize that dominant peaks in the motion spectrum are typically the ones with the largest amplitude or power values in the

spectrum, as they represent the primary periodic motion frequency. For example, Figure 2f illustrates “three motion peaks with highest peak,” showing how dominant motion-induced peaks in the accelerometer spectrum are identified and subsequently compared to peaks in the PPG spectrum for motion artifact suppression. Ex-1005, Fig. 2f.

164. As stated in ¶49, dominant peaks, identifiable by the largest amplitude or power values, are routinely used to align with PPG peaks during artifact suppression.

165. The ‘647 Patent confirms that “the largest frequency peak ... represents the fundamental frequency.” Ex-1001, Table 2. It further confirms the significance of identifying dominant motion-induced peaks for artifact removal, explaining that coherence between the spectral peaks of the PPG and motion signals indicates noise contamination, requiring those peaks to be discarded. *Id.*, 26:44-51; 20:33-36. This corresponds to Lai’s disclosure of comparing dominant peaks in the motion spectrum to PPG peaks for effective artifact removal.

166. A POSITA would understand that Lai’s method of leveraging dominant spectral peaks—i.e., motion spectrum peaks having the largest power or amplitude—directly corresponds to the claimed element, as targeting the most significant motion-induced frequencies is not only routine but logical, as it ensures robust suppression of motion artifacts.

167. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

17. “classification indicating; peak present”

[16] The method of claim 10, wherein the retaining and the discarding are based on: the classification indicating that the movement is a pseudo-periodic movement or a periodic movement; and determining that at least one spectral peak with a corresponding frequency in the given frequency range is present at the first point in time.	[50] The apparatus of claim 44, wherein the retaining and the discarding are based on: the classification indicating that the movement is a pseudo-periodic movement or a periodic movement; and determining that at least one spectral peak with a corresponding frequency in the given frequency range is present at the first point in time.
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168. As detailed in Sections A.6 and B.7, Lai discloses classifying motion types into periodic, pseudo-periodic, or random movements based on structured patterns in the accelerometer spectrum. The classification directly informs the retaining and discarding processes by identifying whether motion artifacts stem from periodic or pseudo-periodic movements, which necessitate targeted suppression. For example, Lai describes detecting periodic motion artifacts such as footsteps or arm swings by comparing structured harmonic patterns in the accelerometer spectrum with the PPG spectrum. Ex-1005, 6-7.

169. Further, as detailed in Sections B.8, Lai also discloses determining whether at least one spectral peak is present in the cardiac frequency range of the PPG spectrum at a given point in time. By focusing on peaks within the physiological heart rate range, Lai's method identifies valid cardiac-related components. Ex-1005, 6-7; Fig. 2c.

170. These steps—classification of motion patterns and identification of spectral peaks—are inherently interconnected. The classification step distinguishes between motion patterns (e.g., periodic or pseudo-periodic), which informs the subsequent retention or discarding of spectral peaks. For instance, motion artifacts caused by periodic movements, such as rhythmic footsteps or arm swings, can be detected in the accelerometer spectrum and used to suppress corresponding peaks in the PPG spectrum. Ex-1005, 6-7.

171. Therefore, a POSITA would recognize that Lai discloses the classification of motion types and the retention or discarding of spectral peaks based on their relevance to cardiac signals.

172. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

18. “amplitude modulation”

[19], [72G] classifying the classification of the movement by comparing an amount of amplitude modulation in the second TFS computed to an amplitude modulation threshold, wherein the classification indicates whether the movement rises to a level of causing the motion artifacts based on a result of the comparing.	[53], [75G] a classification unit, the classification unit configured to: classify the classification of the movement by comparing an amount of amplitude modulation in the second TFS computed to an amplitude modulation threshold, wherein the classification indicates whether the movement rises to a level causing the motion artifacts based on a result of the comparing
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173. Although Lai’s classification utilizes a frequency closeness measure, which is compared to a predefined threshold (parameter C_m) to determine whether a PPG is influenced by motion artifacts, rather than explicitly computing amplitude modulation (AM), a POSITA would recognize that AM is a well-known method for analyzing signal variations and is inherently represented in time-frequency analysis through spectral energy changes over time. *See also* ¶60. As stated in Section B.6, Lai already calculates spectral energy values, which correspond to amplitude-related variations in the second TFS. The thresholding mechanism Lai employs to remove irrelevant or fluctuating spectral components can logically be extended to include AM analysis. A POSITA, aware of standard practices in the field, would

find it routine to apply AM analysis techniques to directly compare an amount of amplitude modulation in the second TFS to a predefined threshold. Such an analysis would classify whether the motion rises to a level causing motion artifacts, consistent with the claimed method.

