Everything You Wanted to Know About Smart Healthcare

Fulbright Lecture 2023 – KL Deemed University

Guntur, India, 1-31 July 2023

Homepage

Prof./Dr. Saraju Mohanty
University of North Texas, USA.

Outline

- Healthcare → Smart Healthcare
- Smart Healthcare - Characteristics
- Smart Healthcare - Components
- Smart Healthcare - Examples
- Smart Healthcare - Challenges
- Conclusions and Future Directions

Healthcare
to
Smart Healthcare

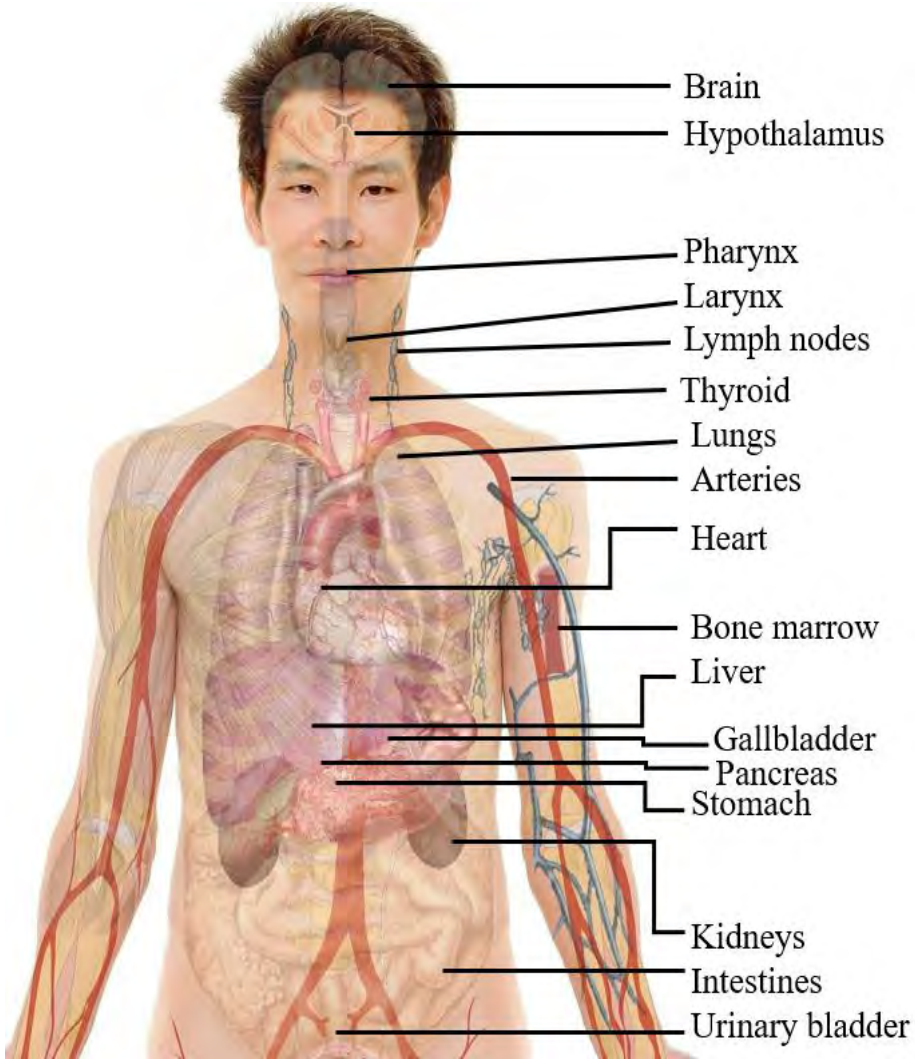
Human Body and Health

Human Body

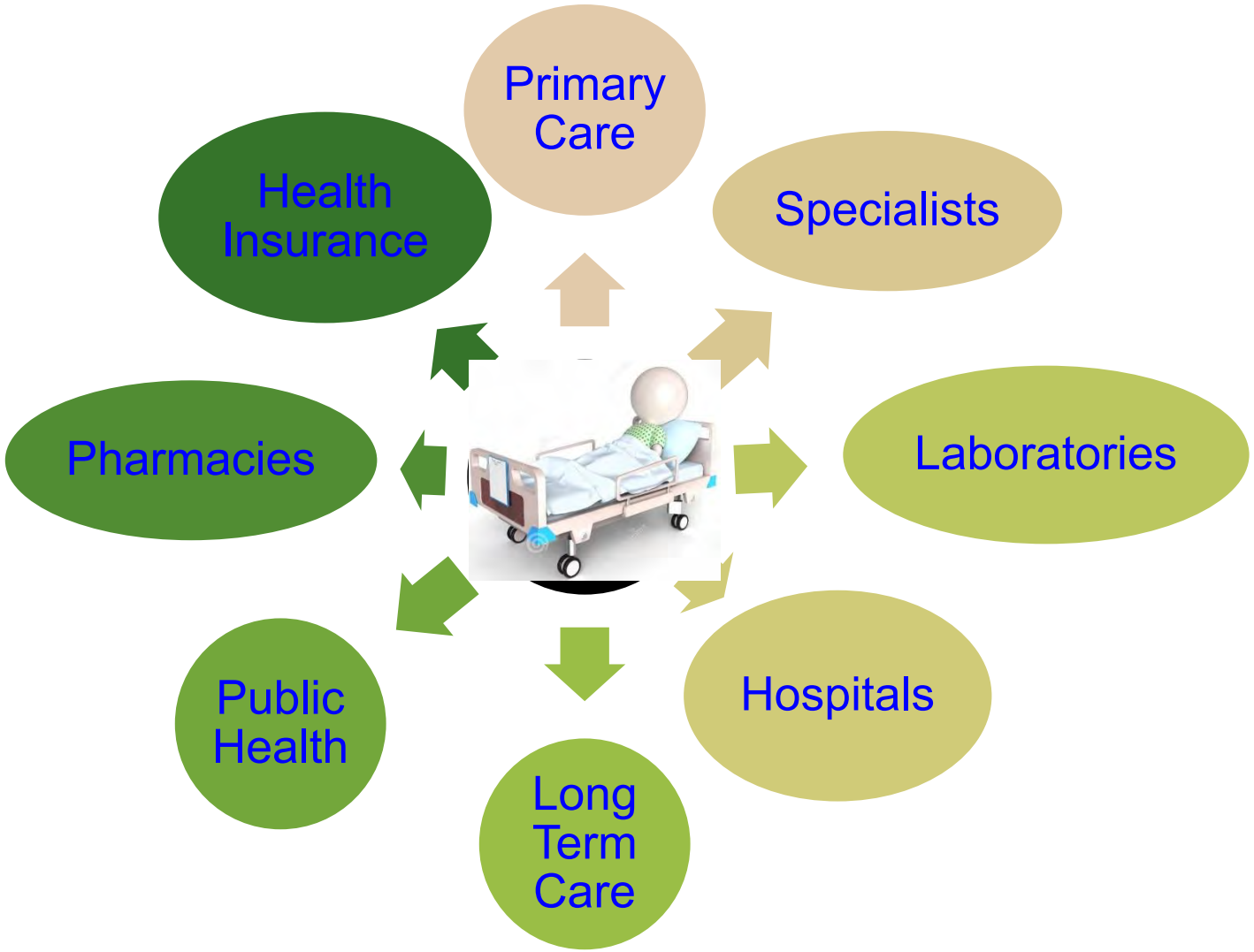
- From an engineering perspective, the human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical …).

Health

- Human health is a state of complete physical, mental and social well-being.



Traditional Healthcare

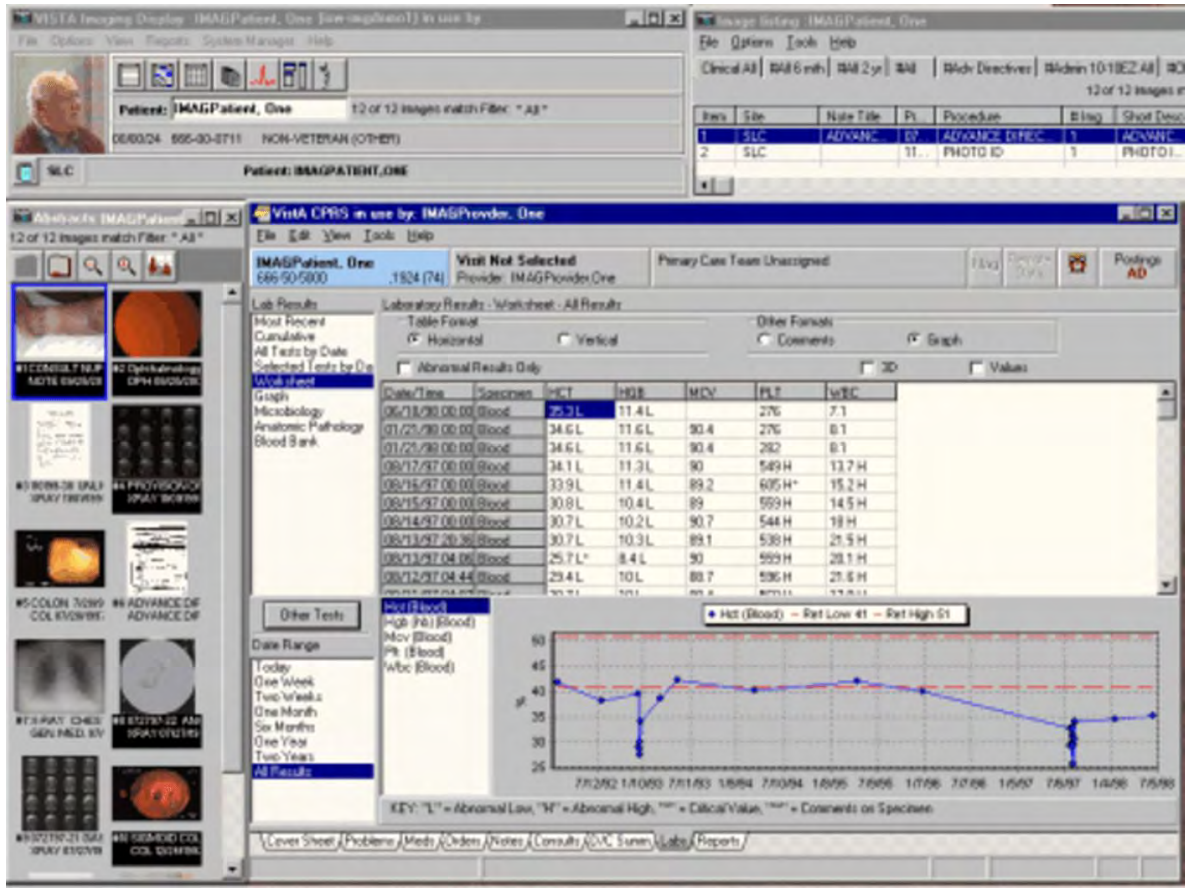


- Physical presence needed
- Deals with many stakeholders
- Stakeholders may not interact
- May not be personalized
- Not much active feedback
- No follow-up from physicians

Telemedicine

Telemedicine is the use of telecommunication and information technology to provide clinical health care from a distance.

