10th Annual PHM Conference
Philadelphia, PA, September 24-27, 2018

Example R&D Efforts in Support of Long-Term Health & Short-Term Performance Improvement at InTelMed

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Visual and Autonomous Exploration Systems Research Laboratory, University of Arizona, Tucson, AZ

Acknowledgements

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DOD/CDMRP, DOE, NASA, NSF, Industry

Edward & Maria Keonjian Endowment (University of Arizona)

Financial Disclosure:
Associated Caltech and UofA Intellectual Property (IP)

Patent number: US 7,481,534
Title: “Optomechanical and digital ocular sensor reader systems”

Patent number: US 7,762,664
Title: “Optomechanical and digital ocular sensor reader systems”

Patent number: US 9,122,956 and international progenies
Title: “Automated feature analysis, comparison, and anomaly detection”

Patent number: US 9,424,489 and international progenies
Title: “Automated feature analysis, comparison, and anomaly detection”

Several PCT, Patent, and Provisional Patent Applications filed on behalf of University of Arizona on *HRV and Respiratory Data Analysis*

Overview

- Overview of InTelMed Center at the University of Arizona
- Example R&D Efforts at the InTelMed Center in Support of PHM for Human Health & Performance
- Summary & Outlook
- Mars Agricultural Research Consortium (MARSAG)
- Upcoming Special Issue of the International Journal of Prognostics and Health Management (IJPHM)
- Invitation to PHM 2019 to be held in Scottsdale, AZ
  (Dr. Wolfgang Fink, General Conference Co-Chair)

UofA's Center for Informatics and Tele-Health in Medicine (InTelMed): Founded in early 2018: **Open for Business**

InTelMed.arizona.edu

- Devise and deploy novel biofeedback-controlled devices by integrating wearable sensors, bi-directional data exchange, cloud-based data analysis, health/disease status modeling and prediction, combined with prescribed intervention/treatment onto human smart service platforms.
- Biofeedback-controlled human smart service systems have the potential to improve health/ treatment outcome for our nation, and, subsequently, decrease outpatient healthcare costs, which constitute the majority of the overall healthcare spending.
- Focus on connected devices across the care continuum: primary care, pediatric to elderly care, ambulatory care, emergency care, intensive care, remote monitoring and home-based care.

Example R&D Efforts at the InTelMed Center in Support of PHM for Human Health & Performance

- Effort #1 (Sensor Development):

  PHM Theme: Sensors in Extreme Environments

  Wireless Intraocular Pressure Sensor and Associated External Reader Systems in Support of Glaucoma Diagnosis and Therapy

- Effort #2 (Data Analytics):

  PHM Theme: Data Analytics, ML, DL

  ECG Data Analysis to obtain Heart Rate Variability Information and Performance Pattern Identification

- Effort #3 (Data Analytics):

  PHM Theme: Robust Classification & Mitigation

  Respiratory Waveform Data (i.e., Breathing Cycles) Analysis to Select YOGA Breathing Patterns for Immediate Intervention

Effort #1 (Sensor Development):

PHM Theme: Sensors in Extreme Environments

Wireless Intraocular Pressure Sensor (WIPS)

Enhancing and Optimizing Glaucoma Treatment and Management

Glaucoma: Incurable Disease Causing Blindness

Exhibit 4 ◆ Flow in a Normal Eye

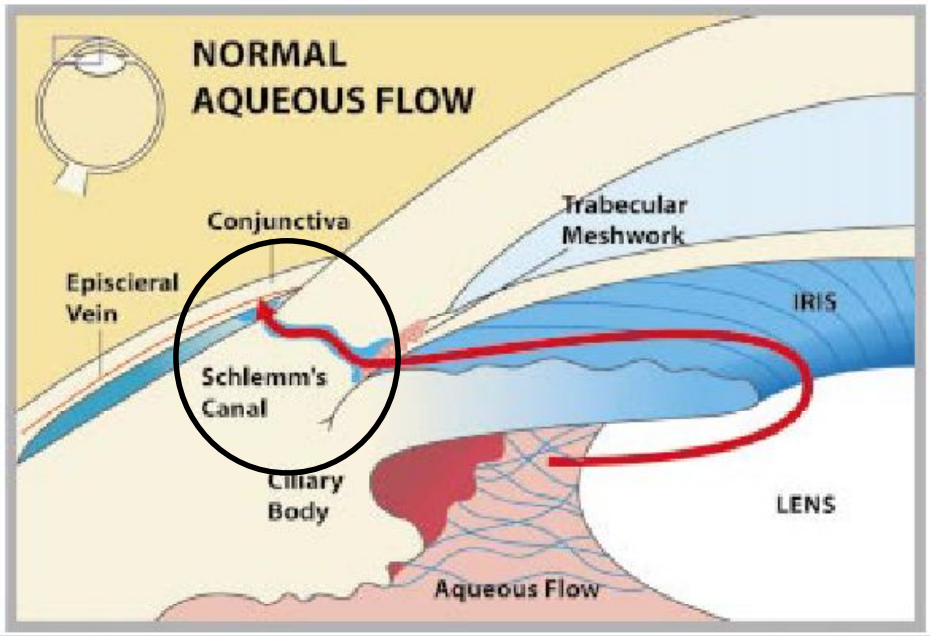
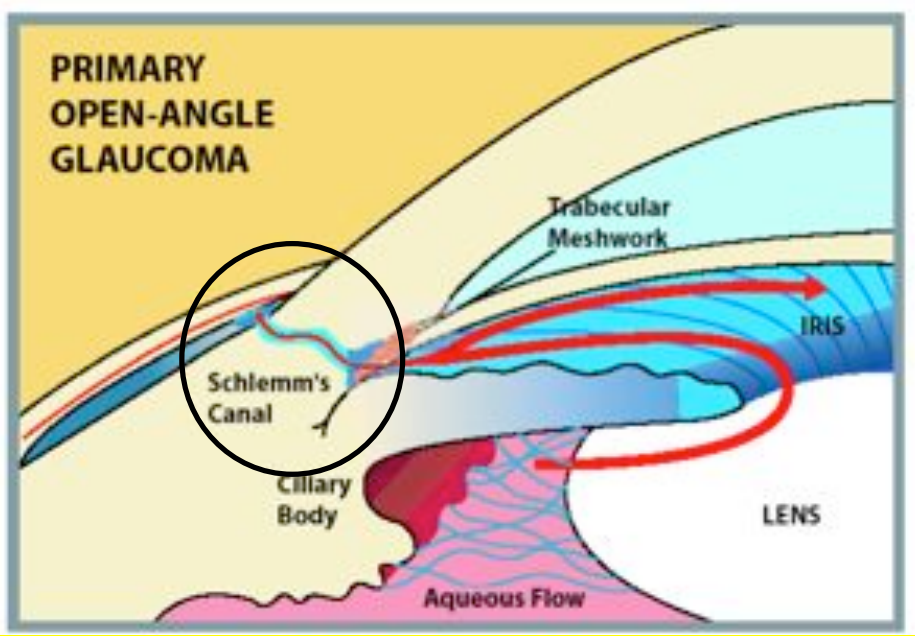


Exhibit 5 ◆ Flow in an Eye with POAG



If untreated

[http://www.allaboutvision.com/conditions/hypertension.htm]

[http://www.eyedocsottawa.com/wp-content/uploads/2010/12/glaucoma_600x255.jpg]

Standard of Care in IOP Measurement

~67 million people worldwide have glaucoma (2nd leading cause of blindness, incurable), expected to rise to ~80 million by 2020!

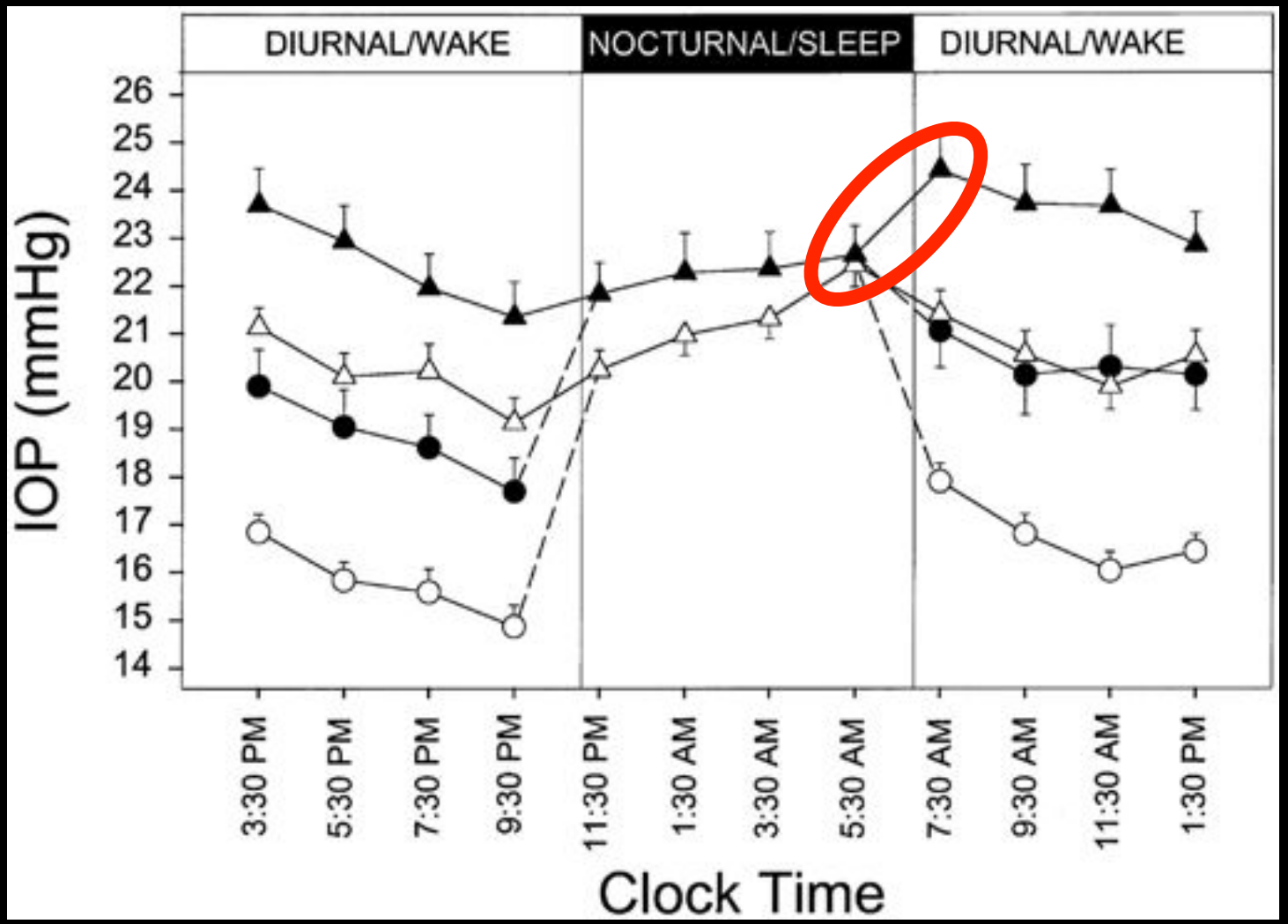
Fig. 2: Measuring IOP using a *Goldmann Applanation Tonometer*, requires topical anesthetic

[http://gemclinic.ca/about_glaucoma.php]

Fig. 3: Using a *Tono-Pen* to measure IOP, requires topical anesthetic

[https://www.ophthalmologymanagement.com/issues/2013/january-2013/taking-iop-measure-beyond-goldmann]

Glaucoma: Diurnal Variations of IOP

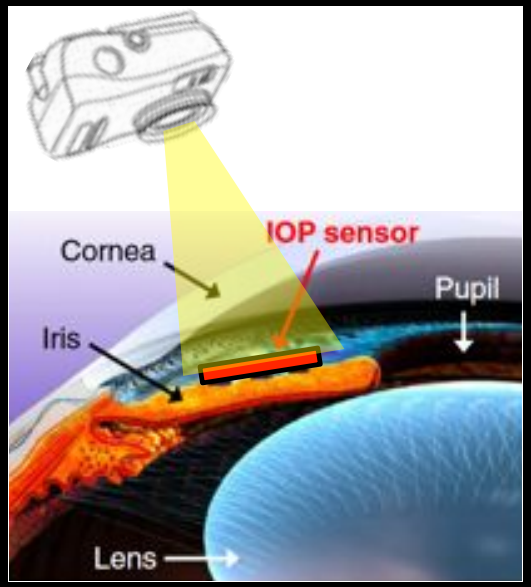


J. H. K. Liu, X. Zhang, D. F. Kripke, and R. N. Weinreb, "Twenty-four-Hour Intraocular Pressure Pattern Associated with Early Glaucomatous Changes," IOVS. **44**(4), 1586-1590 (2003) [doi: 10.1167/iovs.02-0666].