174. Further, a POSITA would recognize this classification process as corresponding to the claimed “classification unit,” functionally implemented to perform the determination. Therefore, Lai’s method logically encompasses the claimed classification process based on AM analysis.

175. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

19. “sensor type”

[25] The method of claim 21, wherein the amplitude modulation threshold is dependent on a type of the motion detector sensor.	[54] The apparatus of claim 53, wherein the amplitude modulation threshold is dependent on a type of the motion detector sensor.
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176. A POSITA would understand that the selection of AM thresholds inherently depends on the type of motion detector sensor used. Motion sensors, such as accelerometers and gyroscopes, have varying sensitivities to motion due to differences in their design, sensor architecture, and measurement principles. For

example, accelerometers measure linear motion, while gyroscopes measure angular velocity, resulting in different amplitude modulation characteristics in their respective outputs. Additionally, manufacturer-specific variances in sensor calibration and design affect the signal’s amplitude and sensitivity to motion artifacts.

177. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

20. “identifying 3 frequencies”

[22A] The method of claim 21, wherein, in determining whether the movement is either the pseudo-periodic movement or the periodic movement, versus the random movement includes, the method further includes: identifying a first, second, and third frequency associated, respectively, with a first, second, and third spectral peak in the second TFS at a point in time in the second TFS, the first, second, and third peaks having largest power or amplitude values relative to other peaks in the second TFS at the point in time, the first spectral peak being a largest	[56A] The apparatus of claim 55, wherein, in determining whether the movement is either the pseudo-periodic movement or the periodic movement, versus the random movement includes, the method further includes: identifying a first, second, and third frequency associated, respectively, with a first, second, and third spectral peak in the second TFS at a point in time in the second TFS, the first, second, and third peaks having largest power or amplitude values relative to other peaks in the second TFS at the point in time, the first spectral peak being a largest
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spectral peak amongst the first, second, and third spectral peaks	spectral peak amongst the first, second, and third spectral peaks
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178. As detailed in Sections B.7 and B.16, Lai teaches “determining whether the movement is either a pseudo-periodic movement or a periodic movement” and that “the dominant spectral peak has a largest power or amplitude value relative to other peaks located at the second point in time in the second TFS.” A POSITA would understand that periodic motion is characterized by a dominant peak and harmonically related secondary peaks, while pseudo-periodic motion exhibits slightly irregular yet structured patterns. In contrast, random motion lacks coherence and displays irregular or broadband energy distributions.

179. Further, Lai ranks spectral peaks based on their amplitude or power. Figures 2e and 2f illustrate the detection of peaks with the highest energy, noting that “three motion peaks with the highest peak” represent how “motion leads to high energy in both channels.” Ex-1005; Fig. 2e, 2f. A POSITA would interpret this as corresponding to the claimed “first, second, and third peaks having largest power or amplitude values relative to other peaks in the second TFS at the point in time,” with “the first spectral peak being a largest spectral peak” among them.

180. The identification and ranking of these peaks facilitate classification of movement types by analyzing the coherence and harmonic structure of the

motion spectrum. This classification aligns with the ‘647 Patent’s confirmation that structured patterns in motion spectra indicate repetitive activities causing motion artifacts. Ex-1001, 17:24-26.

181. In short, Lai’s disclosure of identifying and ranking motion peaks to evaluate harmonic patterns directly supports the interpretation that the first, second, and third peaks are used to classify motion as periodic, pseudo-periodic, or random, depending on their coherence and structure.

182. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

21. “first, second ratio”

[22B], [56B] computing a first ratio of the second frequency identified to the first frequency identified and determining a first comparison result by comparing the first ratio computed to a first ratio value; and computing a second ratio of the third frequency identified to the first frequency identified and determining a second comparison result by comparing the second ratio computed to a second ratio value, wherein the classification further indicates that the movement is either the pseudo-periodic movement or the periodic movement, versus the random movement, based on the first comparison result and the second comparison result.