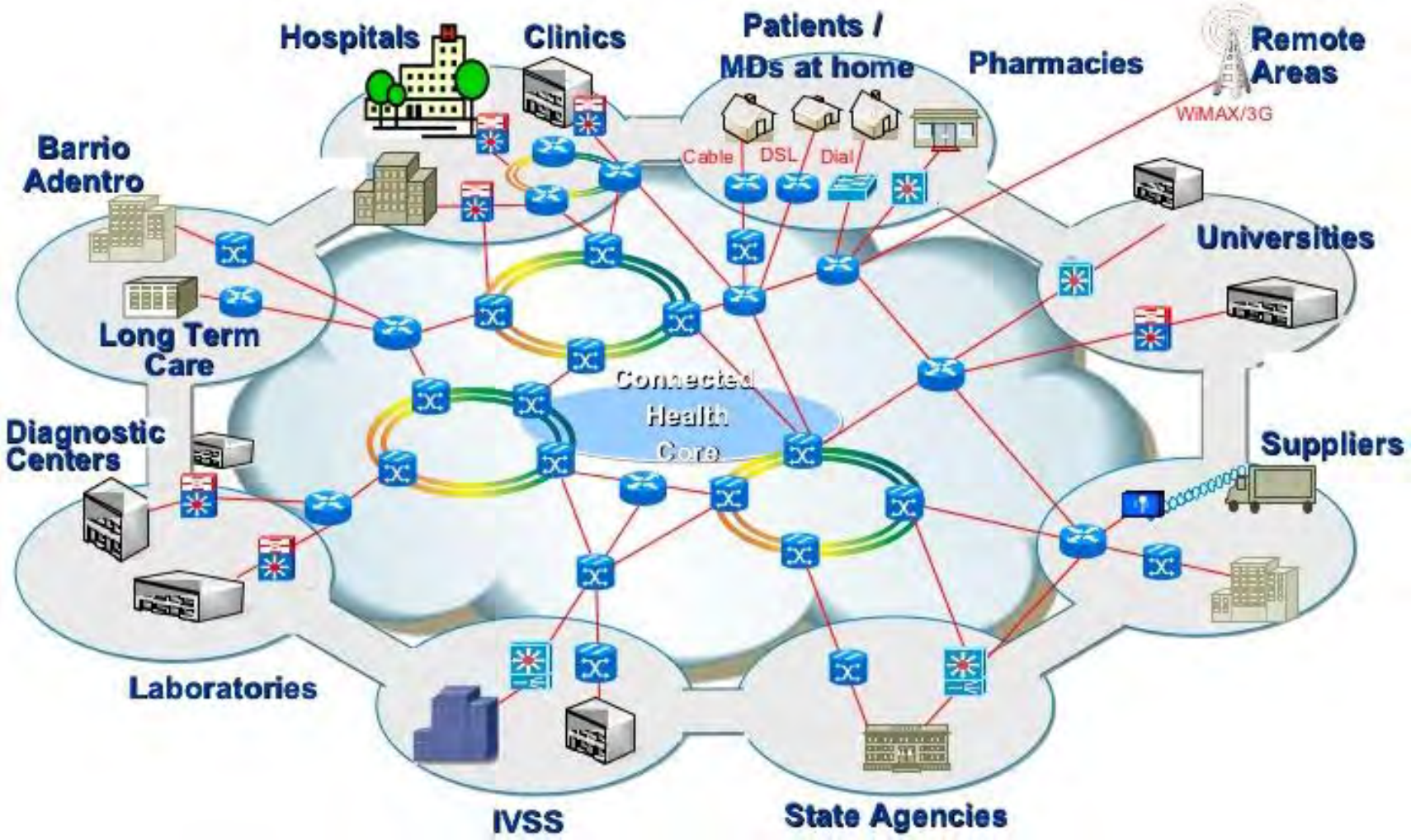
Electronic Health (eHealth)



Source: W. O. Nijeweme-d'Hollosy, L. van Velsen, M. Huygens and H. Hermens, "Requirements for and Barriers towards Interoperable eHealth Technology in Primary Care," *IEEE Internet Computing*, vol. 19, no. 4, pp. 10-19, July-Aug. 2015.

eHealth: The use of information and communication technologies (ICT) to improve healthcare services.

Connected Health (cHealth)



Source: https://www.slideshare.net/tibisay_hernandez/connected-health-venfinal

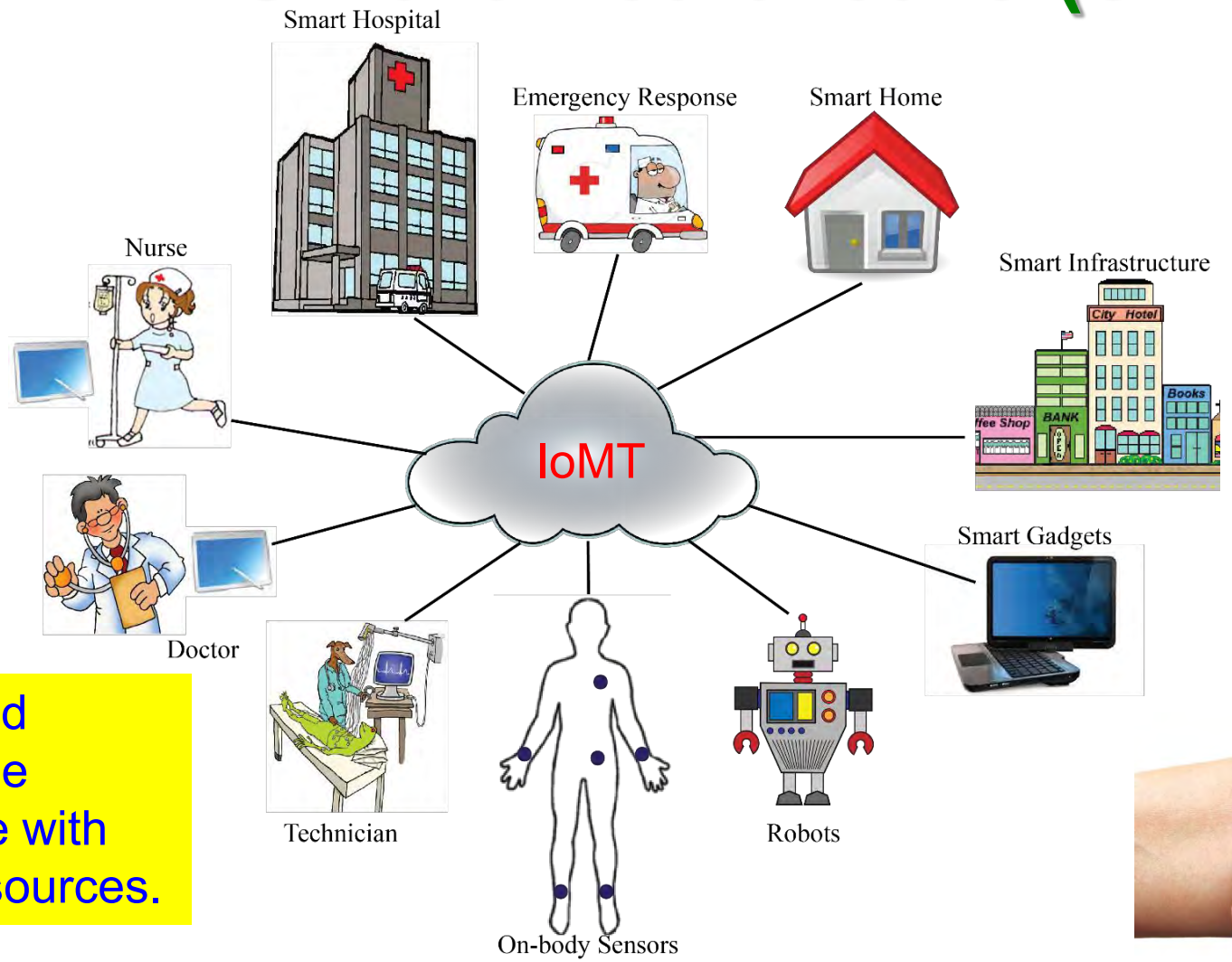
cHealth: Connections of the various healthcare stake holders through Internet to share appropriate data to better serve the patients.

Mobile Health (mHealth)

mHealth: Healthcare supported by *mobile devices* that uses mobile telecommunications and multimedia technologies for the delivery of healthcare services and health information.

Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

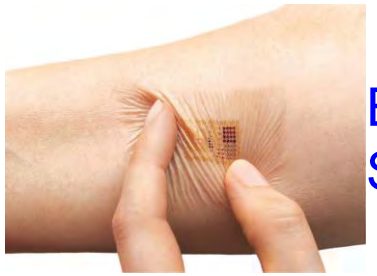
Smart Healthcare (sHealth)



Fitness Trackers

Headband with Embedded Neurosensors

Quality and sustainable healthcare with limited resources.



Embedded Skin Patches

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 7, Issue 1, January 2018, pp. 18-28.

Transitions in Healthcare

Healthcare

eHealth

The use of information and communication technologies (ICT) to improve healthcare services.

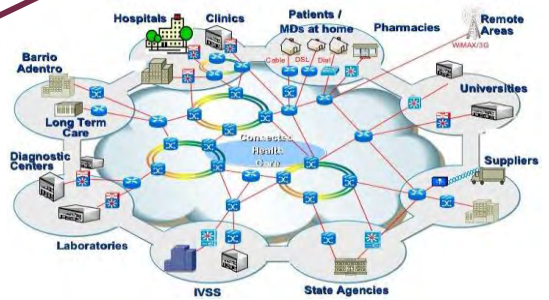
Telemedicine

Telemedicine is the use of telecommunication and information technology to provide clinical healthcare from a distance.

mHealth

Healthcare supported by *mobile devices* that uses mobile telecommunications and multimedia technologies for the delivery of healthcare services and health information.