Wireless Intraocular Pressure Sensor (WIPS) Development

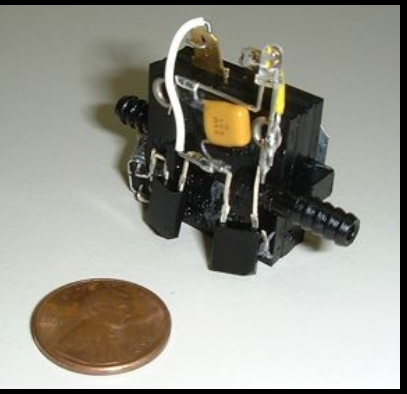
Optically Powered and Optically Data-Transmitting

Conceptual Setup

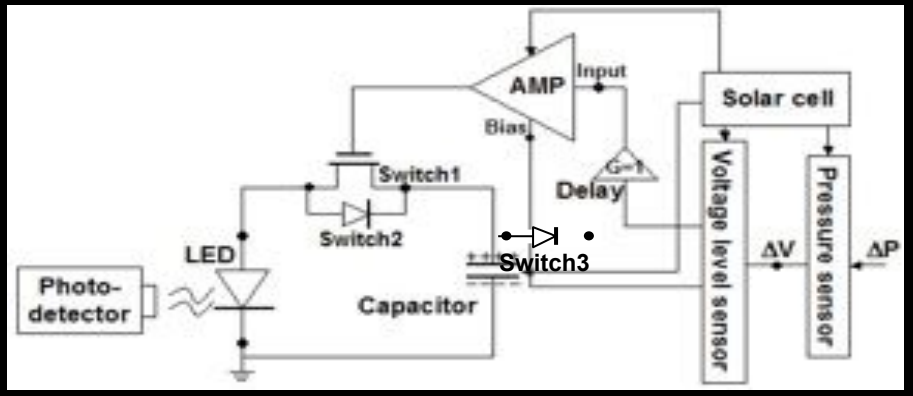


WIPS Test Setup

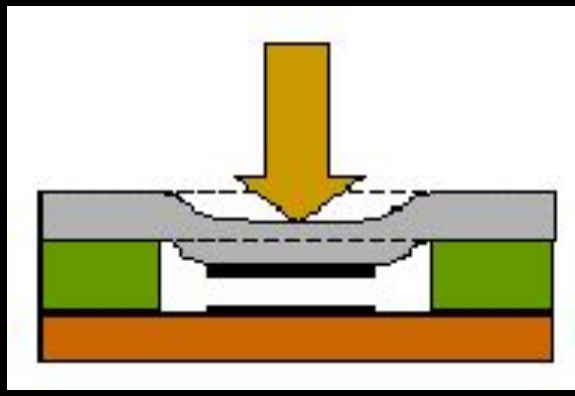
WIPS POC



WIPS Circuit Layout

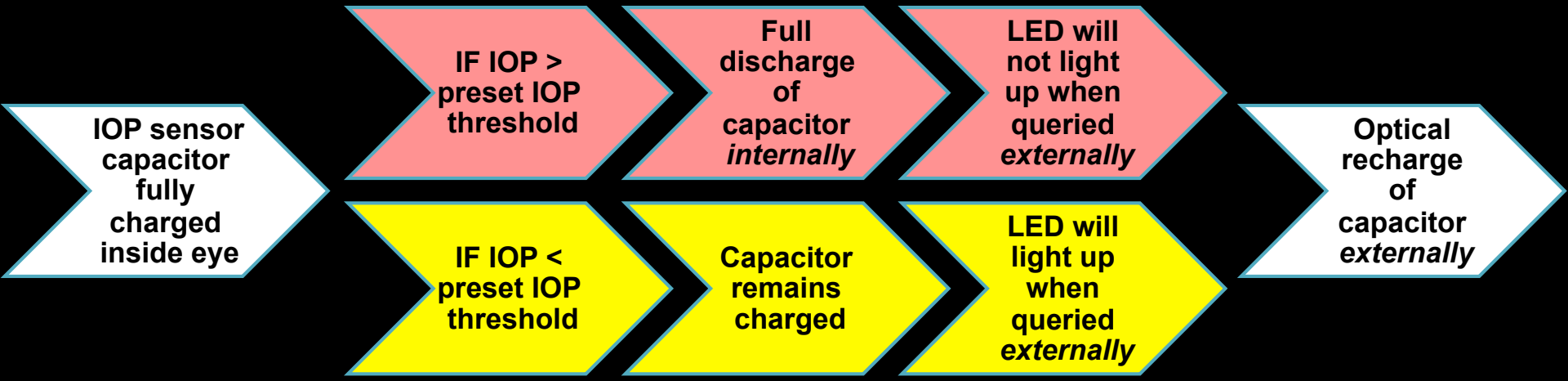


MEMS Capacitive Pressure Sensor

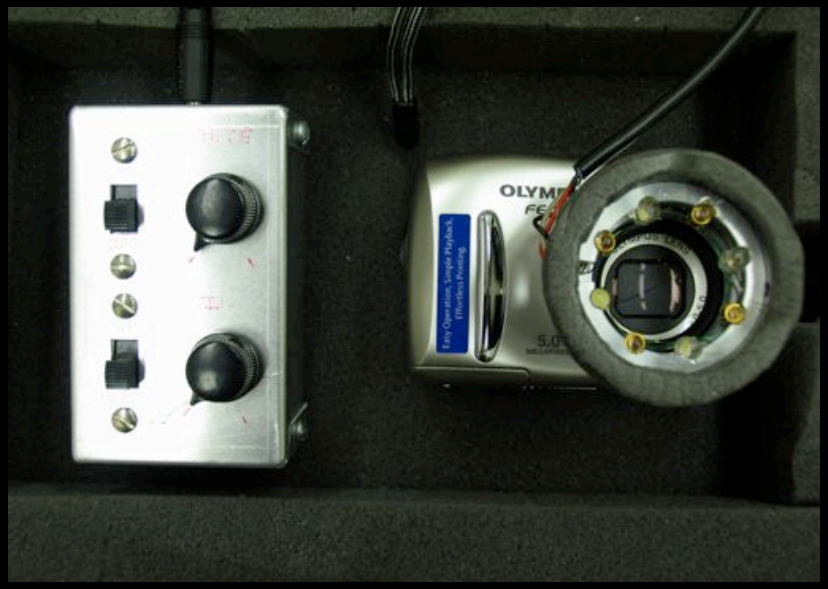


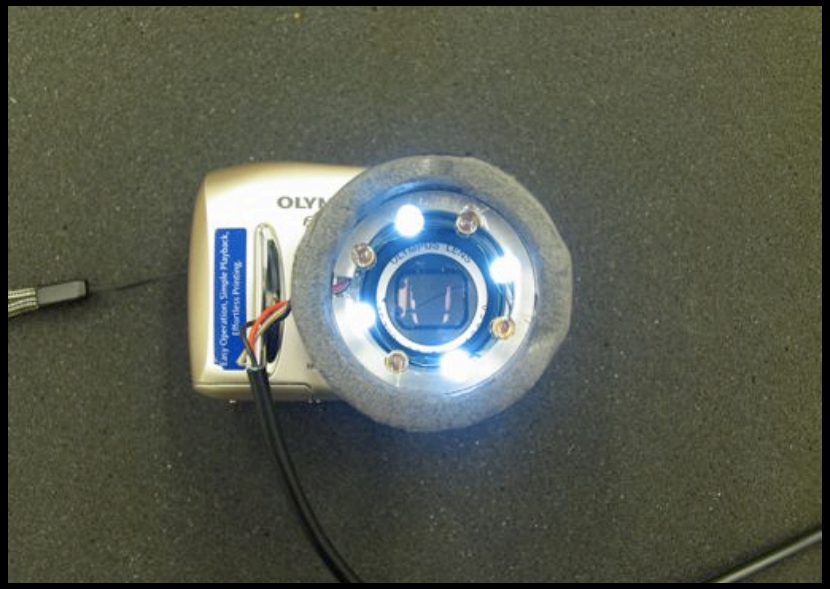
Caltech US-Patent #7,131,945

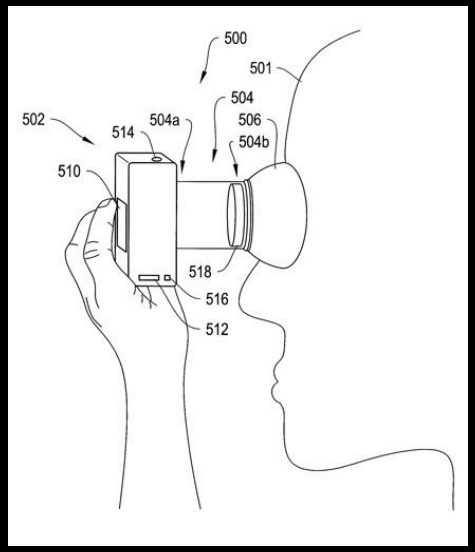
WIPS: Functional Flowchart

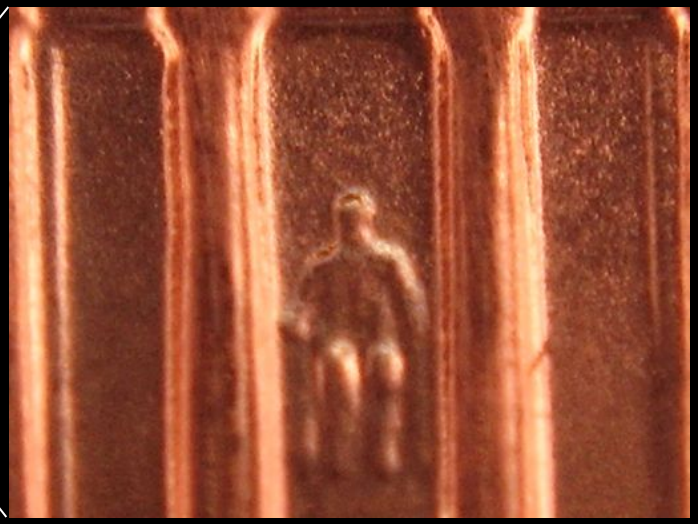


Digital Sensor Reader for Anterior Ocular Chamber (Fink, Caltech)