183. Lai identifies dominant spectral peaks in the motion spectrum based on amplitude (or power), explaining that repetitive activities, such as footsteps or

arm movements, produce structured patterns with harmonics. Ex-1005, 6-7

(“Motion artefacts corresponding to periodic footsteps and arm movements with harmonics can be recognised by comparing the resulting PPG spectrum and the motion spectrum”). A POSITA would recognize that these harmonics manifest as consistent frequency relationships between dominant peaks, providing a clear basis for distinguishing periodic or pseudo-periodic motion from random motion, which lacks such structured coherence.

184. The ‘647 Patent acknowledges that repetitive movements “can result in predominately either one or two dominant peaks depending on the severity of repetitive motions,” while non-repetitive, i.e., random, motion artifacts appear as “a broadband spectrum without a dominant peak.” Ex-1001, 26:43-48. A POSITA would recognize that repetitive (periodic or pseudo-periodic) movements produce harmonics that manifest as integer frequency ratios between peaks (e.g., 2:1 or 3:1). Conversely, incoherent (random) motion patterns yield non-integer ratios.

185. Thus, a POSITA would recognize that applying standard signal processing techniques to verify integer-ratio relationships among the dominant spectral peaks identified by Lai is a logical and routine method for distinguishing harmonic patterns indicative of periodic or pseudo-periodic motion from random motion. A POSITA would further recognize cross-checking frequency ratios (e.g., second-to-first and third-to-first peak ratios) as a useful tool in confirming

harmonic relationships as it enhances reliability by minimizing the risk of misclassification (e.g., due to noise or transient artifacts). Additionally, the second ratio allows for precise differentiation of pseudo-periodic motion, which may slightly deviate from perfect integer ratios, from both periodic and random movements.

186. Thus, Lai renders this element obvious in light of the common knowledge in the art.

22. “ratio value”

[23] The method of claim 1, wherein the first ratio value is 2 and the second ratio value is 3.	[57] The apparatus of claim 56, wherein the first ratio value is 2 and the second ratio value is 3.
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187. As detailed in Section B.21, identifying integer-ratio relationships among dominant spectral peaks in Lai is a routine method for detecting periodic or pseudo-periodic motion.

188. The ‘647 Patent acknowledges that “check[ing] if the movement is pseudo-periodic (e.g. during walk, jog, run)” involves the “[t]he assumption is when movement is pseudo-periodic the accelerometer data should comprised [sic] of a fundamental frequency component and harmonics of the fundamental frequency at its double and third frequency band. This means the ratio of the first

harmonic to the fundamental frequency should be almost 2 and the second harmonic to the fundamental should be around 3.”

189. A POSITA would readily recognize the assumption for selecting ratio values 2:1 and 3:1, representing the fundamental frequency and its higher order harmonics, is based on a logical and well-known choice.

190. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

23. “average value”

[24A] The method of claim 1, wherein, in an event the classification of the movement indicates random movement, the reconstructing includes: computing an average value of a number of prior reconstructed representations outputted prior to the reconstructing, the number based on a duration of consecutive motion artifacts, detected prior to the reconstructing.	[58A] The apparatus of claim 55, wherein, in an event the classification of the movement indicates random movement, the reconstructing includes: computing an average value of a number of prior reconstructed representations outputted prior to the reconstructing, the number based on a duration of consecutive motion artifacts, detected prior to the reconstructing.	
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191. As detailed in Section B.9, Lai discloses that for random movements, i.e., “where HR is not detectable in the window,” fallback mechanisms rely on

prior reconstructed representations, such as using the “previous window’s HR value.” Ex-1005, 6-7; Ex-1001, 36:25-34. Additionally, the ‘647 Patent confirms that averaging prior reconstructed values, e.g., through a “moving average of several past HR beats or some other variant,” is a routine and well-established practice in the field. A POSITA would recognize that applying a moving average, particularly for durations of consecutive motion artifacts, logically extends these fallback strategies to ensure robust and continuous signal reconstruction under random movement conditions.

192. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

24. “bandpass filter, pre-processing, average value”

[24B], [58B] computing a bandpass filter cutoff frequency based on the average value computed; filtering the preprocessed heart-related signal by applying the band pass filter computed to produce a filtered, pre-processed heart-related signal; and wherein the reconstructed representation is based on an average peak-to-peak interval value of the filtered, pre-processed heart-related signal.
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193. As detailed in B.9, fallback mechanisms relying on prior reconstructed values, such as applying a moving average, were well known and documented. Similarly, bandpass filtering was a routine and well-known pre-processing step for PPG and accelerometer signals, and was widely used to isolate

physiologically relevant components and remove noise or motion artifacts. See Section A.7. For example, bandpass filtering was known in the art to apply to remove baseline drift and focus on the cardiac frequency range of 0.5 to 30 Hz (corresponding to heart rates of 30-180 bpm). See Section B.10; *see also* Ex-1006, 3 (describing bandpass filtering of “raw PPG signal and the acceleration signal in a given time window” as a preprocessing step that “removes noise and motion artifacts outside of the frequency band of interest”).

194. The ‘647 Patent confirms that “[t]here are a number of general techniques used for artifact detection and removal. One of the methods used to remove motion artifacts is adaptive filtering” and acknowledges that “[a]n adaptive filter is easy to implement”). Ex-1001, 7:65-68 through 8:1; 8:12-13. A POSITA would recognize that using a moving average of prior HR values to compute the bandpass filter cutoff frequency enables the filter to dynamically adapt to the most likely heart rate range, thereby minimizing the influence of noise and motion artifacts.

195. Integrating these approaches reflects standard practices in signal processing. As the reconstructed representation is based on the average peak-to-peak interval of the filtered, pre-processed heart-related signal, a POSITA would recognize that bandpass filtering improves signal fidelity by emphasizing cardiac components and suppressing artifacts.

196. Thus, Lai renders this element obvious in light of the common knowledge in the art.

25. “concurrently”

[25] The method of claim 1, wherein the heart-related signal and the motion signal are produced, concurrently.
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197. As stated in ¶51, a POSITA would recognize that concurrent production and analysis of the heart-related and motion signals is routine and well-known in the field and necessary for motion artifact suppression in real-time applications. For example, Lai discloses that “[t]he algorithm takes streaming PPG and accelerometer data as inputs” Ex-1005, 6. This indicates that both signals are captured and analyzed in parallel to detect and mitigate motion artifacts in the PPG signal.

198. Thus, Lai discloses this element.

26. “windowed segments”

[26] The method of claim 1, further comprising: segmenting the heart-related signal into a plurality of windowed heart-related signal data segments and the motion signal into a corresponding plurality of windowed motion signal data segments; and	[60] The apparatus of claim 35, further comprising segmentation unit configured to: segment the heart-related signal into a plurality of windowed heart-related signal data segments and the motion signal into corresponding plurality of windowed motion signal data segments,
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repeating the reconstructing and the outputting for each windowed heart-related signal data segment and each corresponding motion signal data segment.	wherein the reconstruction unit and the output unit reconstruct the representation and output the reconstructed representation, respectively, based on each windowed heart-related signal data segment and each corresponding motion signal data segment.
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199. As detailed in Sections A.3, A.6 and A.8 above, Lai discloses segmenting the PPG and motion signals into windowed segments for analysis and reconstruction. Lai performs STFT on both signals in overlapping or non-overlapping time windows, enabling localized time-segmented spectral analysis. The ‘647 Patent confirms that “a window segment length T may be set to 8 seconds,” which was standard practice for segmenting signals and well-known in the field. Ex-1001, 23:50-51; *see also* Ex-1004 (0936), 2018-04-18 Office Action, at 6 (“[u]se of windows is considered routine in spectral analysis as windowing is a known technique for breaking down large datasets into smaller, more easily handled subsets”).

200. A POSITA would recognize that segmenting the signals into a plurality of time windows facilitates synchronized processing of the PPG and motion signals, allowing the reconstruction unit to reconstruct the representation for each segment. A POSITA would find it obvious to configure the reconstruction

and output units to process windowed segments of the PPG and motion signals, which is a routine and widely understood approach for time-segmented signal analysis and artifact removal.

201. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

27. “time window”

[27] The method of claim 26, wherein the time window is a value in a range from 2 to 32 seconds.	[61] The apparatus of claim 60, wherein the time window is a value in a range from 2 to 32 seconds.
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202. As analyzed above, Lai discloses segmenting signals into time windows for spectral analysis and reconstruction, applying STFT to the PPG and motion signals on a segment-by-segment basis. *See* B.27. The ‘647 Patent explains that it was known in the art that “the assumption of 8 second data length largely stems from the fact that SpO₂ and heart rates do not change instantaneously” and acknowledges that “hence, an 8 second duration is a reasonable choice.” Ex-1001, 24:48-51.

203. A POSITA would recognize that selecting a time window length within the range of 2 to 32 seconds is a logical and well-supported extension of these teachings since shorter windows (2sec.) provide higher temporal resolution to

capture rapidly changing signals, while longer windows (32sec.) optimize frequency resolution under more stable conditions.

204. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

28. “biomedical sensor”

[28] The method of claim 1, wherein the biomedical sensor is at least one of: a photoplethysmogram (PPG) sensor, piezoelectric sensor, Light Emitting Diode (LED) based sensor, camera sensor, and pulse oximeter sensor, and wherein the motion sensor is an accelerometer.	[62] The apparatus of claim 35, wherein the biomedical sensor is at least one of: a photoplethysmogram (PPG) sensor, piezoelectric sensor, Light Emitting Diode (LED) based sensor, camera sensor, and pulse oximeter sensor, and wherein the motion sensor is an accelerometer.	[63] The apparatus of claim 35, wherein the apparatus includes the biomedical sensor and the motion sensor.
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205. Lai discloses that its algorithm processes heart-related PPG signals and motion signals from an accelerometer for motion artifact suppression. Ex-1005, 6-7 (“Motion artefacts corresponding to periodic footsteps and arm

movements with harmonics can be recognised by comparing the resulting PPG spectrum and the motion spectrum”).

206. The ‘647 Patent acknowledges that it was known in the art that “a spectral sensor and the skin surface subtraction technique to remove the spectrum of acceleration data from that of a PPG signal.” Ex-1001, 9:10-22 (internal citations omitted); *see also* Ex-1006, 7 (“the PPG signal was recorded ... using a pulse oximeter with green LED ... The acceleration signal was also recorded ... using a three-axis accelerometer. Both ... embedded in a wristband”). This confirms the well-established use of PPG sensors with accelerometers for reconstructing heart-related signals.

207. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

29. “co-located”

[29] The method of claim 1, wherein the biomedical sensor and the motion sensor are co-located.

208. As noted in Section B.25 above, heart-related signals and motion signals are concurrently produced and analyzed in Lai’s system.

209. Lai describes the physical arrangement of the sensors, stating that the PPG sensor was “placed at the centre of the bottom case of the device ... to

maintain direct contact with the user’s skin. Three accelerometers measuring orthogonal directions were built into the device to capture motions.” Ex-1005, 10.

210. As a POSITA would understand that the integration of the PPG sensor and accelerometers into the same device indicates their co-location, which facilitates synchronization for accurate signal collection. Thus, co-locating biomedical and motion sensors is a logical and common design choice for watch-type devices.

211. Thus, Lai discloses this element.

30. “heart rate estimate”

[30] The method of claim 1, further comprising employing the reconstructed representation to determine a heart rate estimate.	[64] The apparatus of claim 35, further comprising a heart rate unit configured to employ the reconstructed representation to determine a heart rate estimate.
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212. As detailed in Sections A.2 and B.7 above, Lai reconstructs a representation of the heart-related signal by combining and processing data from raw PPG and accelerometer inputs. A POSITA would understand that this reconstructed representation directly informs and serves as the foundation for determining a heart rate estimate. *See also* Ex-1004 (“[o]ne of ordinary skill in the

art is considered to possess the knowledge to determine a representation of heart rate estimate from the heart rate sensor and/or ECG”).