cHealth



sHealth

Embedded Skin Patches

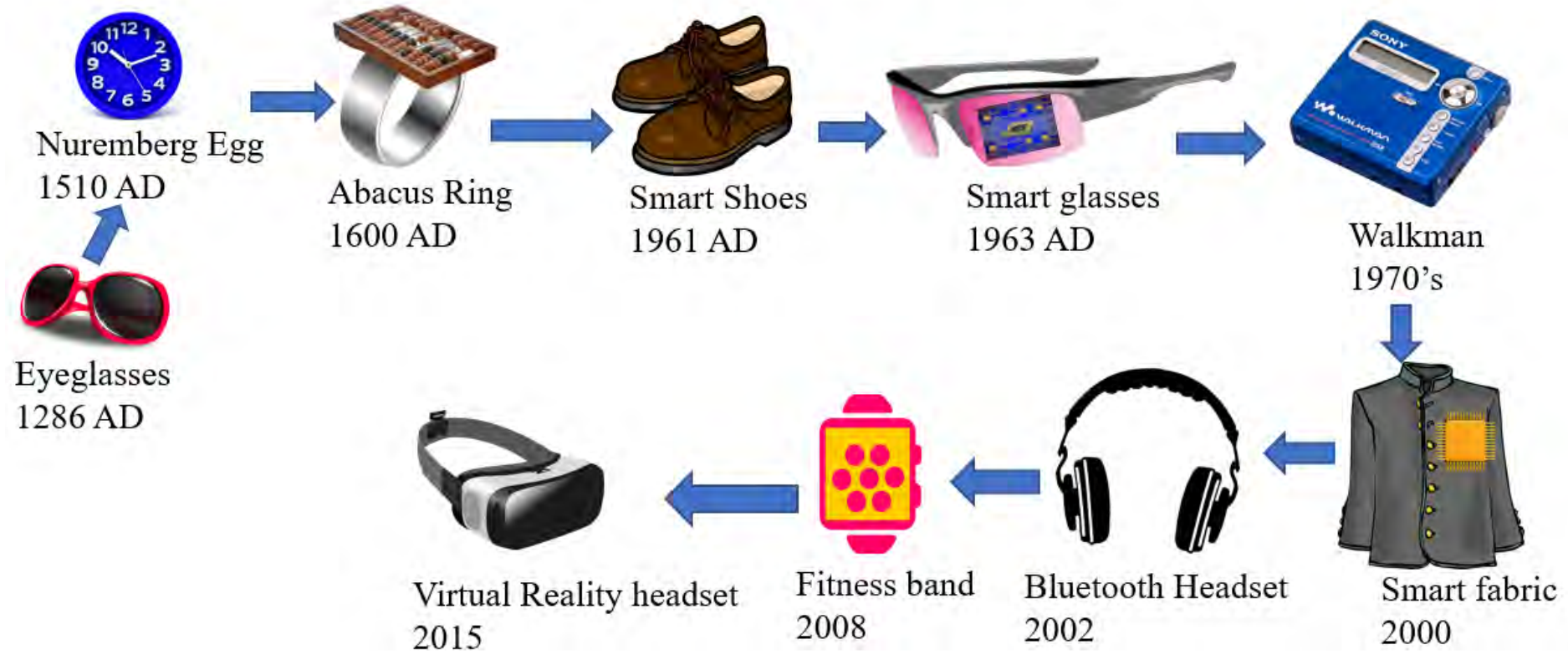
Spire Stone - Breath

Thync's - UltrasoVibeund

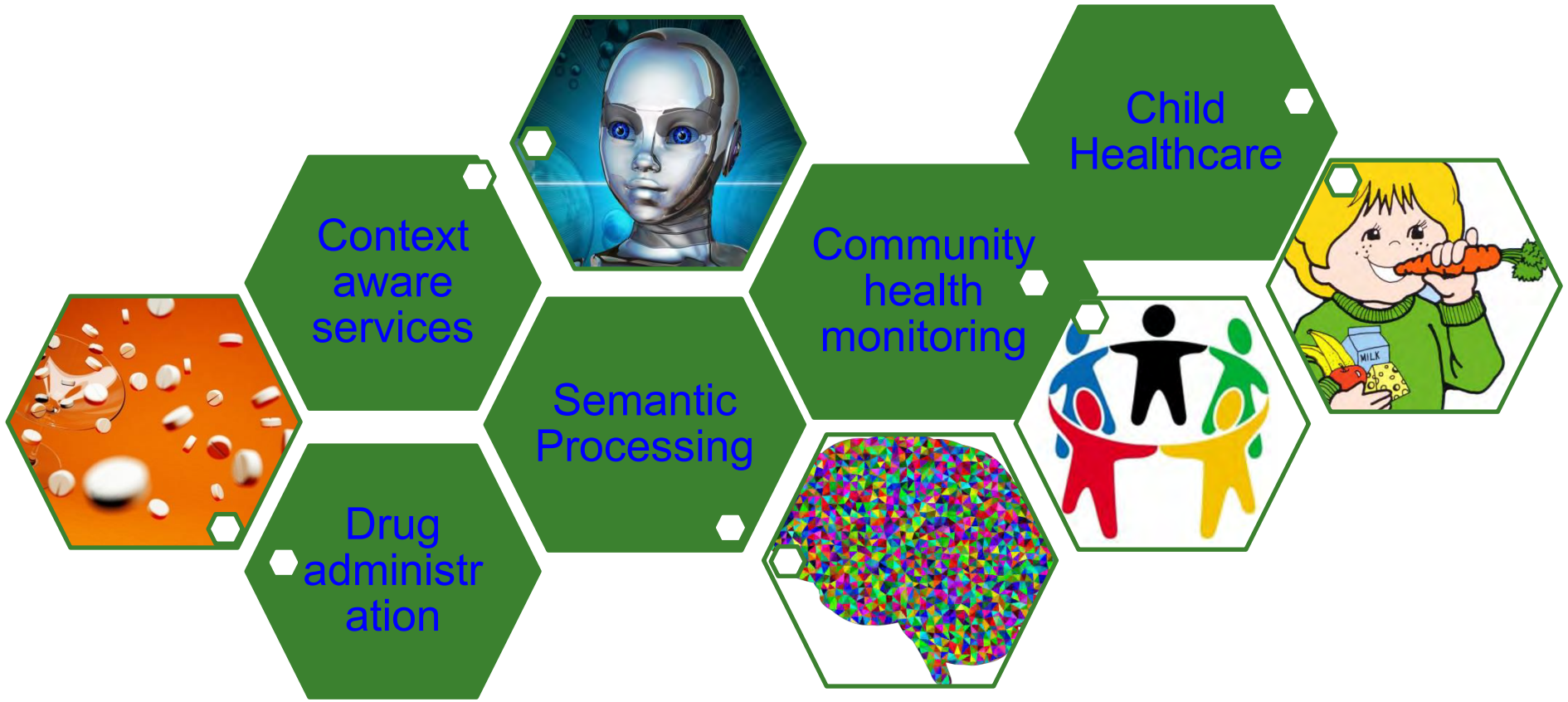
Muse - EEG

Source: Saraju P. Mohanty, "Smart Healthcare: From Healthcare to Smart Healthcare", ICCE 2020 Panel, Jan 2020.

Wearables - Evoluation



Smart Healthcare - Services



Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - Characteristics

What is Smart Healthcare?

Smart Healthcare ←
- Conventional Healthcare
- + Body sensors
- + Smart Technologies
- +Information & Communication Technology (ICT)
- + AI/ML

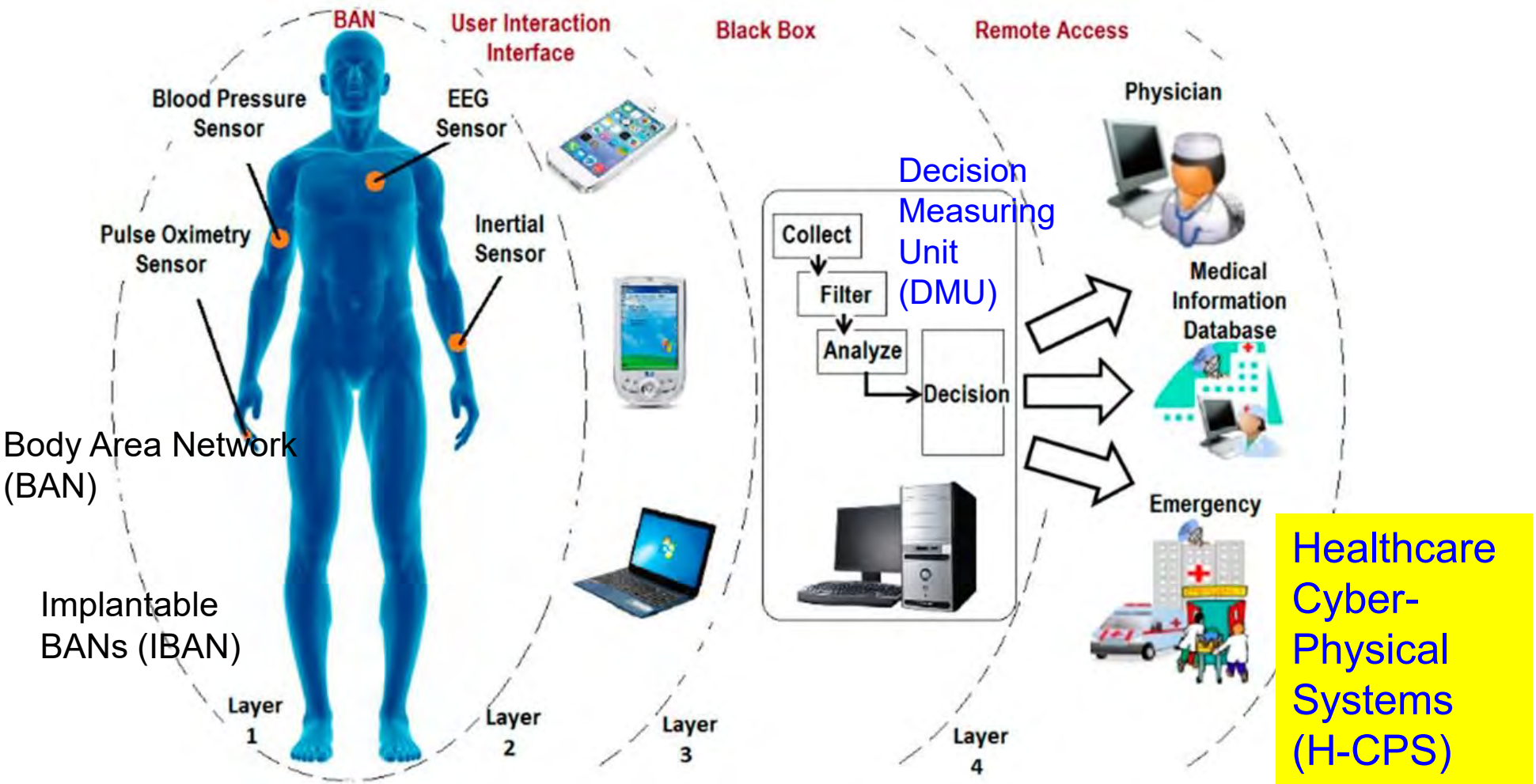
Internet of Medical Things (IoMT)

Internet of Health Things (IoHT)

Healthcare Cyber-Physical Systems (H-CPS)

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - 4-Layer Architecture



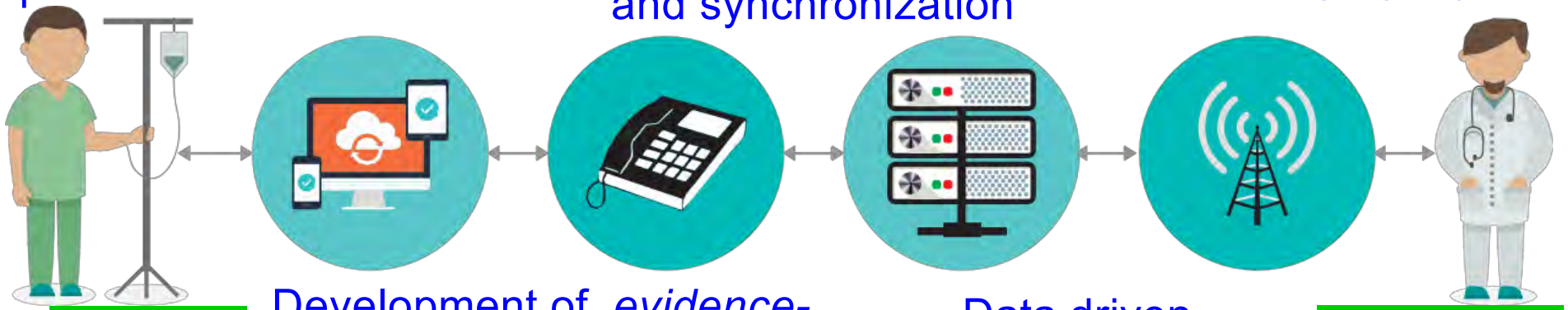
Source: M. Ghamari, B. Janko, R.S. Sherratt, W. Harwin, R. Piechockic, and C. Soltanpur, "A Survey on Wireless Body Area Networks for eHealthcare Systems in Residential Environments", *Sensors*, 2016. 16(6): p. 831.