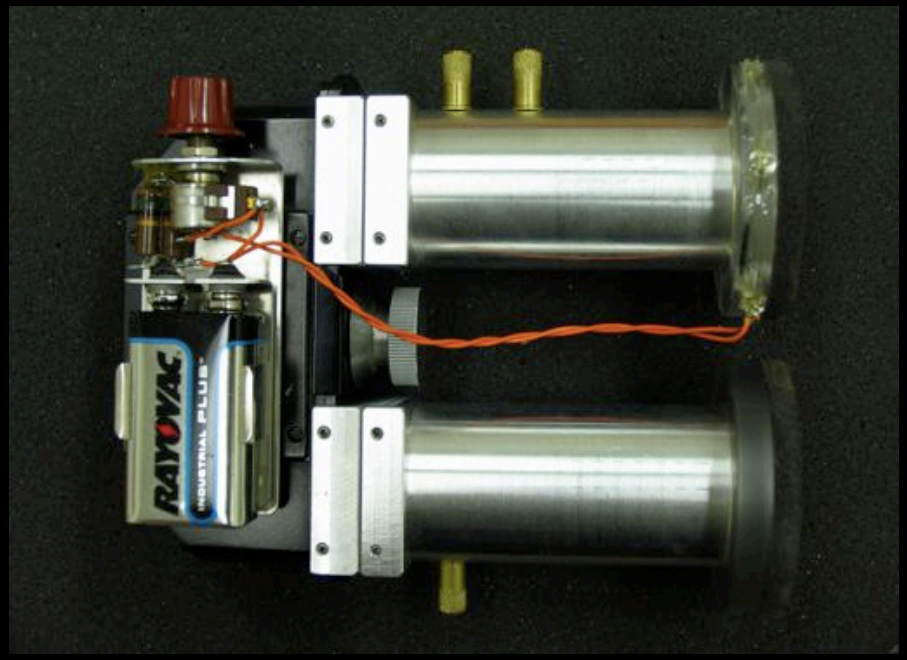


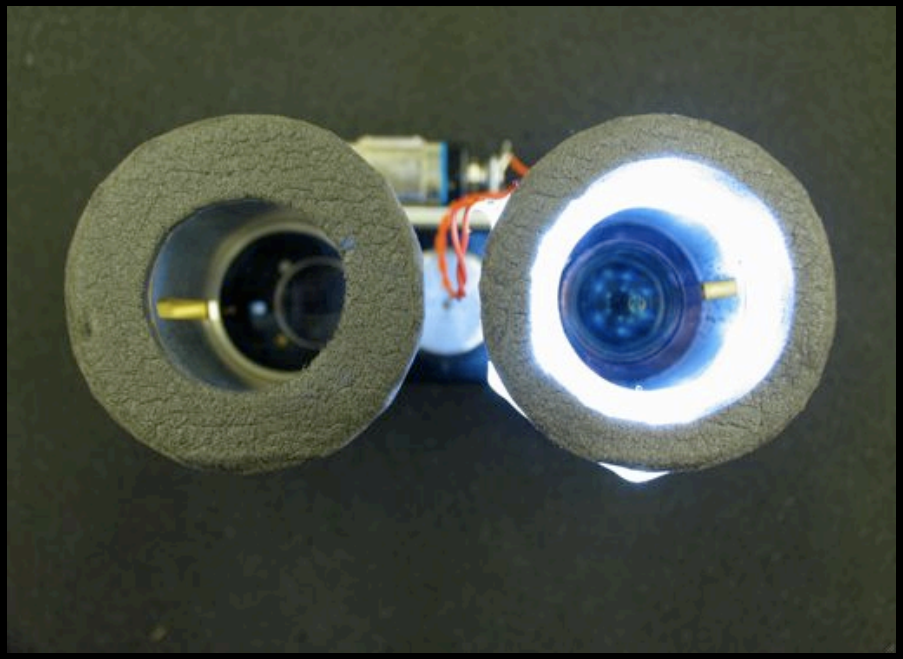




Tarbell & Fink, ARVO 2008; Caltech US-Patents #7,481,534 and #7,762,664; Support: Bausch & Lomb

Optomechanical Sensor Reader for Anterior Ocular Chamber (Fink, Caltech)



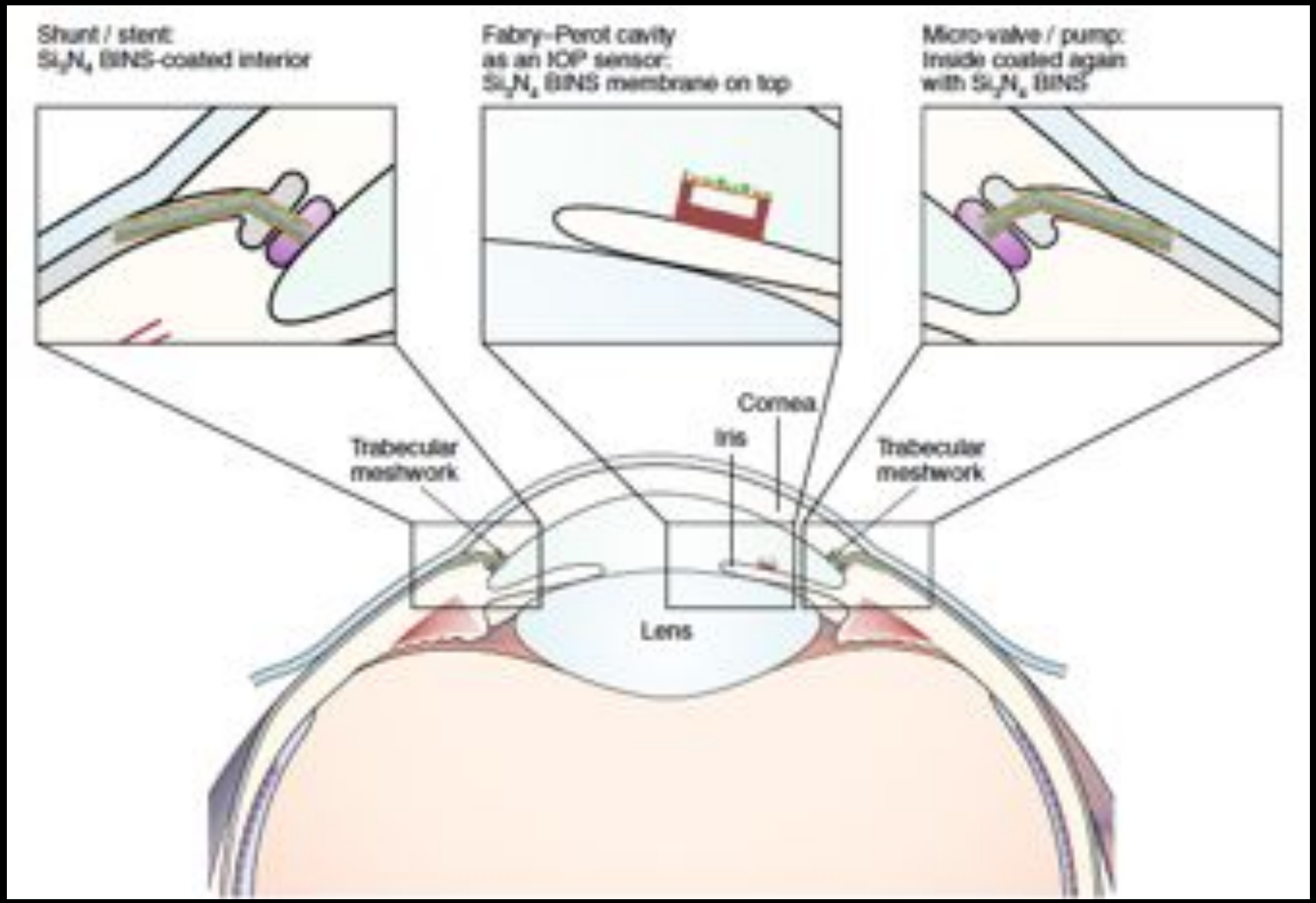


To monitor:

- **Intra-ocular sensors**
- **Implanted drug-delivery devices (e.g., fill level)**
- **Anterior chamber of the eye for clinical purposes**

Tarbell & Fink, ARVO 2008; Caltech US-Patents #7,481,534 and #7,762,664; Support: Bausch & Lomb

Outlook: Future Developments



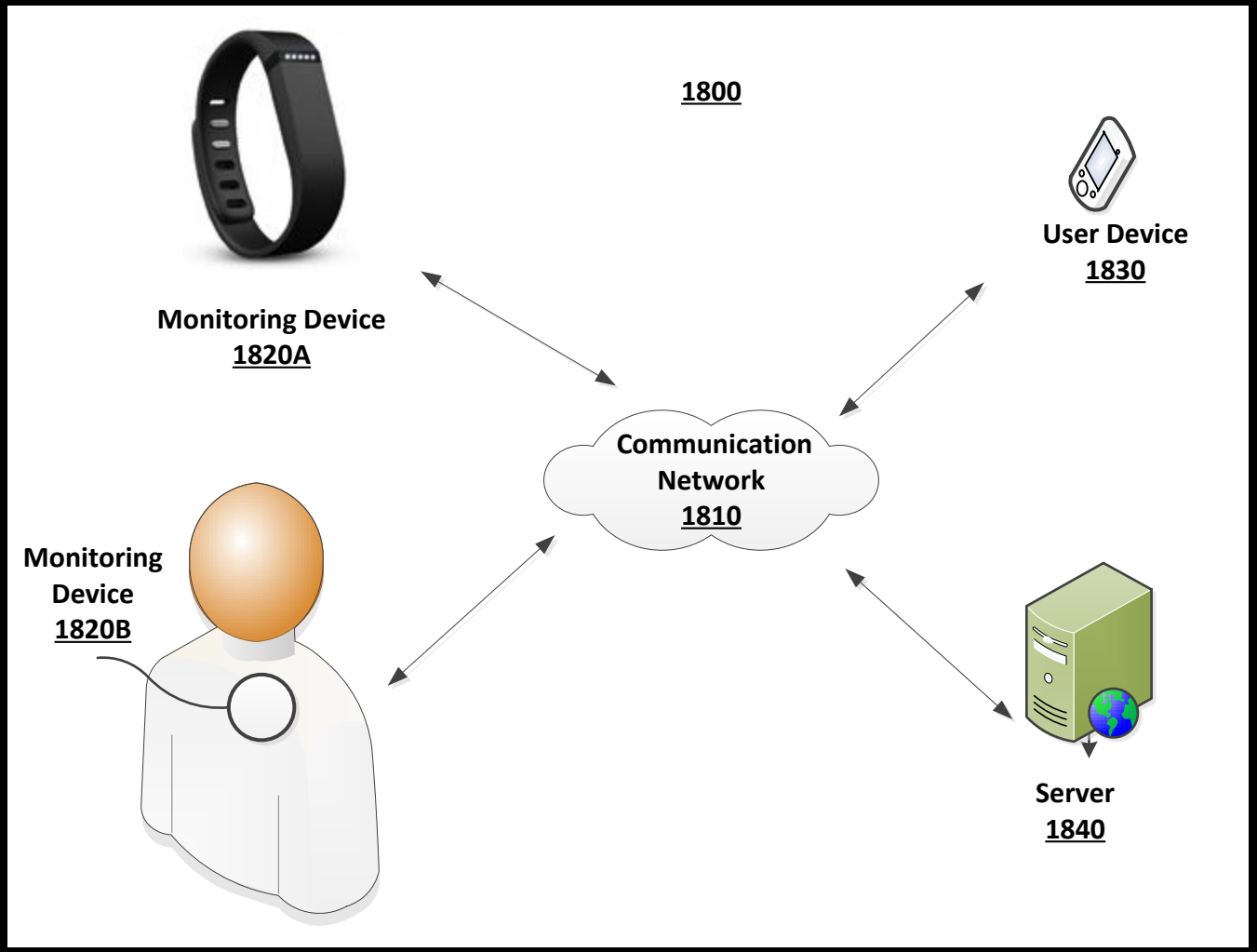
Fink W (2018) *"news & views": Nature-inspired sensors;* Nat Nanotechnol. 13(6):437-438. doi: 10.1038/s41565-018-0164-5

Effort #2 (Data Analytics):

PHM Theme: Data Analytics, ML, DL

ECG Data Analysis
to obtain Heart Rate Variability Information
and Performance Pattern Identification
using Wearable Sensors

Cloud-based Network & Analysis Environment
For Implementing Wearable Sensors for ECG Data



[Fink (University of Arizona) Patent Pending]

Influenceable/Non-Influenceable Factors Affecting HRV

Non-influenceable physiological parameters
age, gender, circadian rhythm, genetics