213. Thus, Lai discloses these elements.

31. “SpO₂ estimate”

[31] The method of claim 1, further comprising employing the reconstructed representation to determine an arterial oxygen saturation (SpO ₂) estimate.	[65] The apparatus of claim 35, further comprising an arterial oxygen saturation (SpO ₂) unit configured to employ the reconstructed representation to determine a SpO ₂ estimate.
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214. While Lai primarily discusses HR estimation, a POSITA would recognize that the same reconstructed signal could naturally be used to derive SpO₂ by using well-established pulse oximetry principles. Lai describes a pipeline where PPG signals, reconstructed through spectral analysis produced by Lai’s algorithm, provides the time-varying spectral components of the PPG signal, are used for physiological monitoring, including functions such as oxygen saturation estimation. Ex-1005, 6 (“Photoplethysmography (PPG) has been used in clinical settings for measuring cardiovascular functions such as heart rate and arterial blood oxygen saturation for decades”).

215. The explicit admissions in the ‘647 Patent further confirm that SpO₂ estimation is an expected outcome when processing reconstructed PPG signals, as these systems are commonly used for multi-parameter physiological monitoring, including HR and SpO₂. As the ‘647 Patent acknowledges, pulse oximeters are widely implemented in systems that reconstruct PPG signals to estimate both heart rate and oxygen saturation. Ex-1001, 6:54-60 (“The pulse oximeter signal contains not only the blood oxygen saturation and heart rate (HR) data, but also other vital physiological information”) (internal citations omitted). Moreover, the ‘647 Patent repeatedly emphasizes the utility of pulse oximeters as versatile vital sign monitors. Ex-1001, 7:7-10 (citing Salehizadeh 2014) (“Utilizing a pulse oximeter as a multi-purpose vital sign monitor has clinical appeal, since it is familiar to the clinician and comfortable for the patient”).

216. These admissions establish that pulse oximeters, which inherently reconstruct PPG signals for SpO₂ estimation, were widely recognized and routinely implemented in systems prior to the ‘647 Patent. See Ex-1004 (0937), 2018-04-18 Office Action, at 7 (“[m]easurement of oxygen saturation from the sensors employed by Venkatraman et al. is a well-known function”).

217. Additionally, the ‘647 Patent describes the OxiMA method, which combats motion artifacts in PPG signals for accurate SpO₂ and HR estimations, demonstrating that SpO₂ estimation is a fundamental feature of reconstructed PPG

signals. Ex-1001, 39:59-62 (“The OxiMA method ... combats motion artifacts that can degrade the accuracy of SpO₂ and HR estimations”).

218. The emphasis on reconstructing motion-contaminated PPG signals to estimate SpO₂ confirms that SpO₂ estimation is an expected and inherent outcome of such reconstruction pipelines.

219. Thus, Lai discloses these elements.

32. “heart-related ailment”

[32] The method of claim 1, further comprising employing the reconstructed representation to detect or predict a heart-related ailment, the heart-related ailment including at least one of a heart rate variability (HRV) condition, atrial fibrillation condition, congestive heart failure condition, and tachycardia condition.	[66] The apparatus of claim 35, further comprising an ailment unit configured to employ the reconstructed representation to detect or predict a heart-related ailment, the heart-related ailment including at least one of a heart rate variability (HRV) condition, an atrial fibrillation condition, a congestive heart failure condition, and a tachycardia condition.
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220. As detailed in section B.31, Lai describes a system for reconstructing PPG signals through spectral analysis for cardiovascular monitoring, including heart rate and oxygen saturation estimation. A POSITA would understand that Lai’s reconstructed signals, which provide time-varying spectral components, are

suitable for detecting or predicting heart-related ailments, including HRV, atrial fibrillation (AF), congestive heart failure (CHF), and tachycardia. Specifically, Lai states: “[PPG] has been used in clinical settings for measuring cardiovascular functions such as heart rate and arterial blood oxygen saturation for decades.” Ex-1005, 6.

221. This demonstrates that Lai contemplated the clinical use of reconstructed PPG signals for a variety of cardiovascular functions. A POSITA would recognize that the time-varying spectral components disclosed in Lai inherently provide the data necessary to evaluate heart rate variability and detect conditions, such as AF and tachycardia, which are directly tied to irregularities in heart rate patterns.