IoMT based H-CPS

Patient-specific care with *context* and enabled through past health records.

Improved inter-device connection and synchronization

Real-time *tracking* and intervention



Patient

Development of *evidence-based guidelines* which can helpful to incorporate the local intelligence in future machine.

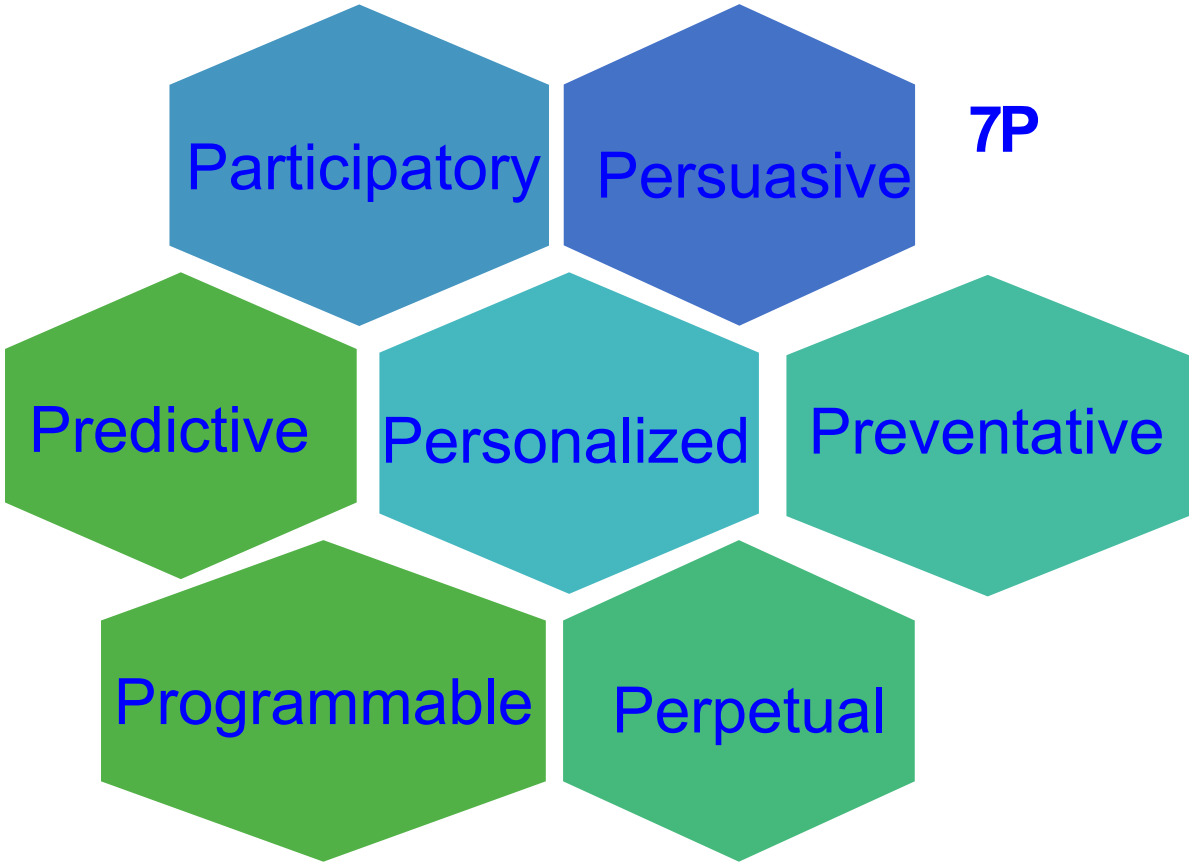
Data driven health *prediction*

Healthcare Provider

Healthcare Cyber-Physical Systems (H-CPS)

Source: Y. Shelke and A. Sharma, "Internet of Medical Things", 2016, Aranca, https://www.aranca.com/knowledge-library/special-reports/ip-research/the-internet-of-medical-things-iomt, Last Visited 10/18/2017.

Smart Healthcare – 7Ps



Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Smart Healthcare Tasks

Personal & Community

- Remote Monitoring
- Self-management of chronic conditions
- Performance improvement
- Behavior modification
- Stress Monitoring
- Therapy Result Measurement
- Social Activities
- Diet Management
- Detection & Diagnosis
- Remote Treatment

In Hospitals

- Real-time Patient Monitoring
- Equipment Tracking
- Performance improvement
- Behavior modification
- Detection & diagnosis
- Treatment
- Product Recalls
- Prevent Medication Error
- Smart Alert System

Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", IEEE Consumer Electronics Magazine, 2019, Accepted.

IoMT Advantages & Limitations

Advantages

Patients/Users

- Real-time interventions in emergency
- Cost reduction
- Reduced morbidity and financial burden due to less follow up visits

Healthcare Service Providers

- Optimal utilization of resources
- Reduced response time in emergency

Manufacturers

- Standardization/compatibility and uniformity of data available
- Capability to sense and communicate health related information to remote location

Limitations

Technical Challenges

- Security of IoT data - hacking and unauthorized use of IoT
- Lack of standards and communication protocols
- Errors in patient data handling
- Data integration
- Need for medical expertise
- Managing device diversity and interoperability
- Scale, data volume and performance

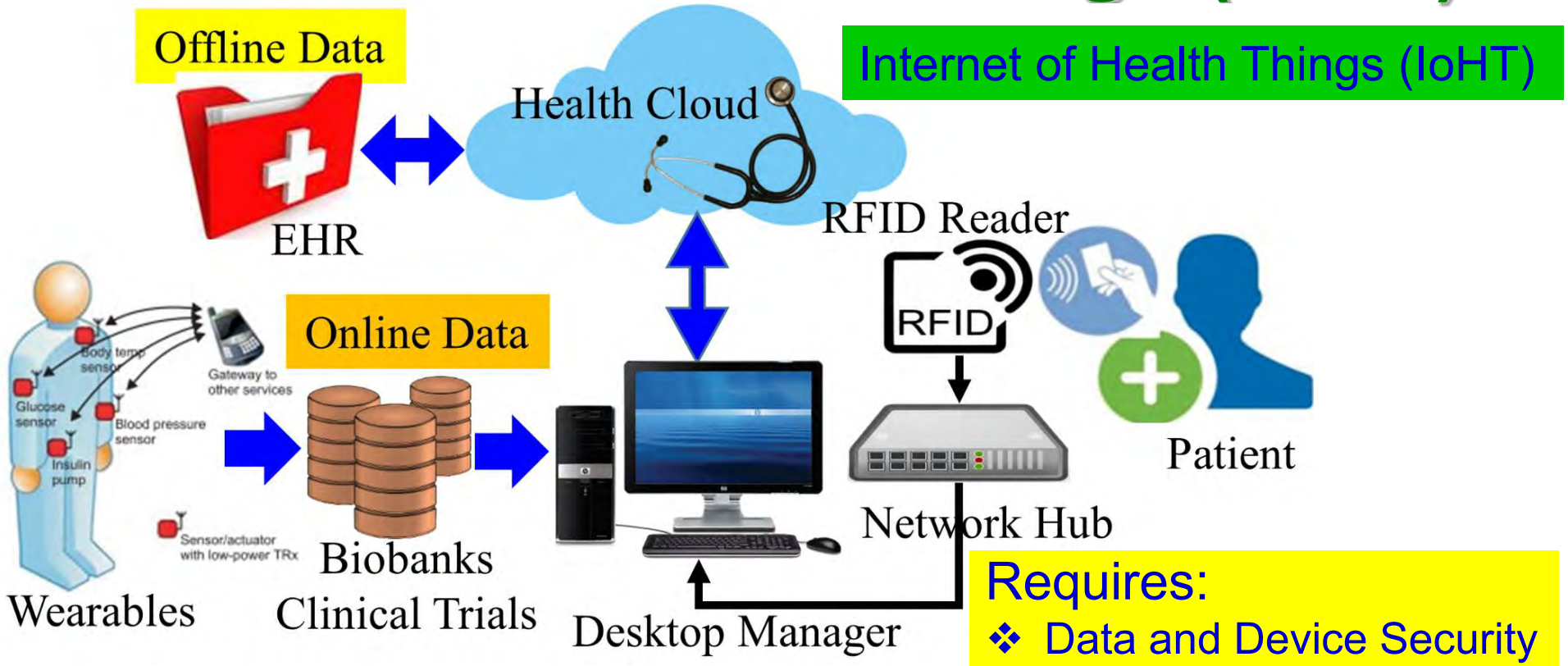
Market Challenges

- Physician compliance
- Data overload on healthcare facility
- Mobile hesitation
- Security policy compliance

Source: Y. Shelke and A. Sharma, "Internet of Medical Things", 2016, Aranca, https://www.aranca.com/knowledge-library/special-reports/ip-research/the-internet-of-medical-things-iomt, Last Visited 10/18/2017.