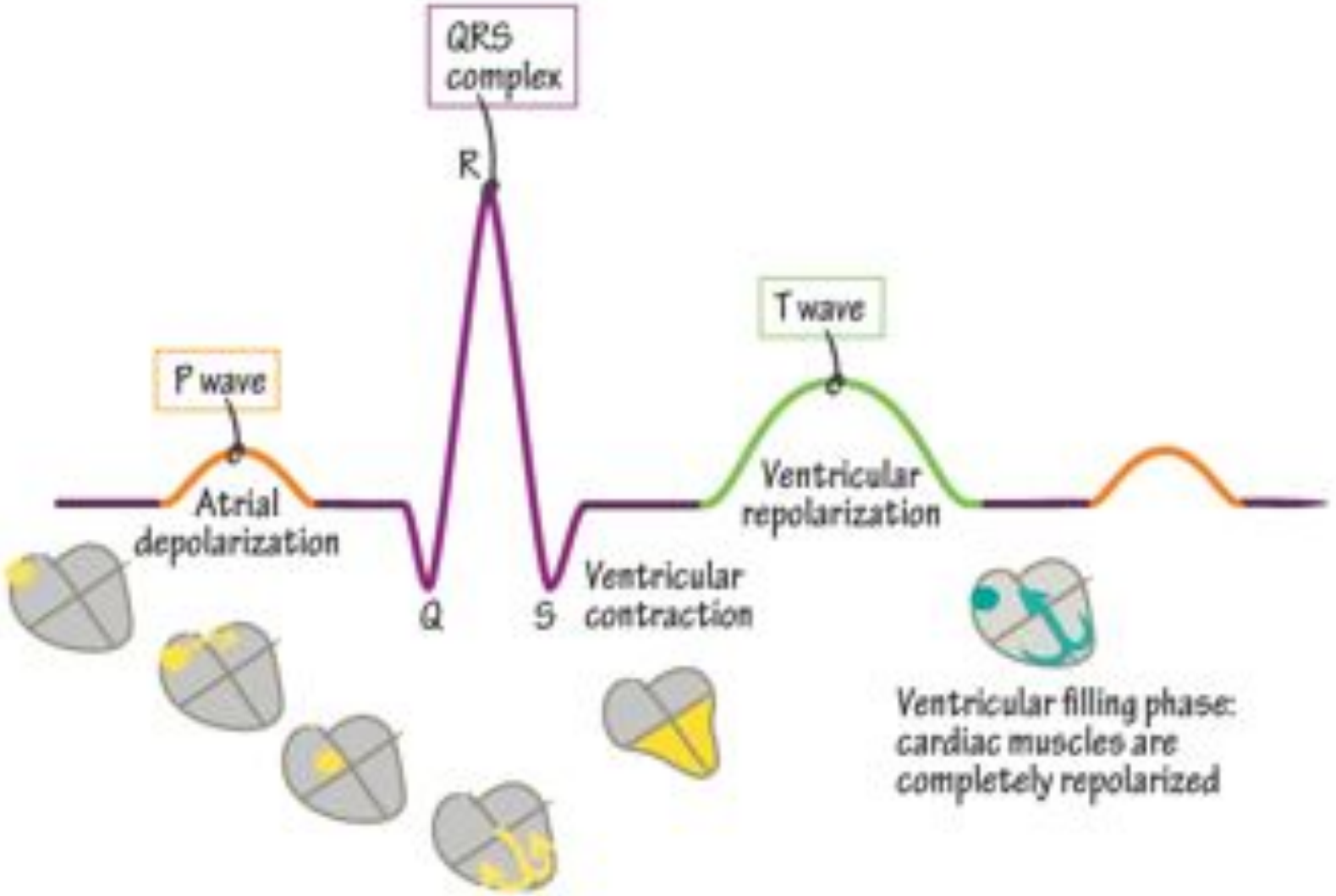
Diseases
sepsis, heart disease, lung diseases, renal diseases, psychiatric diseases, metabolic diseases

Influenceable lifestyle factors
Physical fitness, sporting activity, increased body weight, smoking, alcohol abuse

External factors
hear*, noise*, night shift work, harmful substances, medications

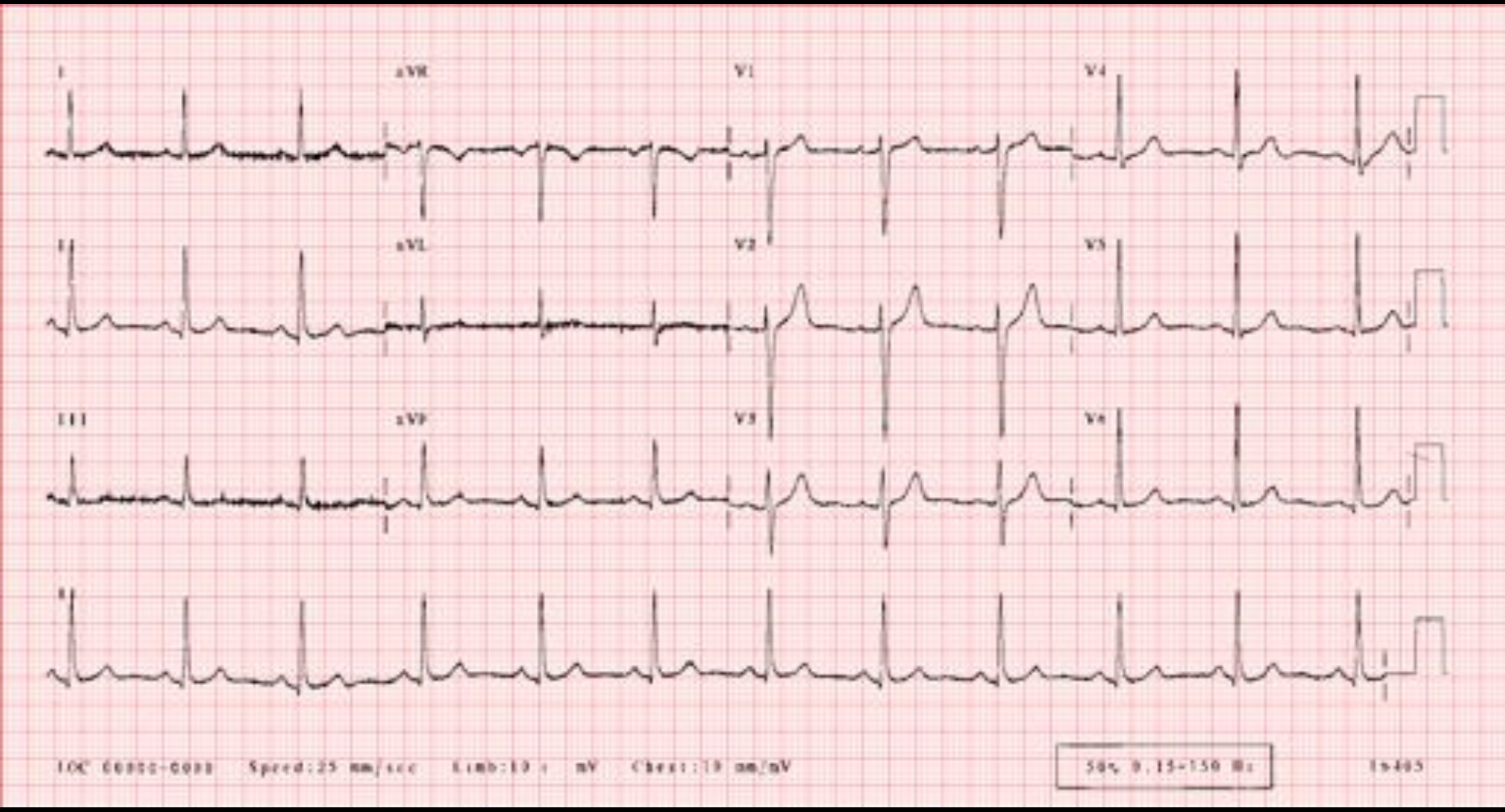
[After Image courtesy: http://www.markwk.com/hrv-for-beginners.html]

QRST Complex Definition



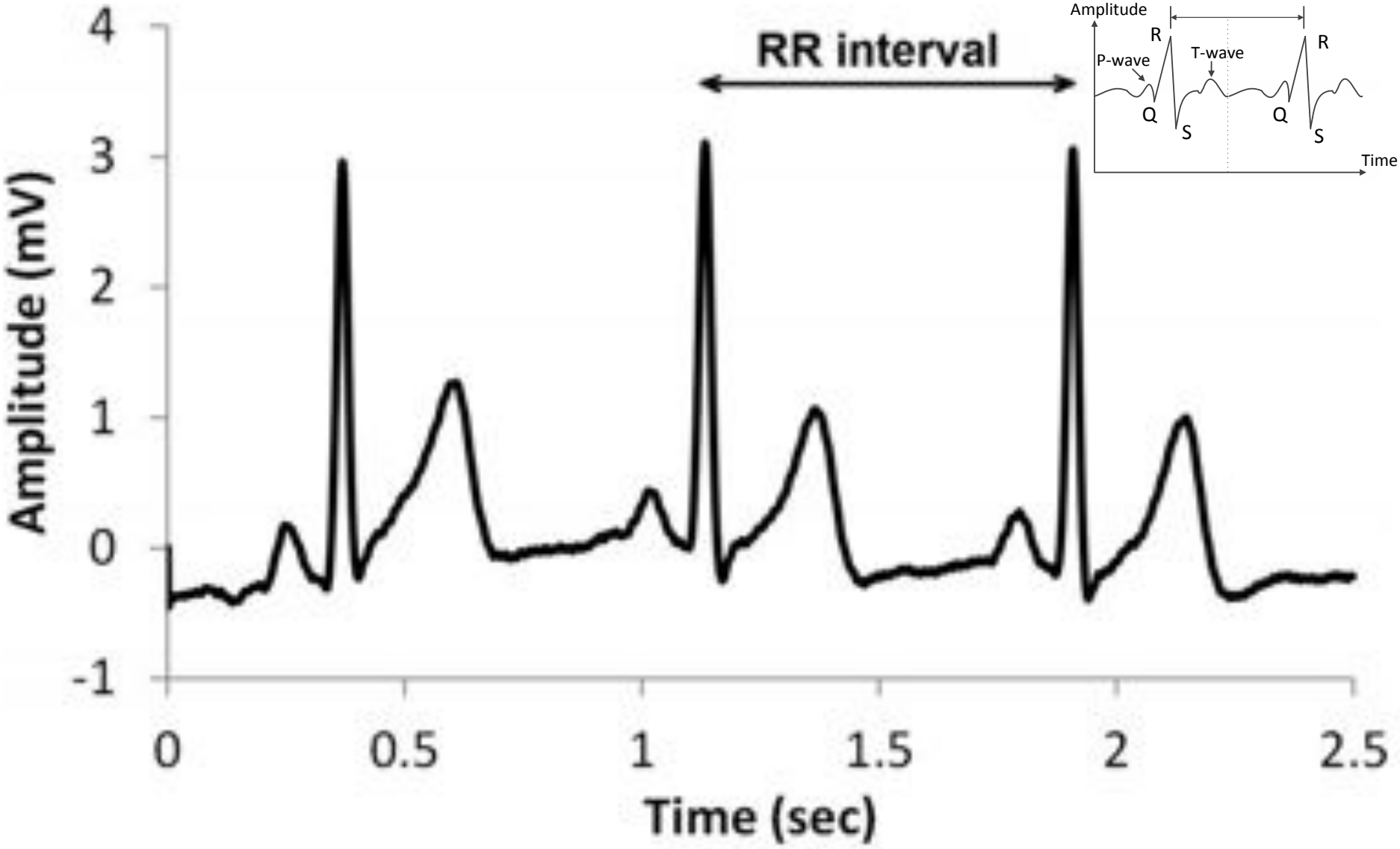
[Image courtesy: https://drawittoknowit.com/pop-quizzes/physiology/why-is-the-p-wave-smaller-than-the-qrs-complex]