222. The ‘647 patent confirms that reconstructed PPG signals are commonly used to detect or predict HRV, AF, CHF, and tachycardia. Ex-1001, 19:28-35 (“[t]he heart-related ailment [includes] at least one of a heart rate variability (HRV) condition, atrial fibrillation condition, congestive heart failure condition, and tachycardia condition”).

223. The ‘647 Patent further acknowledges the broad utility of pulse oximeters in monitoring multiple cardiovascular parameters. Ex-1001, 6:54-60 (“The pulse oximeter signal contains not only the blood oxygen saturation and

heart rate (HR) data, but also other vital physiological information”) (internal citations omitted).

224. These admissions establish that the use of reconstructed PPG signals for detecting HRV, AF, CHF, and tachycardia was well-known and widely implemented prior to the ‘647 patent.

225. Additionally, the ‘647 Patent describes the OxiMA method, which enhances reconstructed PPG signals by mitigating motion artifacts, thereby improving their utility for HR and rhythm-related analyses. Ex-1001, 39:59-62. (“The OxiMA method ... combats motion artifacts that can degrade the accuracy of SpO2 and HR estimations”).

226. A POSITA would understand that the improved reconstruction techniques disclosed in OxiMA inherently facilitate the detection of HRV, AF, CHF, and tachycardia, as these conditions rely on the analysis of reconstructed heart rate signals.

227. Thus, a POSITA would find it obvious to apply Lai’s reconstructed PPG signals to detect or predict HRV, AF, CHF, and tachycardia. The admissions in the ‘647 Patent and its references further confirm that detecting these ailments using reconstructed PPG signals reflects a routine and predictable application of well-established methods.

228. Thus, Lai discloses these elements.

33. “real-time”

[33] The method of claim 1, wherein the reconstructing and the outputting are performed in real-time with respect to production of the heart-related signal and the motion signal.	[67] The apparatus of claim 35, wherein the reconstruction unit and the output unit are configured to reconstruct and to output, respectively, in real-time with respect to production of the heart-related signal and the motion signal.
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229. As stated in ¶52, configuring the reconstruction and output units to operate in real time with respect to signal production are routine and well-known in the field.

230. As detailed in B.25, Lai’s algorithm concurrently processes streaming PPG and accelerometer signals. Ex-1005, 6 (“[t]he algorithm takes streaming PPG and accelerometer data as inputs”); *see also* Ex-1001, 8:12-13 (“[a]n adaptive filter is easy to implement and it also can be used in real-time applications”).

231. Thus, Lai discloses these elements.

34. “non-real-time”

[34] The method of claim 1, wherein the reconstructing and the outputting are performed in non-real-time with	[68] The apparatus of claim 35, wherein the reconstruction unit and the output unit are configured to reconstruct and to output, respectively,
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respect to production of the heart-related signal and the motion signal.	in non-real-time with respect to production of the heart-related signal and the motion signal.
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232. The ‘647 Patent states that “[t]he OxiMA method can be easily implemented in real-time.” Ex-1001, 41:17-18. This acknowledgment of real-time implementation implies flexibility, making non-real-time implementations an equally feasible and logical design choice.

233. A POSITA would recognize that reconstruction and output can be configured to occur asynchronously relative to signal production to accommodate non-real-time applications, such as offline analysis or post-event diagnostics, where strict real-time processing is not required. This flexibility reflects well-established practices in the field for adapting signal processing methods to specific applications.

234. Thus, Lai renders these elements obvious in light of the common knowledge in the art.

VIII. SECONDARY CONSIDERATIONS

235. I am not aware of any evidence of secondary considerations of non-obviousness of the claims 1-75 of the ‘647 Patent. However, I reserve the right to rebut if the Patent Owner identifies any.

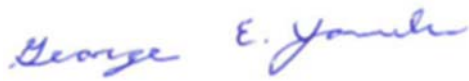
IX. CONCLUSION

236. For the reasons set forth above, it is my opinion that claims 1-75 of the '647 Patent are unpatentable in view of the prior art.

237. In signing this Declaration, I understand that the Declaration will be filed as evidence in a contested case before the PTAB.

238. I declare, under the penalty of perjury, that all statements made herein of my knowledge are true, and that all statements made on information and belief are believed to be true.

Dated: January 31, 2025

By: 
George E. Yanulis