Smart Healthcare - Components

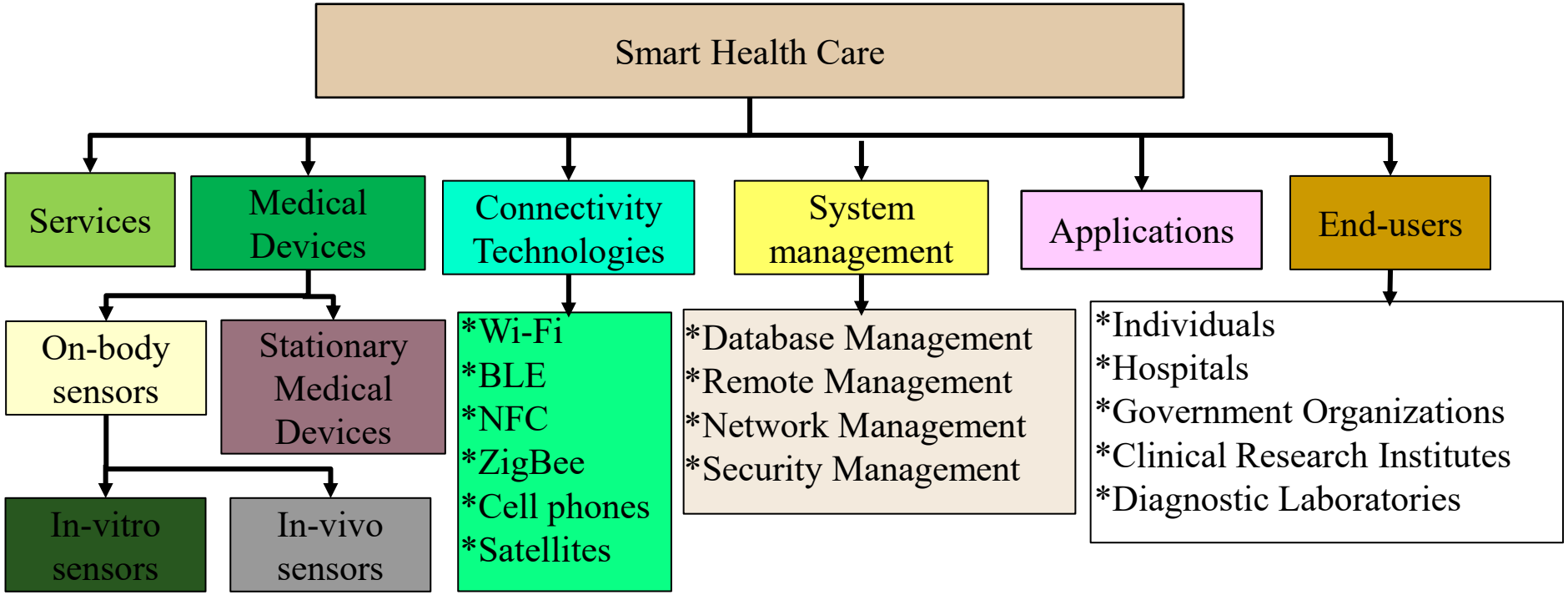
Internet of Medical Things (IoMT)



IoMT is a collection of medical sensors, devices, healthcare database, and applications that connected through Internet.

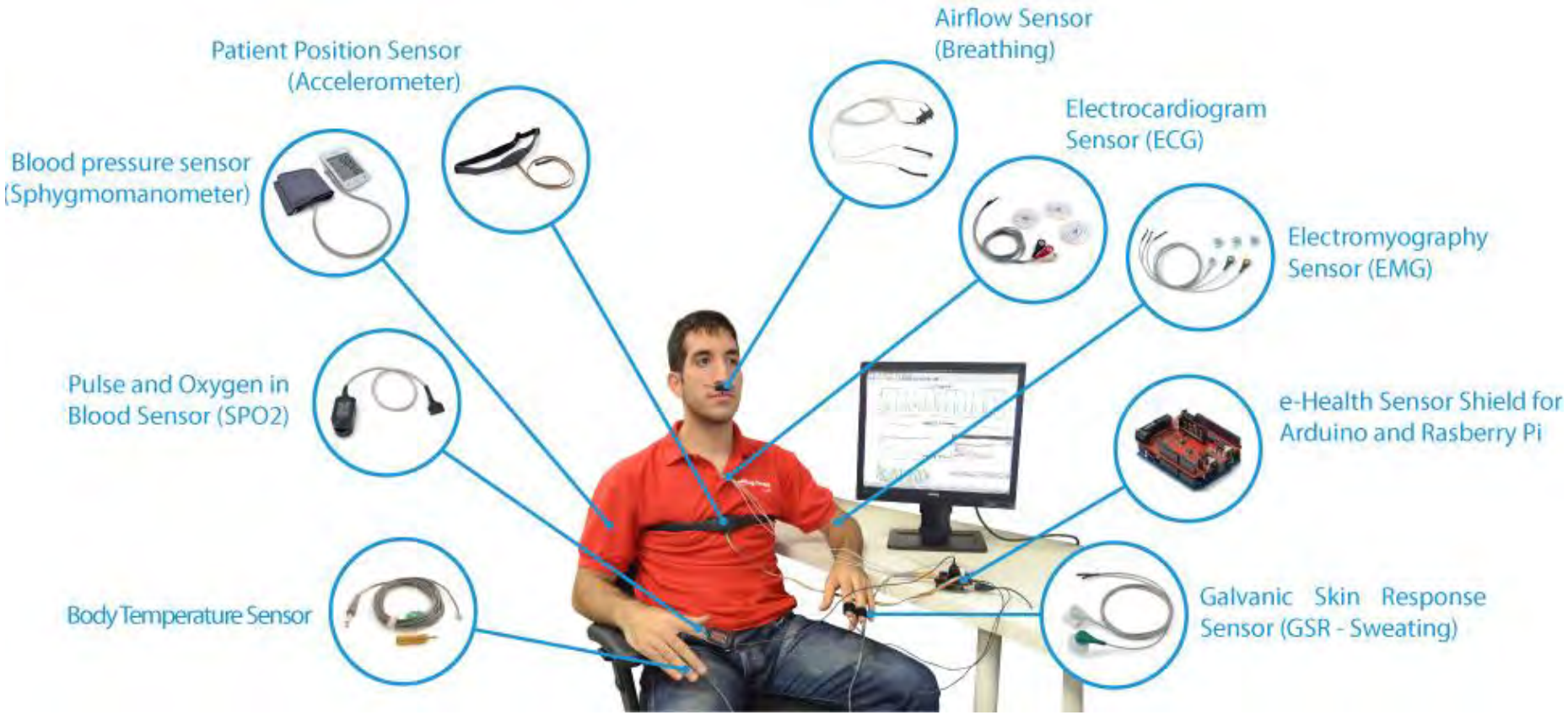
Source: http://www.icemiller.com/ice-on-fire-insights/publications/the-internet-of-health-things-privacy-and-security/
Source: http://internetofthingsagenda.techtarget.com/definition/IoMT-Internet-of-Medical-Things

Smart Healthcare – Components



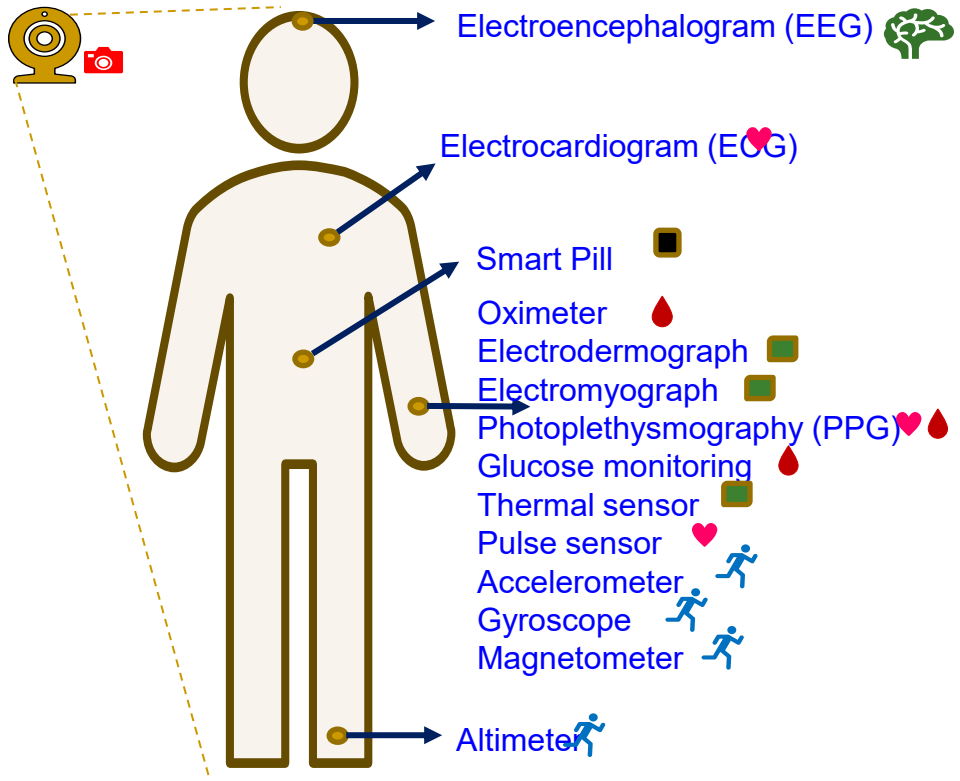
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", IEEE Consumer Electronics Magazine (CEM), Volume 7, Issue 1, January 2018, pp. 18-28.

Sensor Technology - Healthcare



Source: http://www.libelium.com/e-health-low-cost-sensors-for-early-detection-of-childhood-disease-inspire-project-hope/