Real World ECG Recording



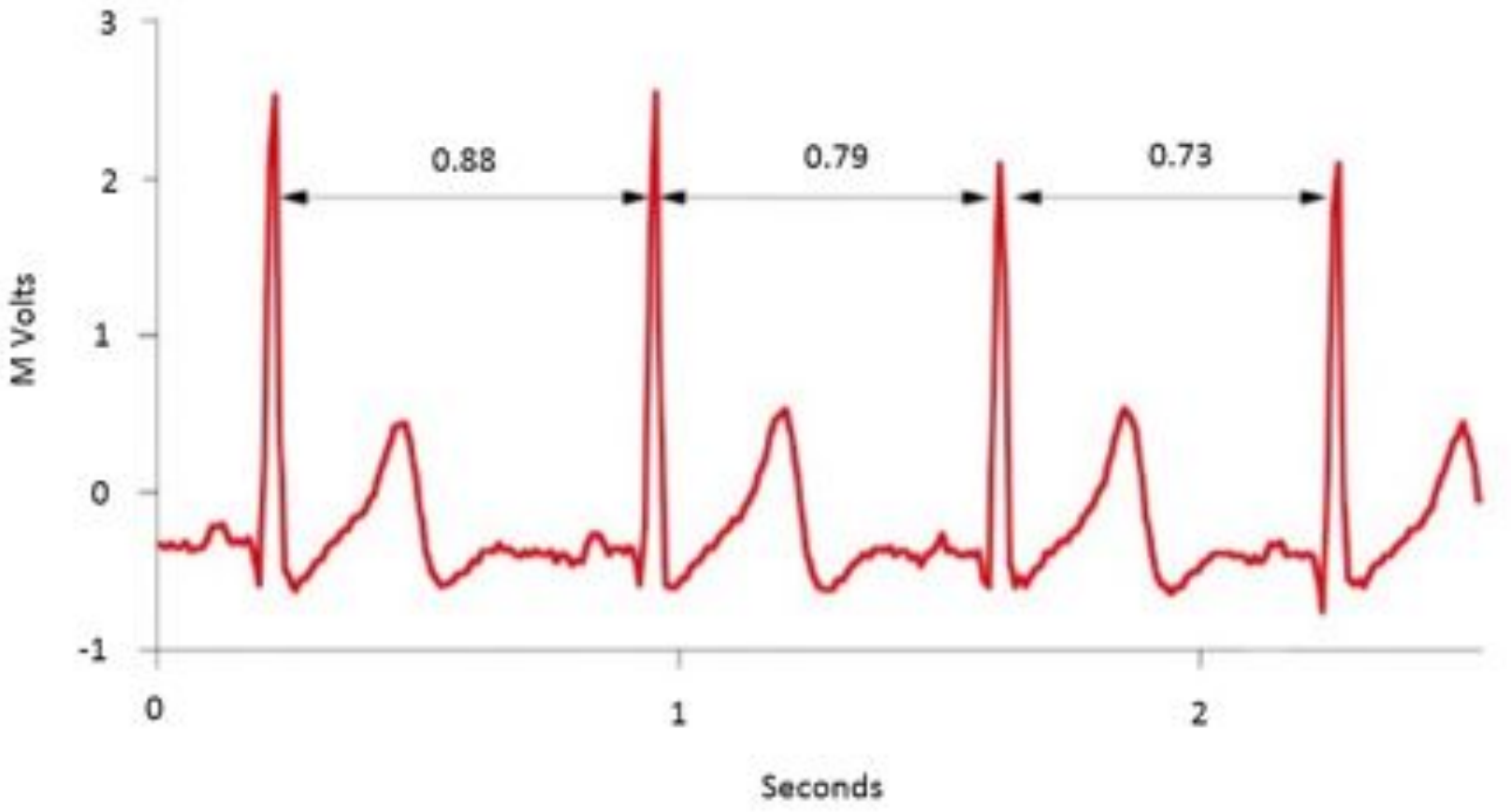
[Image courtesy: https://ecglibrary.com/norm.php]

RR-Interval Determination



[Image courtesy: https://www.researchgate.net/figure/A-typical-ECG-signal-showing-the-RR-interval_fig1_325170226]

Heart Rate Variability (HRV) Determination: Difference between RR-Intervals

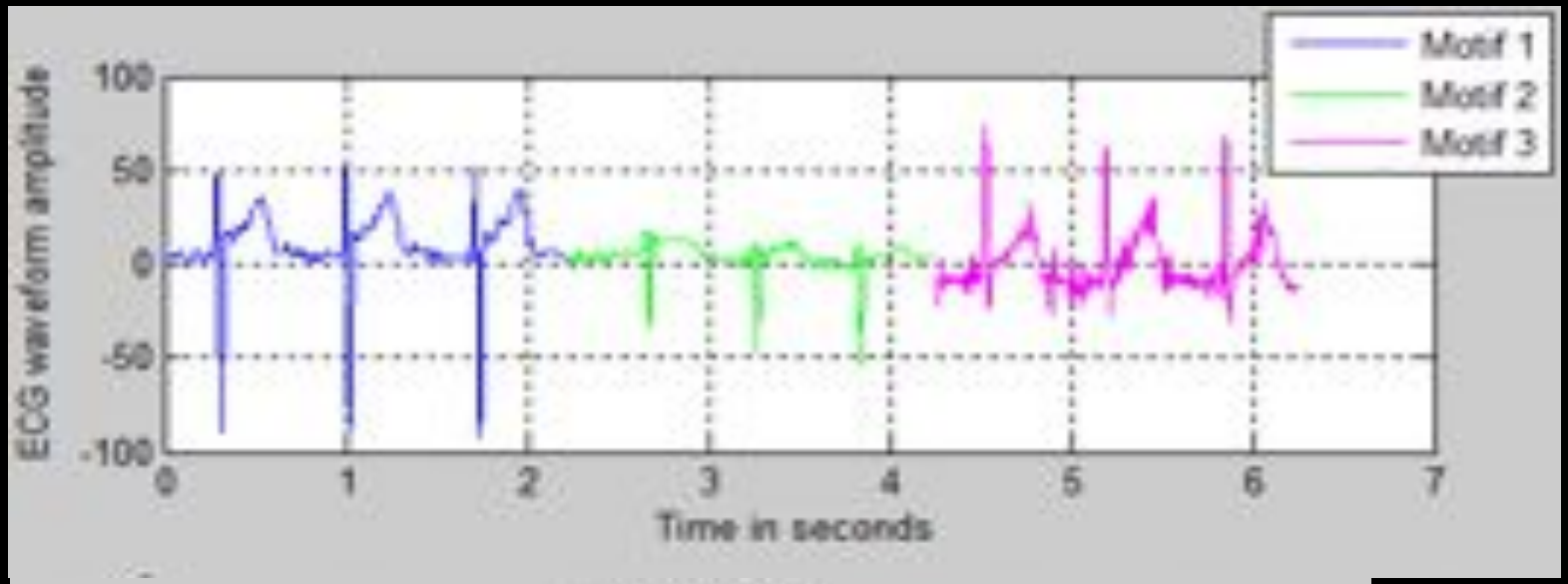


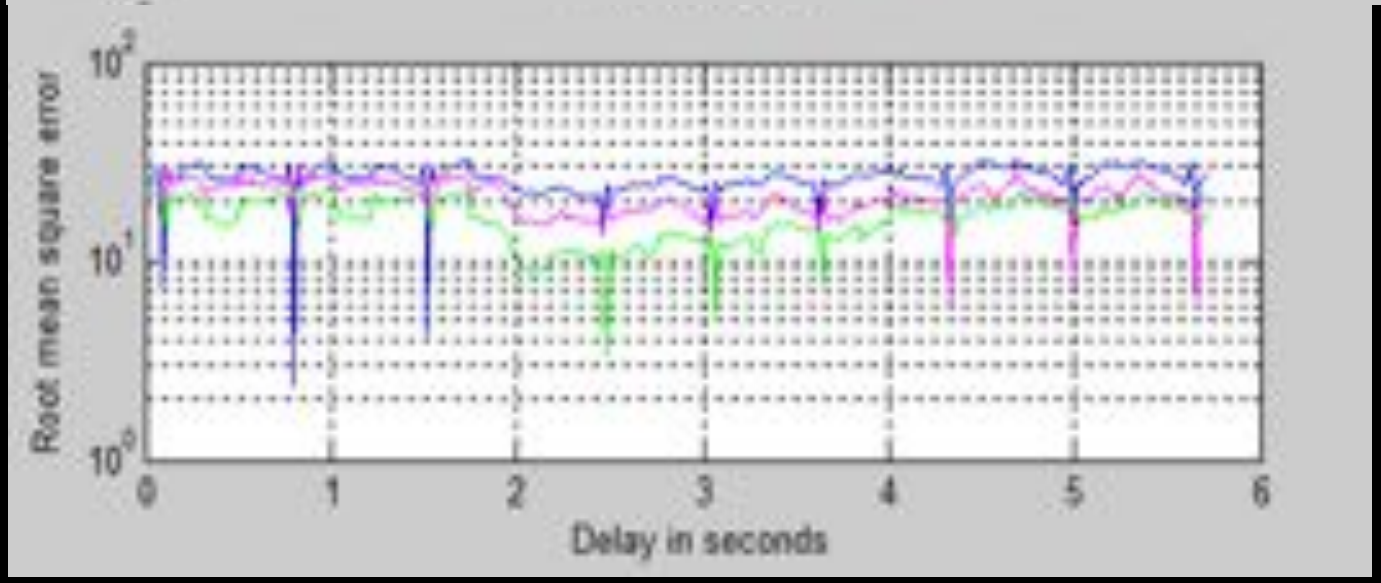
[Image courtesy: https://www.scienceforsport.com/heart-rate-variability-hrv/]

Determination of HRV from ECG Data

$$RMSSD = \sqrt{\frac{1}{N-1}\left(\sum_{i=1}^{N-1}\left(\left(R_{i+1}-R_i\right)-\left(R_i-R_{i-1}\right)\right)^2\right)}$$

Behavioral Motif Detection in Real Time: Via Root Mean Square Error Minimization





Motifs themselves extracted via, e.g., ANNs!

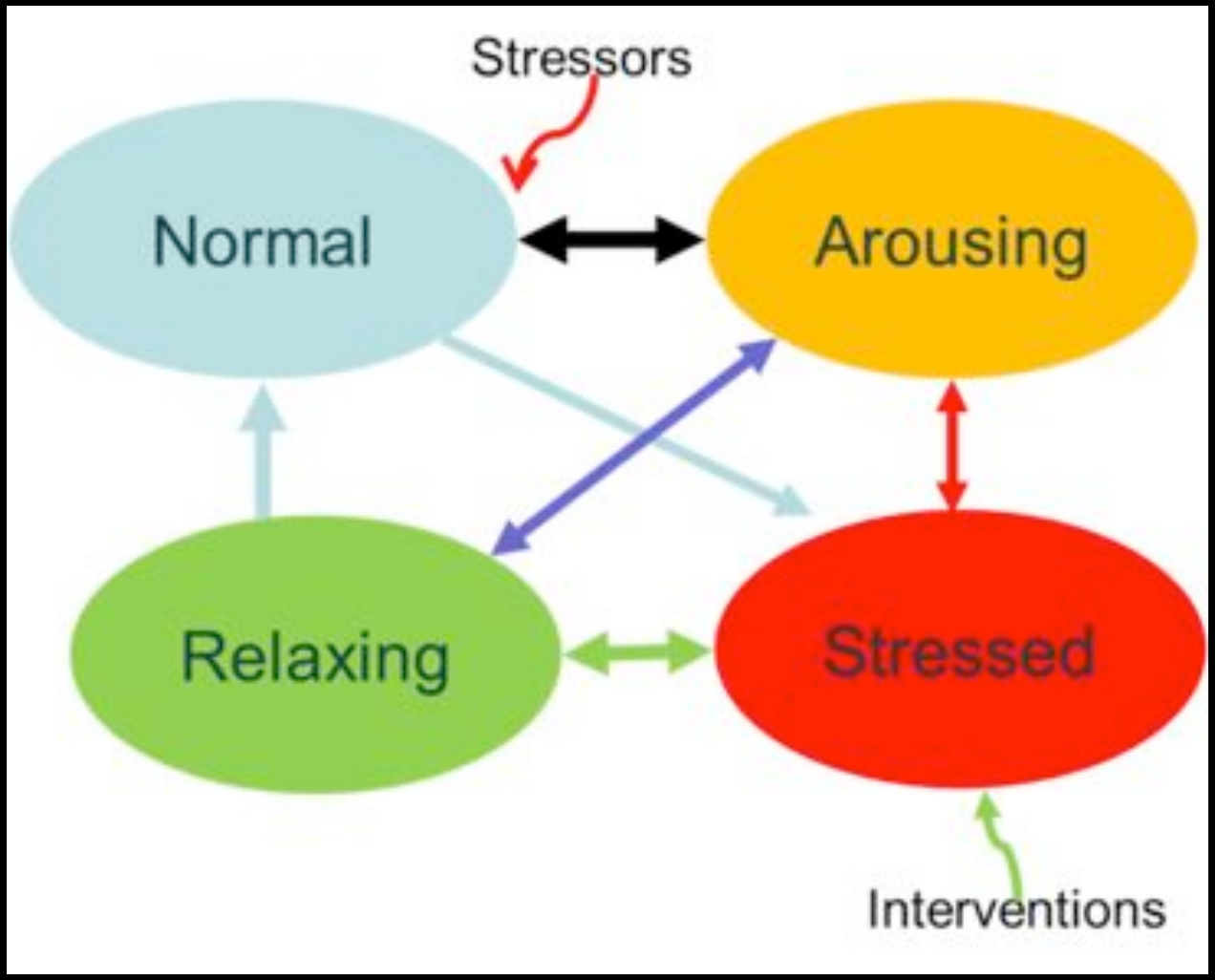
[Fink (University of Arizona) Patent Pending]

Effort #3 (Data Analytics):

PHM Theme: Robust Classification & Mitigation

Respiratory Waveform Data (i.e., Breathing Cycles) Analysis to Select YOGA Breathing Patterns for Immediate Intervention

Emotional Status Changes/Transitions



Roveda J, Fink W (2015) *Stress Management Using Wearable Sensors Using Integrated Data Information*; 2015 Defense Energy Innovation Summit, abstract and poster presentation

Examples of YOGA Breathing Exercises

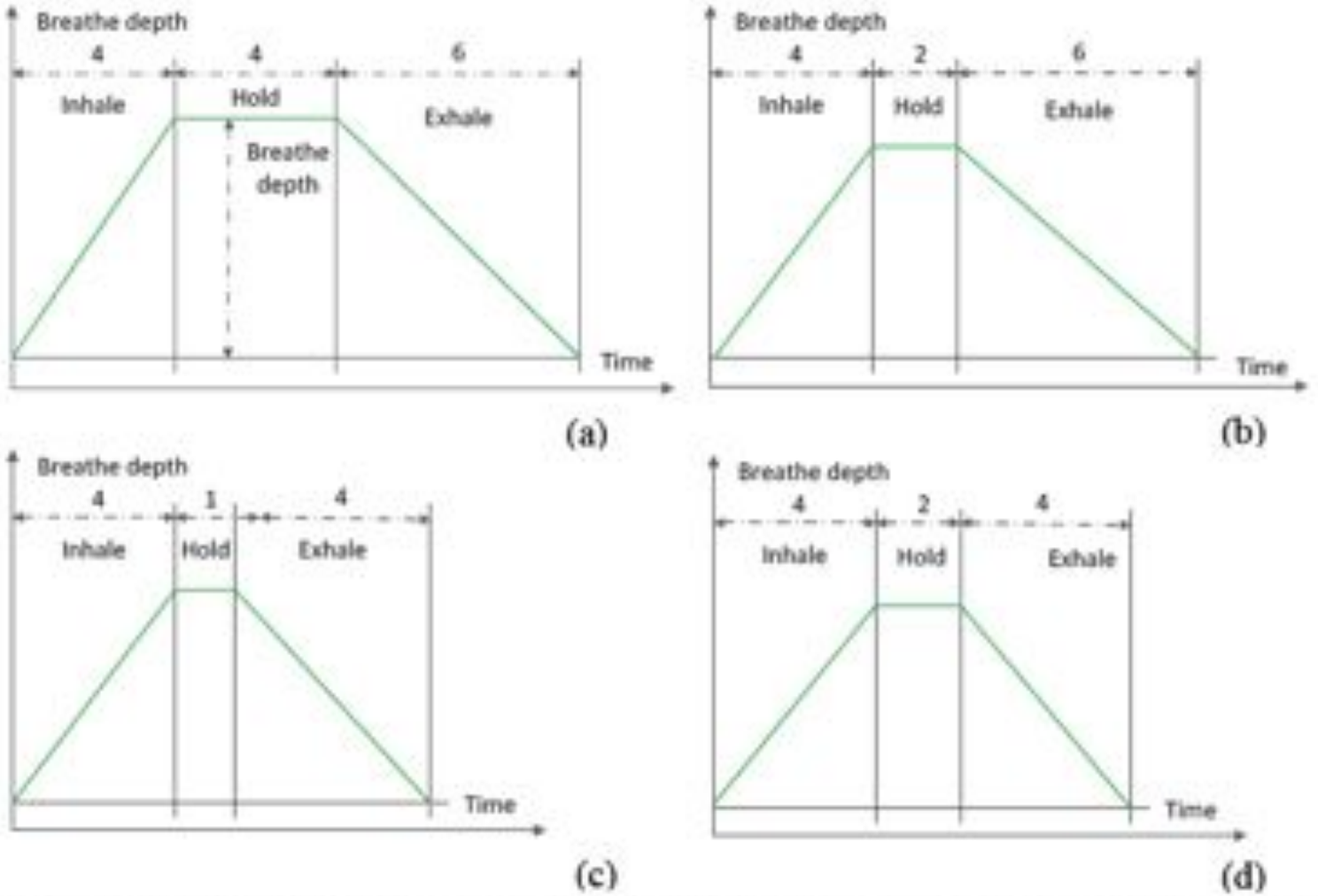
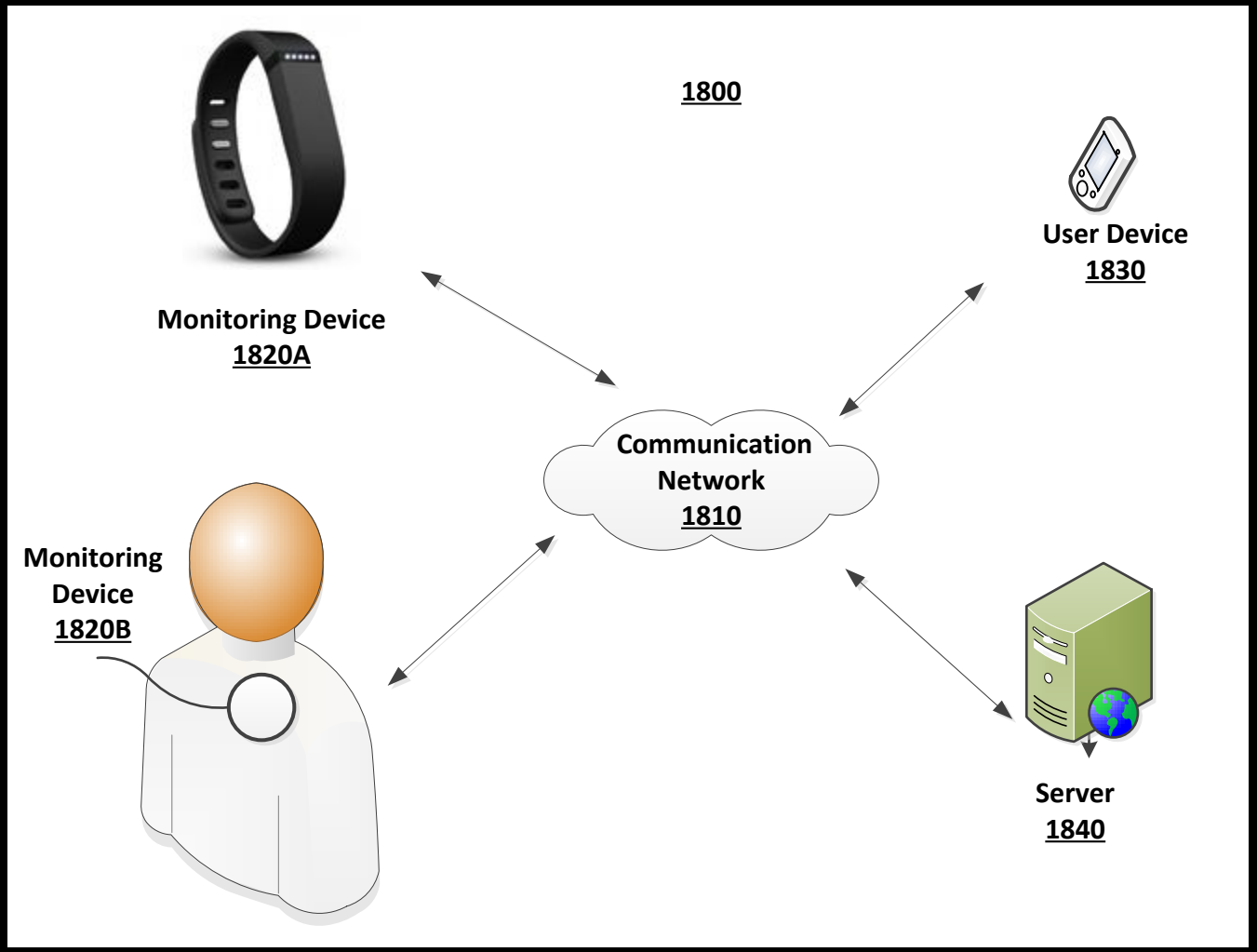


Figure1. Four YOGA breathing exercises represented in trapezoidal waveforms

- Chen K, Fink W, et al. (2015) Wearable Sensor Based Stress Management Using Integrated Respiratory and ECG Waveforms; IEEE International Conference on Body Sensor Network Conf. Proc., Boston, MA, June 9-11, 2015
- Fink (University of Arizona) Patent Pending

Cloud-based Network & Analysis Environment
For Implementing Wearable Sensors for Respiratory Waveforms



[Fink (University of Arizona) Patent Pending]

Raw Respiratory Waveform: Determine Leading FFT Components of Signal for Denoising

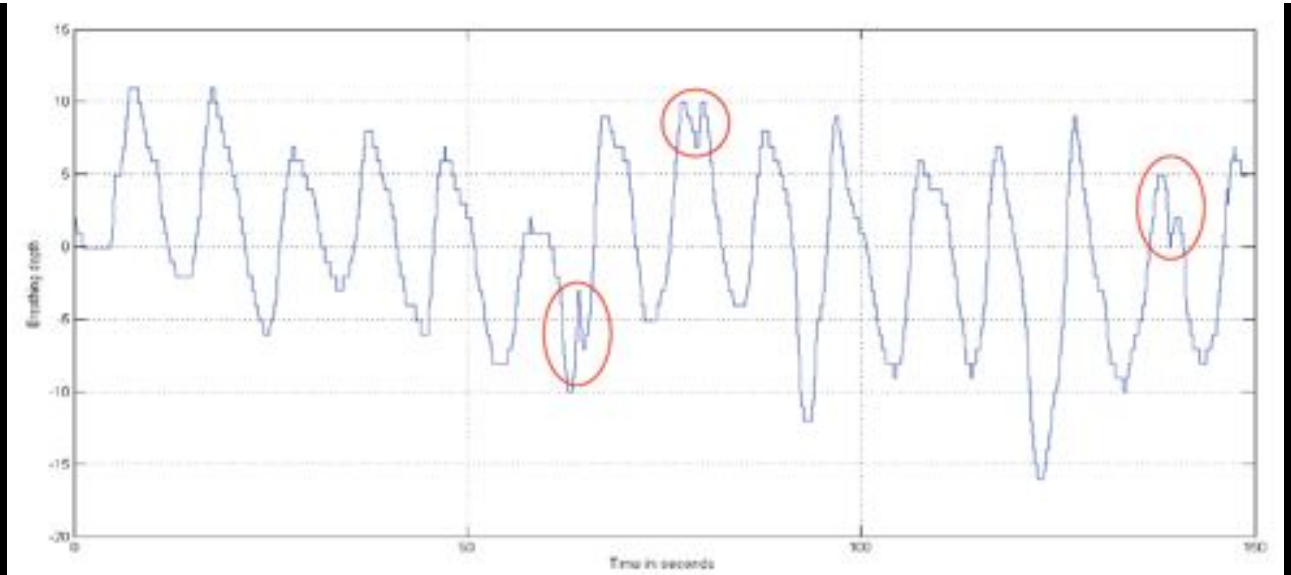


Figure 3. Noisy, Raw Respiratory Waveforms with fourteen cycles in the time domain