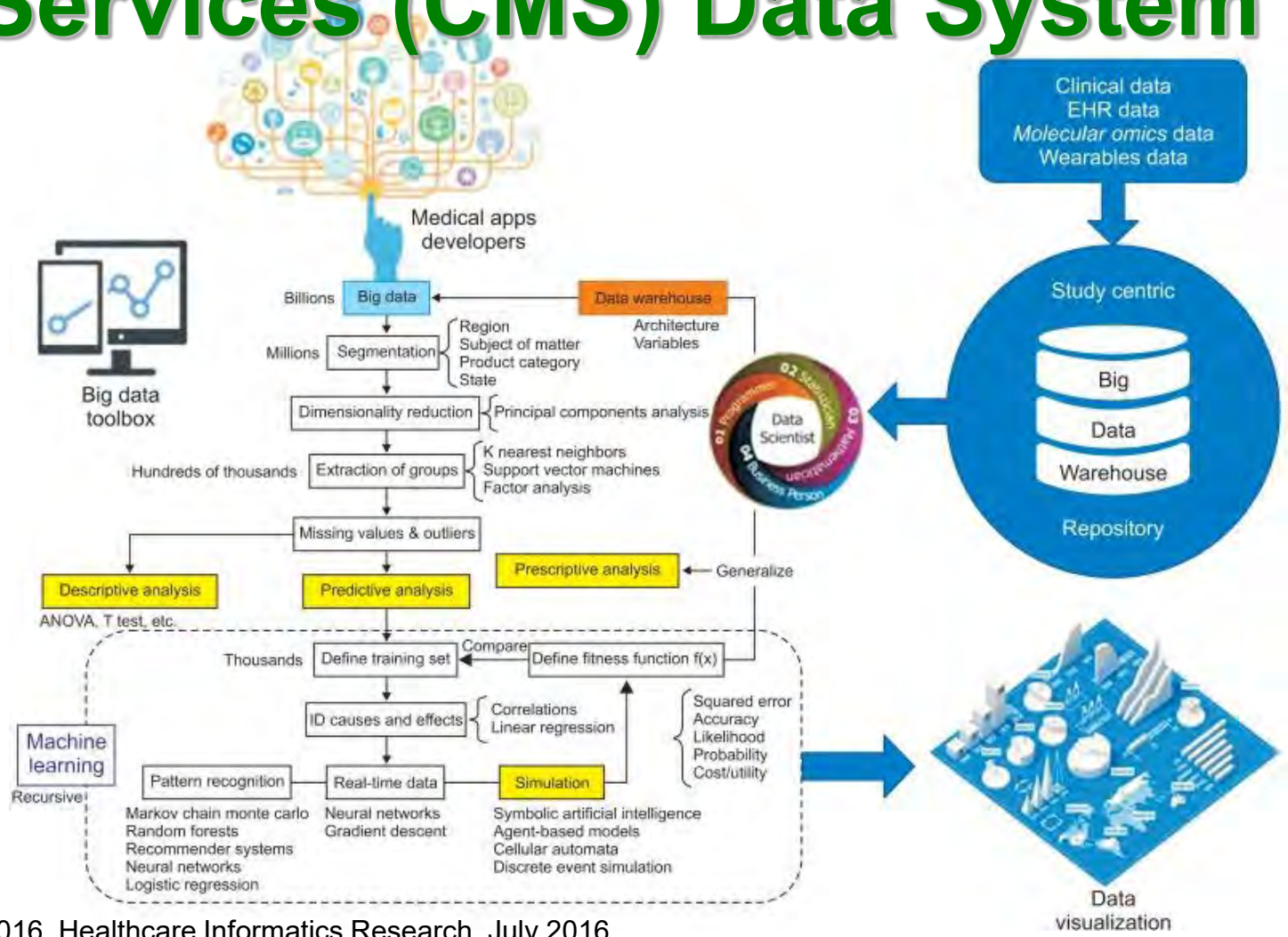
Smart Healthcare Sensors



Types of Sensors

- Brain related applications
- Imaging applications
- Heart related applications
- Skin related applications
- Blood related applications
- Ingestible sensors
- Motion Detection

Center for Medical & Medicaid Services (CMS) Data System

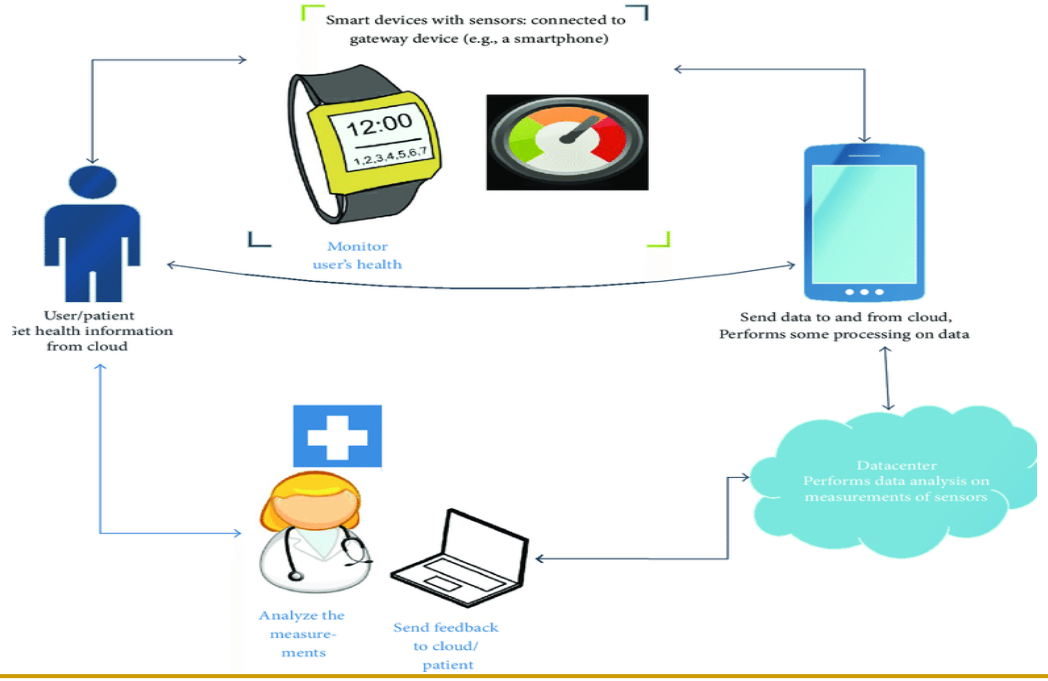


Dimitrov 2016, Healthcare Informatics Research. July 2016

Smart Healthcare - IoMT

- The Internet of Medical Things (IoMT) is the collection of medical devices and applications that connect to healthcare IT systems through online computer networks.
- Medical devices equipped with Wi-Fi allow the machine-to-machine communication that is the basis of IoMT.

Smart Healthcare is defined by the Technology that leads to better diagnostic tools, better treatment for patients, and devices that improves the quality of life for anyone and everyone.

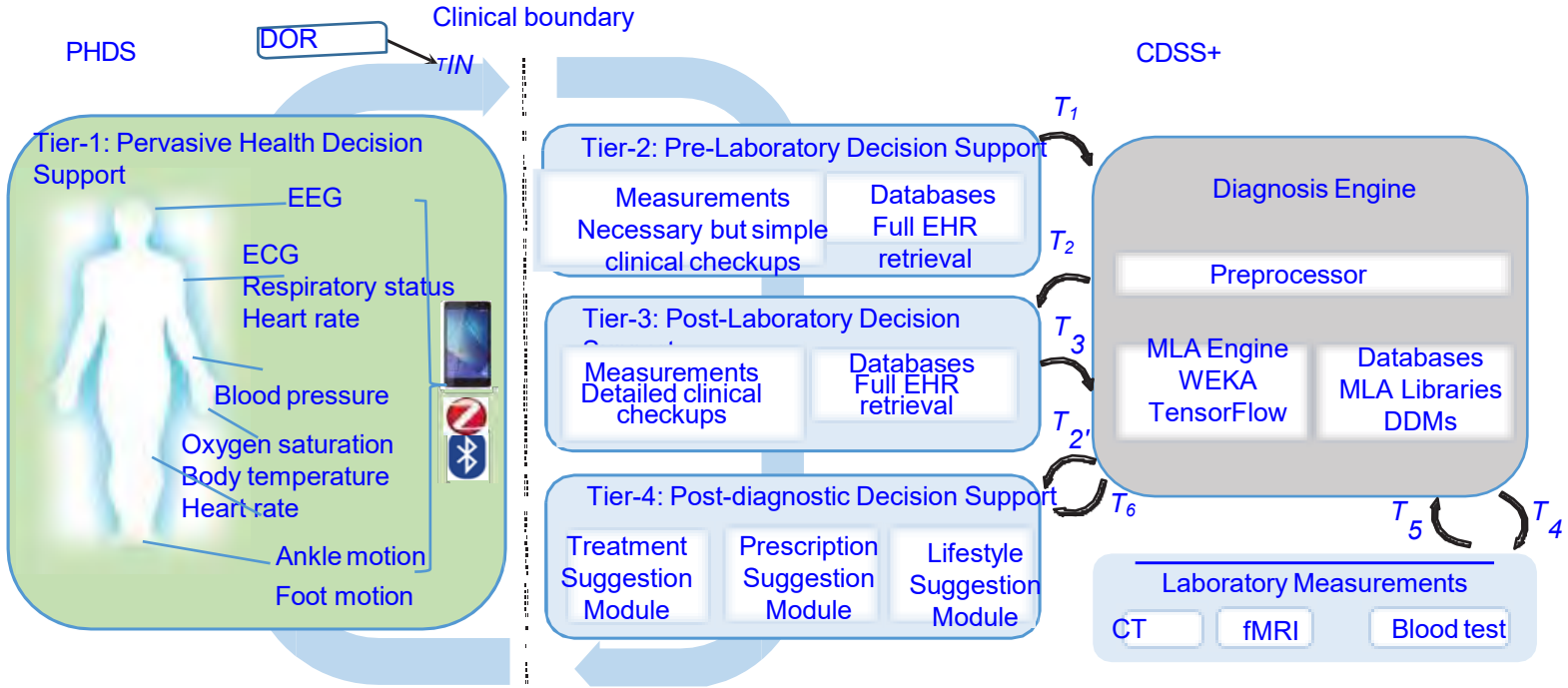


Smart Healthcare Communication

Technology	Frequency Band	Data Rate	Range	Transmission Power
Bluetooth 4.0 (LE)	2.4 GHz	50–200 Kbps	30 m	~10 mW
Zigbee	868 MHz/ 915 MHz/ 2.4 GHz	20–250 Kbps	30 m	30 mW
ANT	2400-2485 MHz	1 Mbps	Up to 10 m	0.01–1 mW
IEEE 802.15.6	2,360-2,400/ 2,400-2,483.5 MHz UWB: 3–10 GHz HBC: 16/27 MHz	NB: 57.5–485.7 Kbps UWB: 0.5–10 Mbps	1.2 m	0.1 μW
Medical Implant Communications Service (MICS)	402-405 MHz	Up to 500 Kbps	2 m	25 μW

Source: V. Custodio, F.J. Herrera, G. López, and J. I. Moreno, "*A Review on Architectures and Communications Technologies for Wearable Health-Monitoring Systems", Sensors*, 2012. 12(10): p. 13907-13946.

Health Decision Support System (HDSS)



Pervasive Health Decision Support (PDHS)

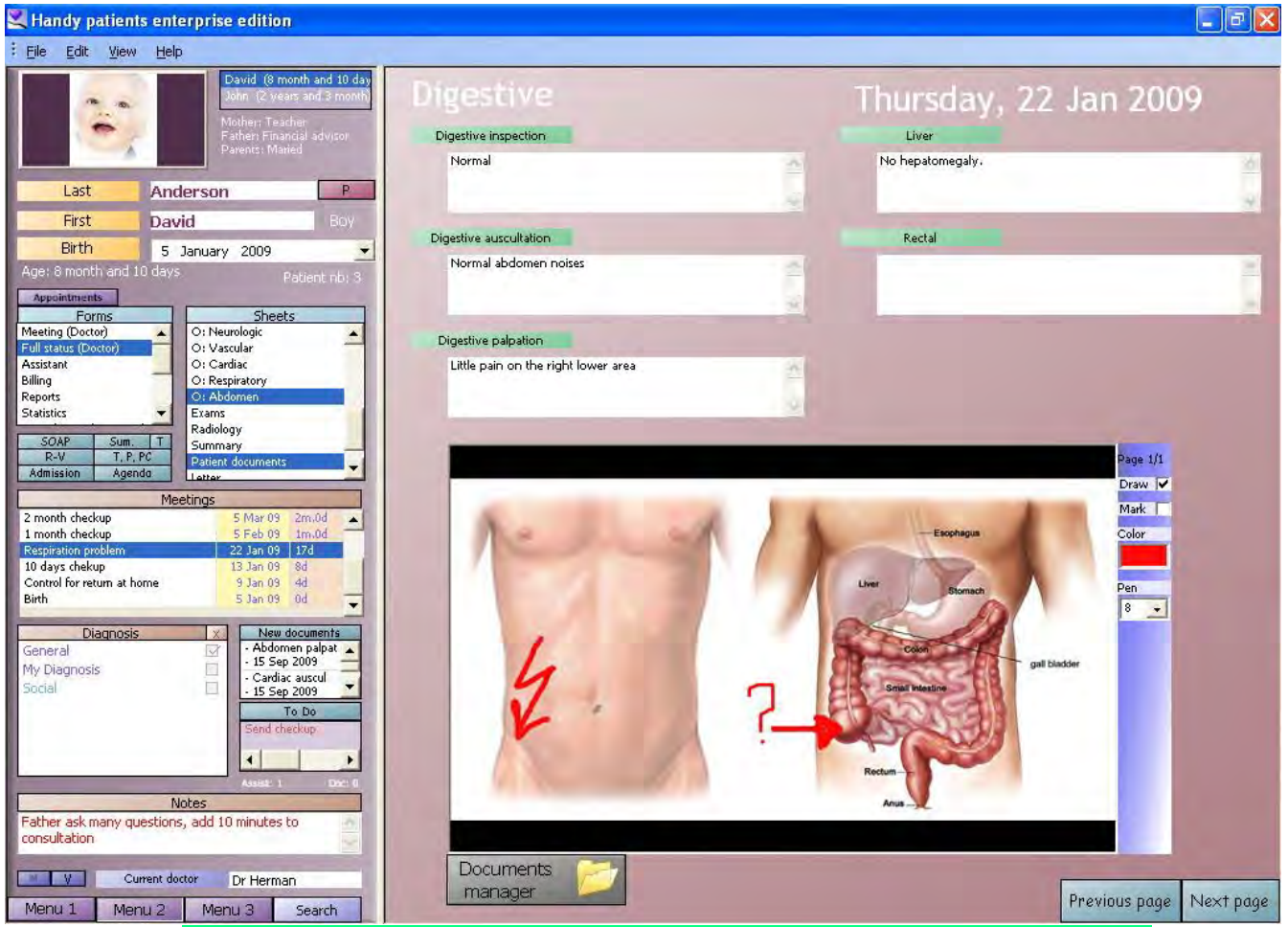
PHDS-assisted Clinical Decision Support System (CDSS+)

Ti - Transition i, DDM - Disease Diagnosis Modules,
DOR - Disease-Onset Record, MLA - Machine Learning Algorithm

Source: Hongxu Yin, Ayten Ozge Akmandor, Arsalan Mosenia and Niraj K. Jha (2018), "Smart Healthcare", Foundations and Trends® in Electronic Design Automation: Vol. 12: No. 4, pp 401-466. http://dx.doi.org/10.1561/1000000054

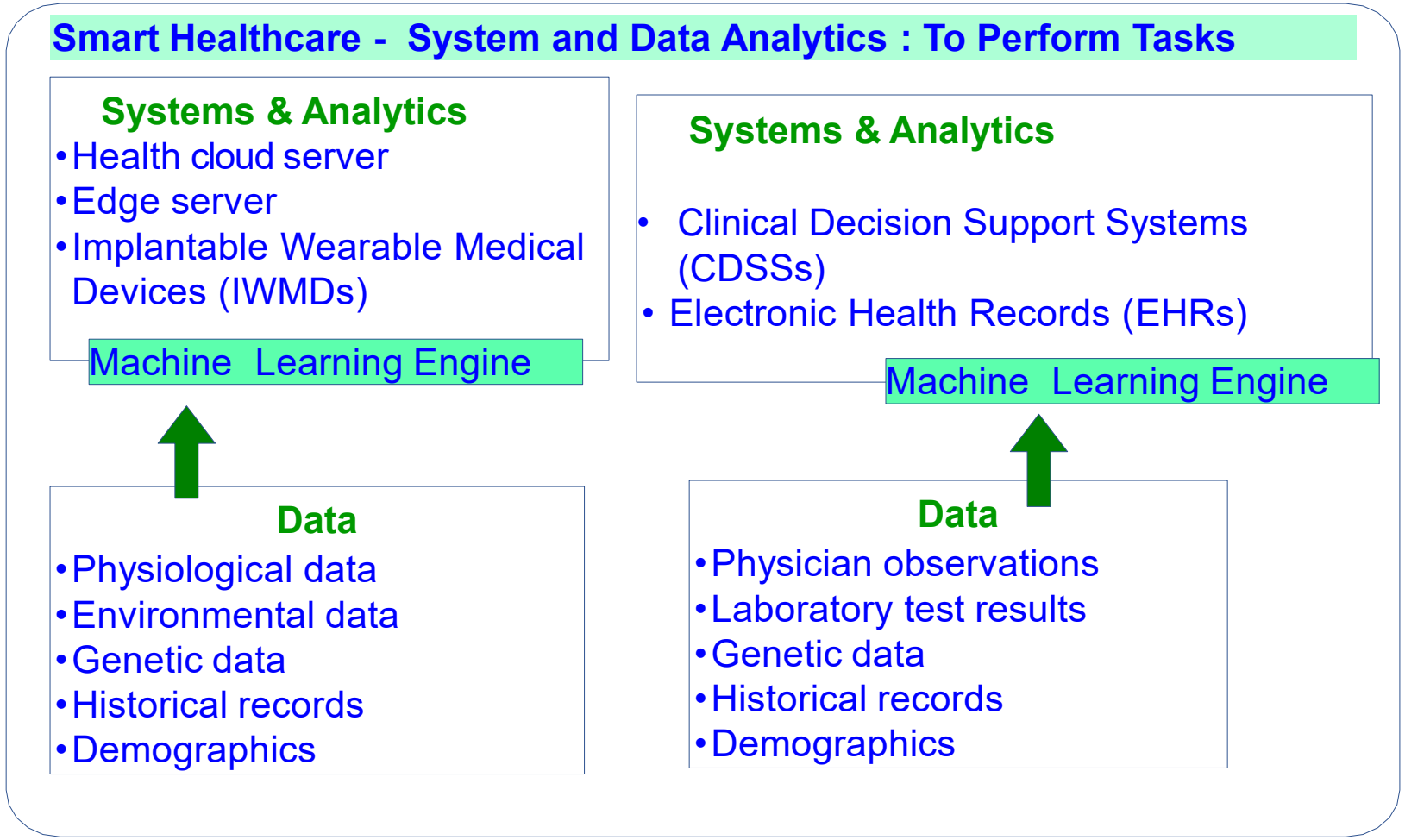
Electronics Health Record (EHR)

- Electronic Health Record (EHR) is the systematized collection of health information of individuals stored in a digital format.
- Created by various health providers such as hospitals and clinics.



Electronic Medical Record (EMR)

Smart Healthcare – AI/ML Framework



Source: Hongxu Yin, Ayten Ozge Akmandor, Arsalan Mosenia and Niraj K. Jha (2018), "Smart Healthcare", *Foundations and Trends® in Electronic Design Automation*, Vol. 12: No. 4, pp 401-466. http://dx.doi.org/10.1561/1000000054

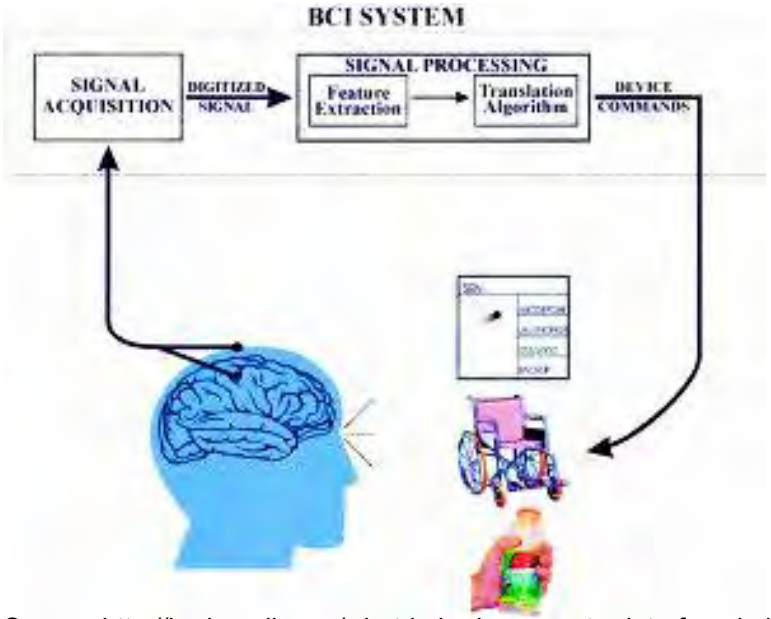
Brain Computer Interface (BCI)

"Currently, people interact with their devices by thumb-typing on their phones. A high-bandwidth interface to the brain would help achieve a symbiosis between human and machine intelligence and could make humans more useful in an AI-driven world."

-- Neuralink - neurotechnology company - Elon Musk.

Sources: http://brainpedia.org/elon-musk-wants-merge-human-brain-ai-launches-neuralink/

Brain Computer Interface (BCI)

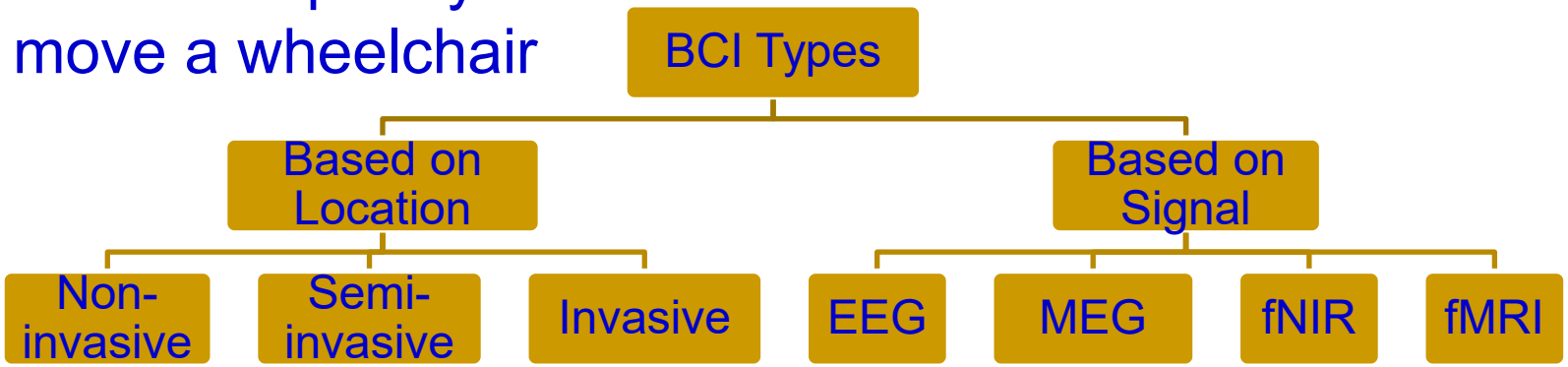


Source: http://brainpedia.org/what-is-brain-computer-interface-bci/

BCI Allows paralysis patients move a wheelchair

Source: http://brainpedia.org/brain-computer-interface-allows-paralysis-als-patients-type-much-faster/