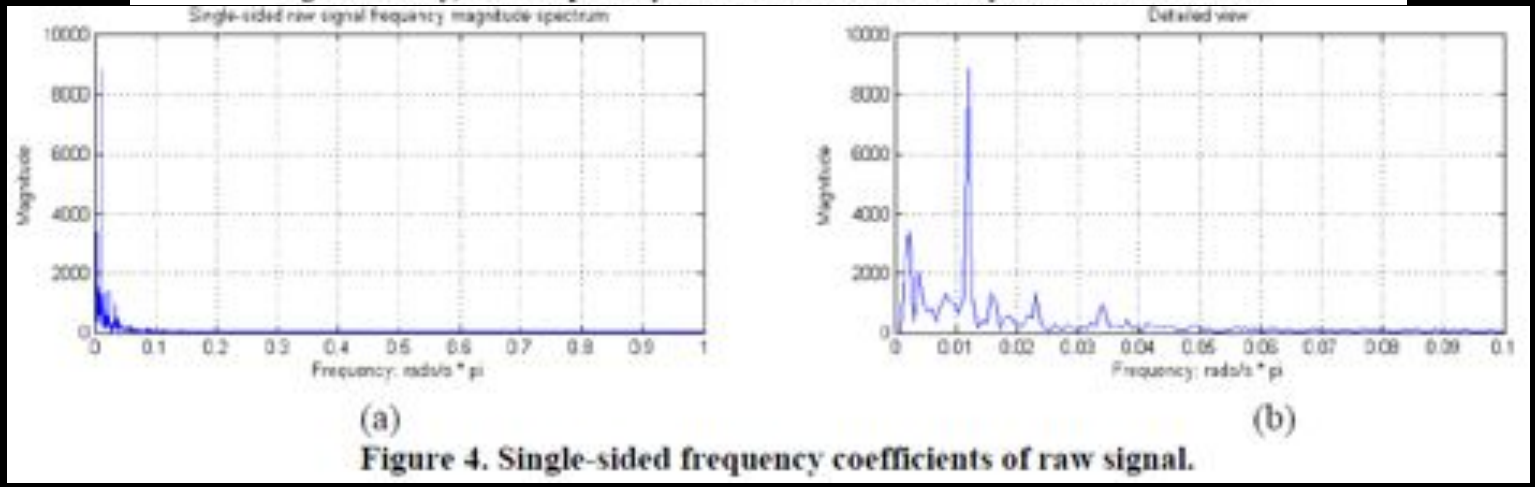


Figure 4. Single-sided frequency coefficients of raw signal.

- Chen K, Fink W, et al. (2015) Wearable Sensor Based Stress Management Using Integrated Respiratory and ECG Waveforms; IEEE International Conference on Body Sensor Network Conf. Proc., Boston, MA, June 9-11, 2015
- Fink (University of Arizona) Patent Pending

IFFT Processed Respiratory Waveform: Simplified Detection of Breathing Cycles

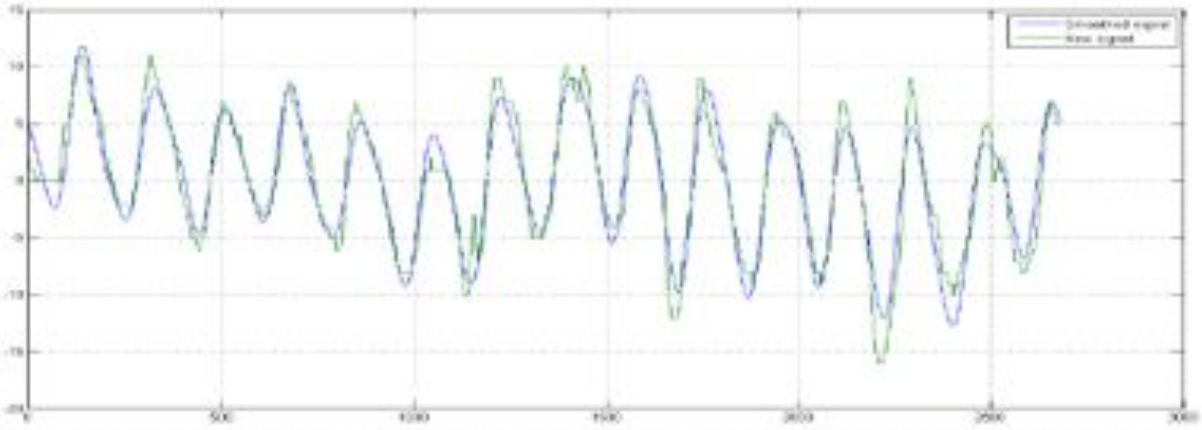


Figure 6. The time domain IFFT processed waveform (blue) with the original raw respiratory waveform (green).

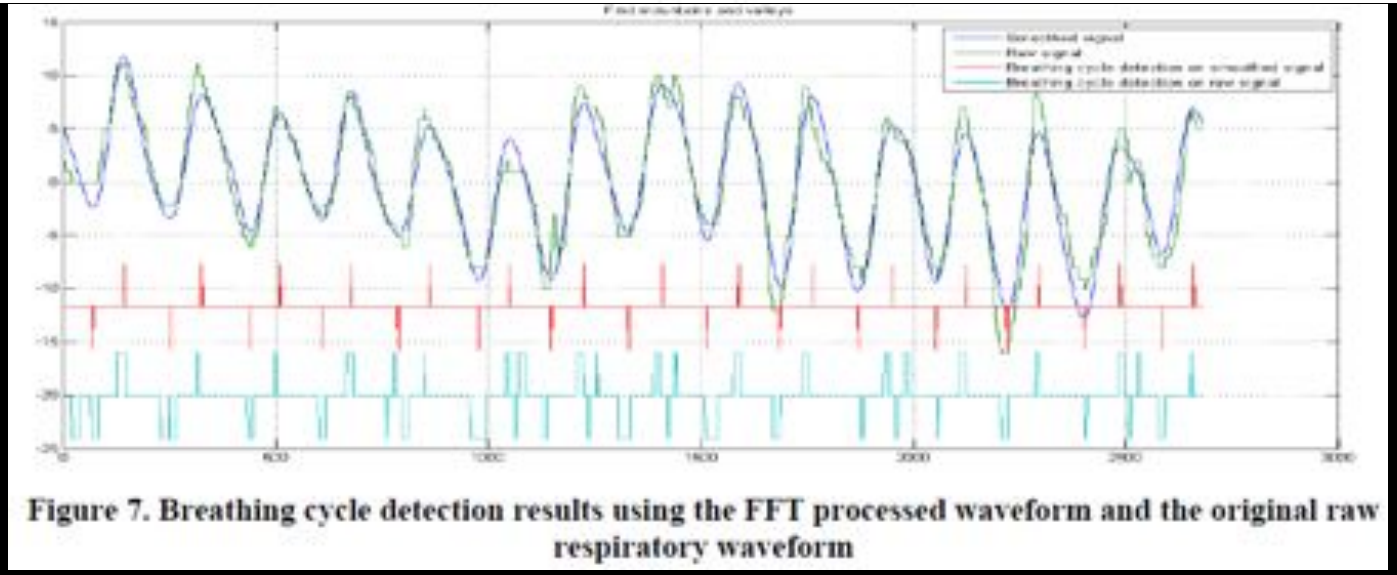


Figure 7. Breathing cycle detection results using the FFT processed waveform and the original raw respiratory waveform

- Chen K, Fink W, et al. (2015) Wearable Sensor Based Stress Management Using Integrated Respiratory and ECG Waveforms; IEEE International Conference on Body Sensor Network Conf. Proc., Boston, MA, June 9-11, 2015
- Fink (University of Arizona) Patent Pending

Time-averaged Breathing Cycles: YOGA Breathing Exercises *Independent* from Breathing Depth

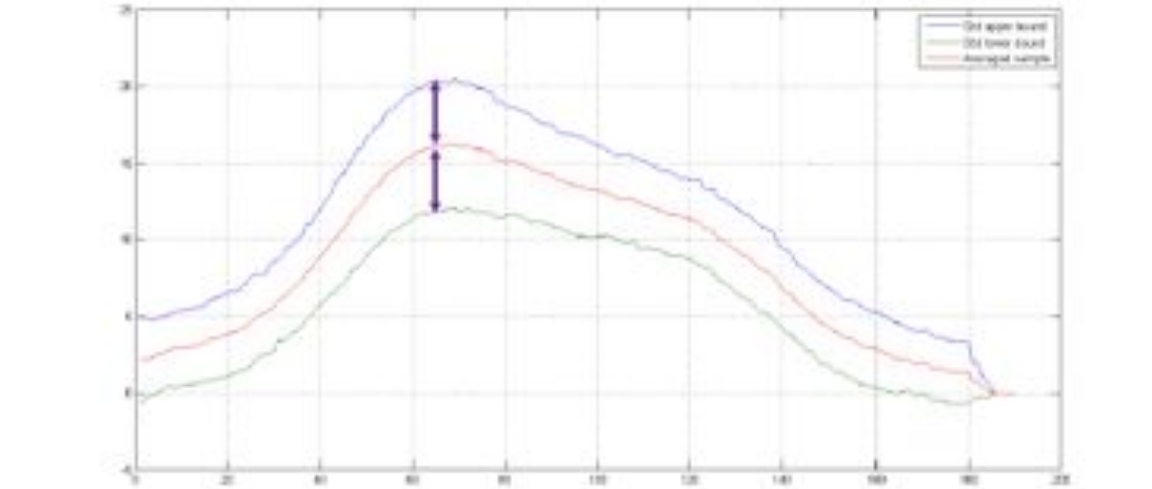


Figure 8. Averaged respiratory waveform with upper bound and lower bound.

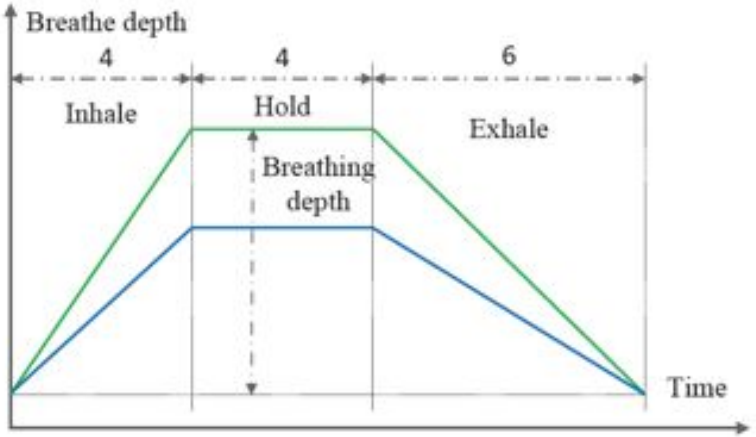


Figure 2. Respiratory waveform of two users with different breathing depth and the same inhale, hold, and exhale time.

- Chen K, Fink W, et al. (2015) Wearable Sensor Based Stress Management Using Integrated Respiratory and ECG Waveforms; IEEE International Conference on Body Sensor Network Conf. Proc., Boston, MA, June 9-11, 2015
- Fink (University of Arizona) Patent Pending

Determination of Optimal YOGA Breathing Exercise: Fitting Error Minimization

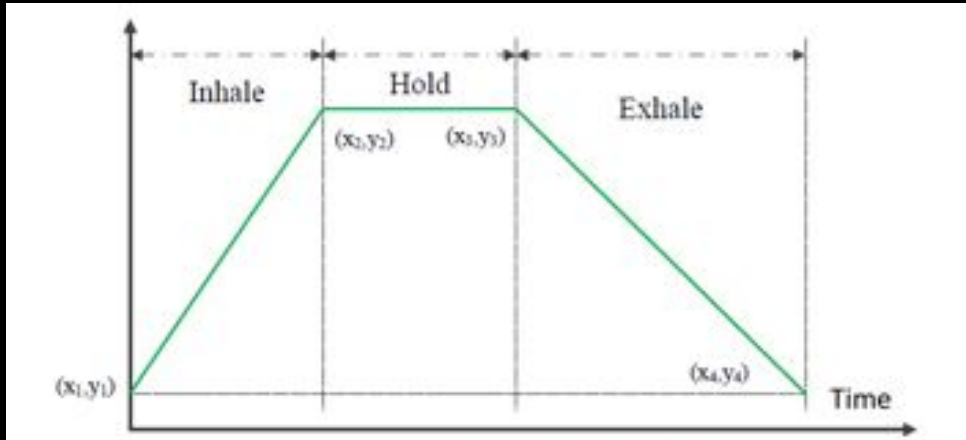
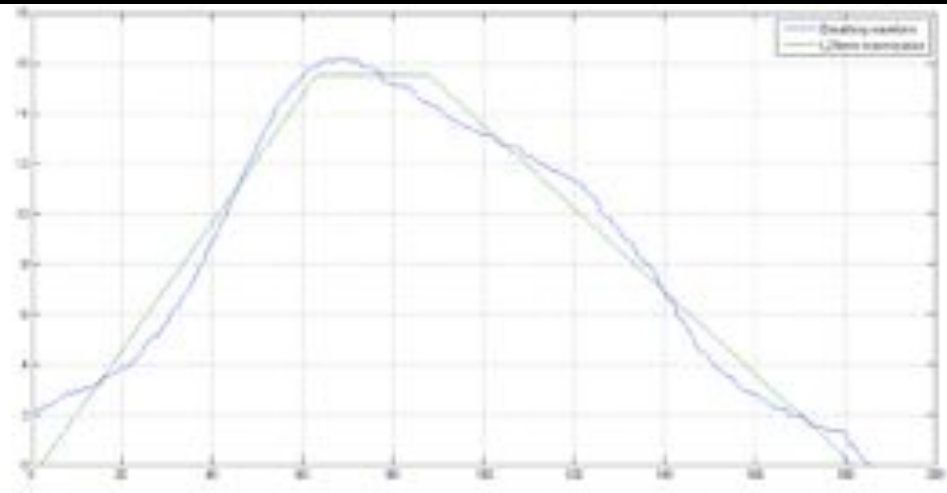
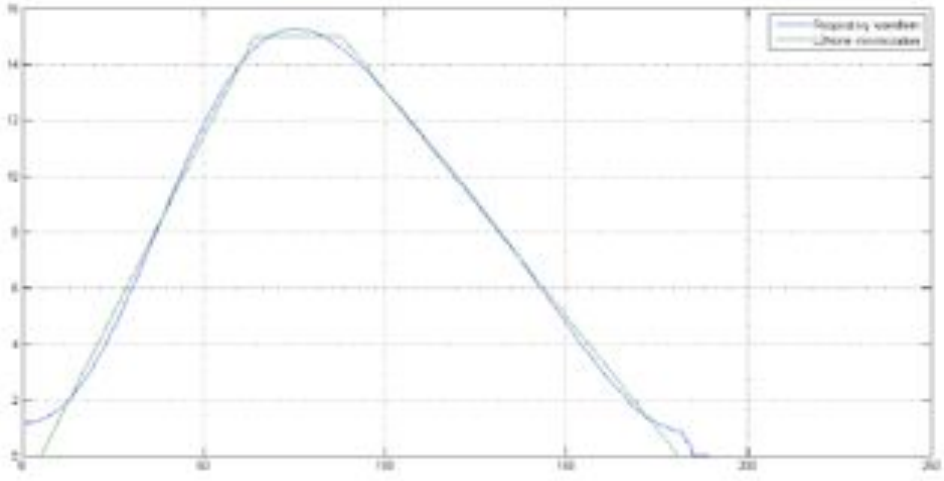


Figure 9. One trapezoidal waveform defined by four points for optimization.





- Chen K, Fink W, et al. (2015) Wearable Sensor Based Stress Management Using Integrated Respiratory and ECG Waveforms; IEEE International Conference on Body Sensor Network Conf. Proc., Boston, MA, June 9-11, 2015
- Fink (University of Arizona) Patent Pending

Summary & Outlook

InTelMed Center addresses the following major market needs:

(1) *Professional medical market*, such as: first responders, paramedics, medics, doctors, clinics, and hospitals

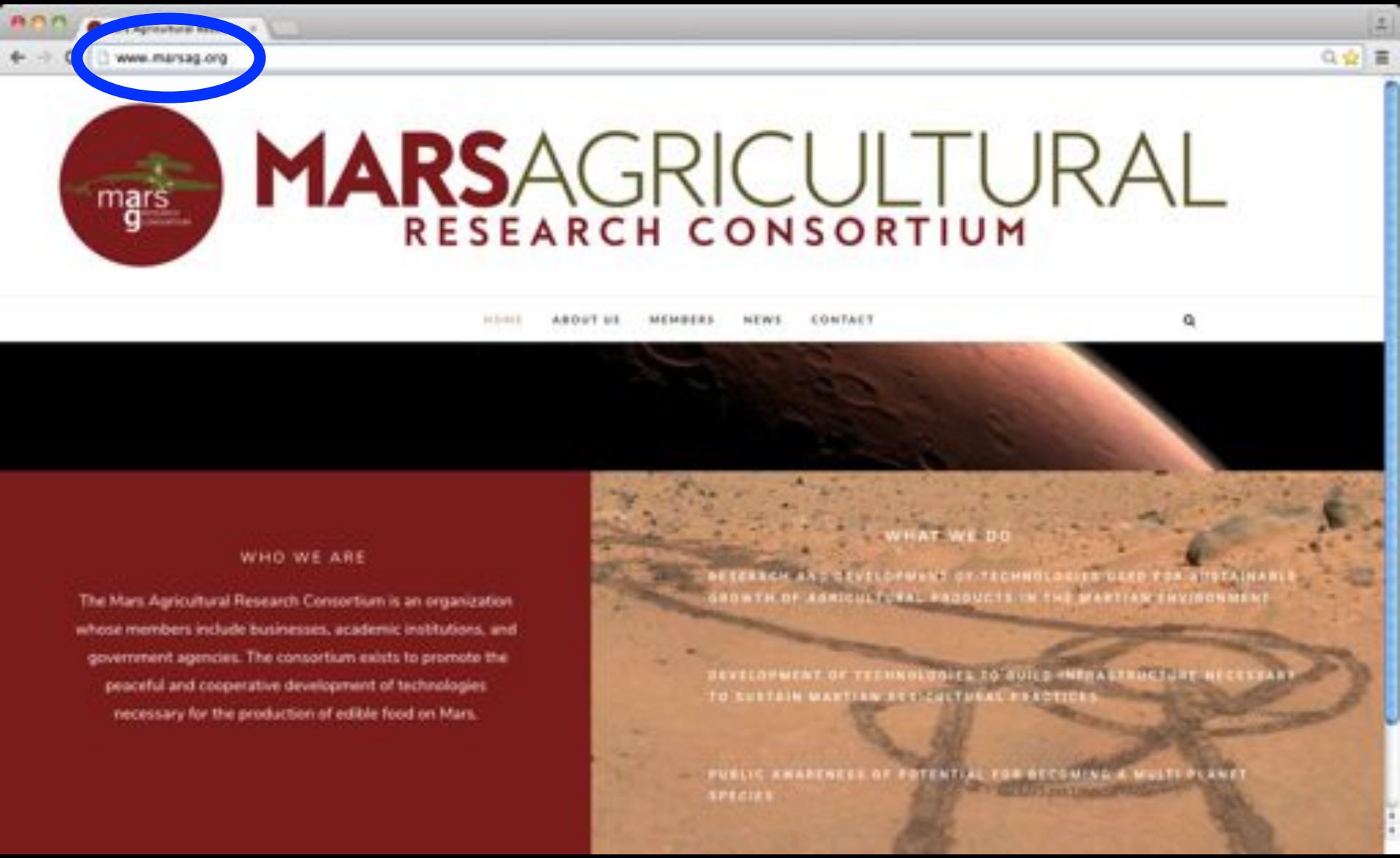
(2) *Military market*, such as: warfighter, forward operating bases

(3) *Emerging field of Mobile Health (M-Health)* and growing global markets for *Telemedicine Technologies*

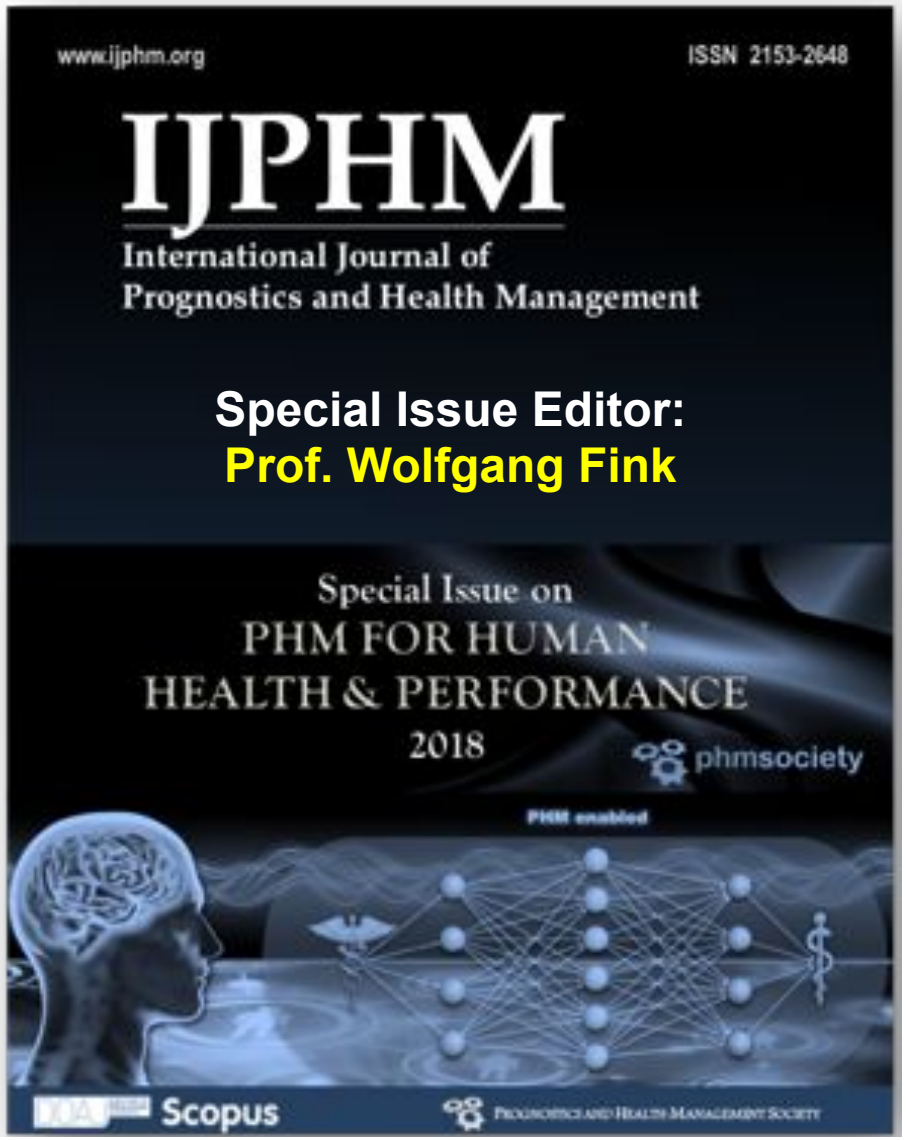
(4) *Enabler for PHM for Human Health & Performance: all data mining, data understanding, and predictive techniques applicable*

(5) *Exemplar for other Medical Applications: same framework*

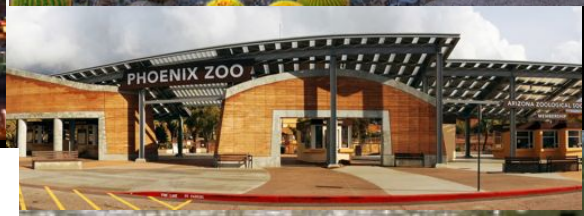
Mars Agricultural Research Consortium (MARSAG):
Currently recruiting Corporate Members



Special Issue of *IJPHM:*
Expected Publication: *December 2018*



Welcome to PHM 2019 in Scottsdale, AZ



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