BCI Allows paralysis patients to Type



Virtual Reality in Healthcare

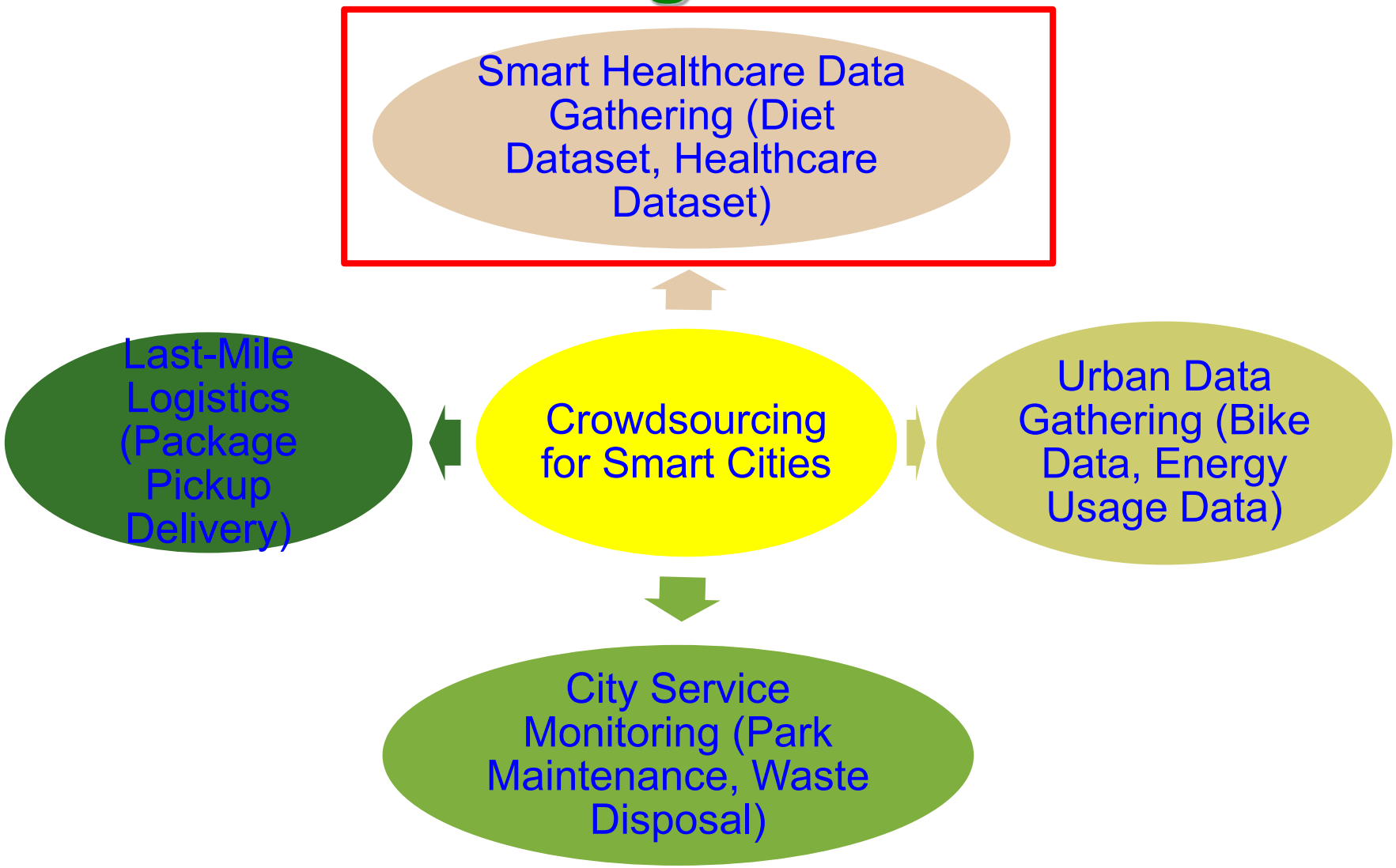
Source: https://touchstoneresearch.com/tag/applied-vr/

In Surgery

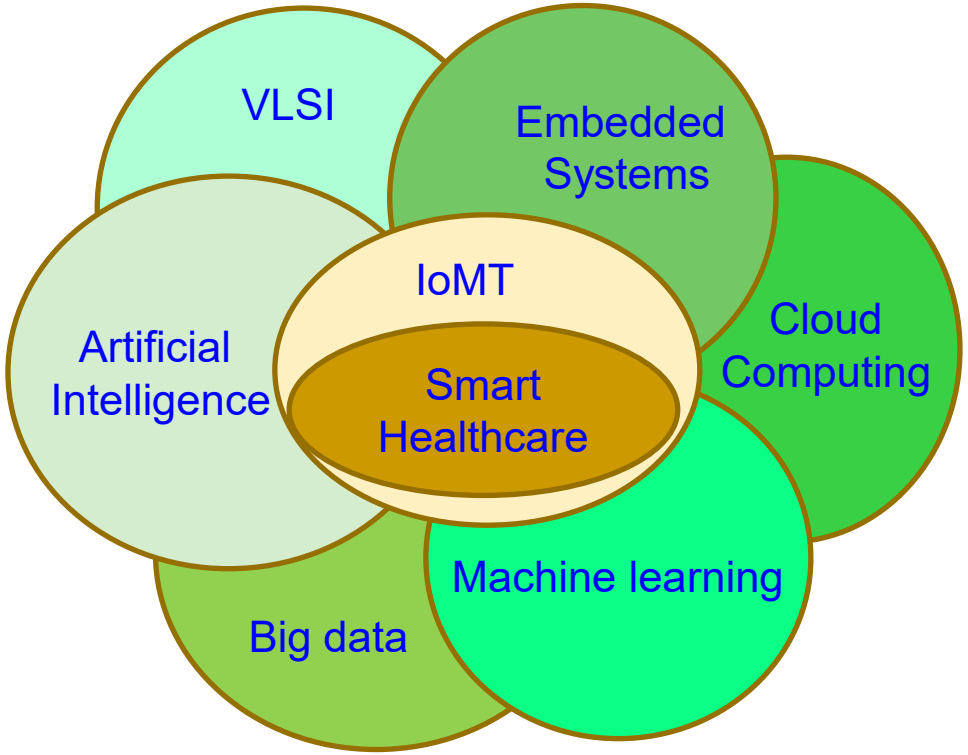
Source: http://medicalfuturist.com/5-ways-medical-vr-is-changing-healthcare/

For Therapy

Crowdsourcing for Smart Cities



Smart Healthcare - Verticals



Smart Healthcare – Specific Examples

Stress is a Global Issue

- In major global economies - 6 in 10 workers experiencing increased workplace stress.
- In USA: 75% of adults reported experiencing moderate to high levels of stress. 1 out of 75 people may experience panic disorder.
- In Australia: 91% of adults feel stress in at least one important area of their lives.
- In UK: An estimated 442,000 individuals, who worked in 2007/08 believed that they were experiencing work-related stress
- Depression is among the leading causes of disability worldwide. 25% of those with depression world-wide have access to effective treatments → 75% don't have.

Source: http://www.gostress.com/stress-facts/

Why Stress Needs to be Resolved?

When there is an encounter with sudden **stress**, your brain floods your **body** with chemicals and hormones such as adrenaline and cortisol.

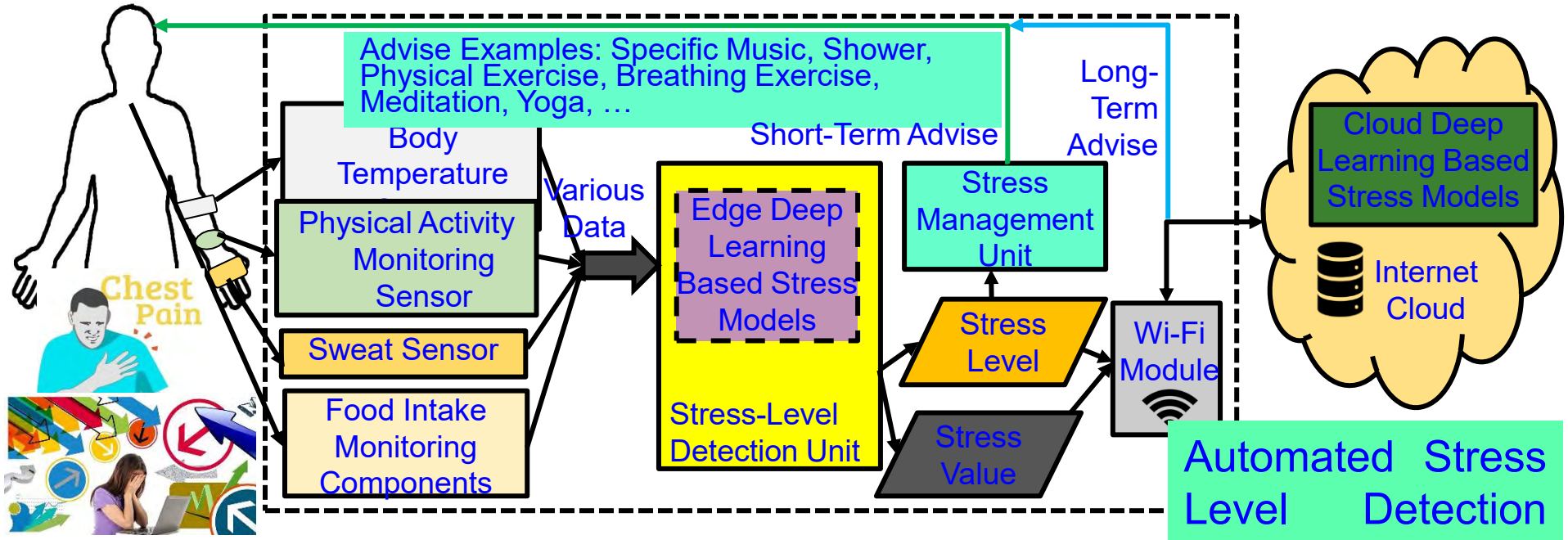
- Lack of Energy
- Type 2 Diabetes
- Osteoporosis
- Mental cloudiness (brain fog) and memory problems
- A weakened immune system, leading to more vulnerable to infections

Distress

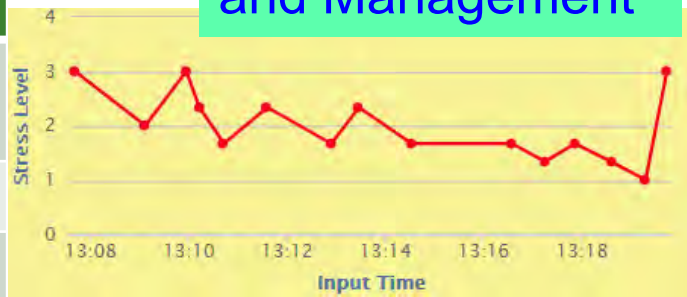
Eustress

Stress is the body's reaction to any change that requires an adjustment or response.

Smart Healthcare - Stress Monitoring & Control

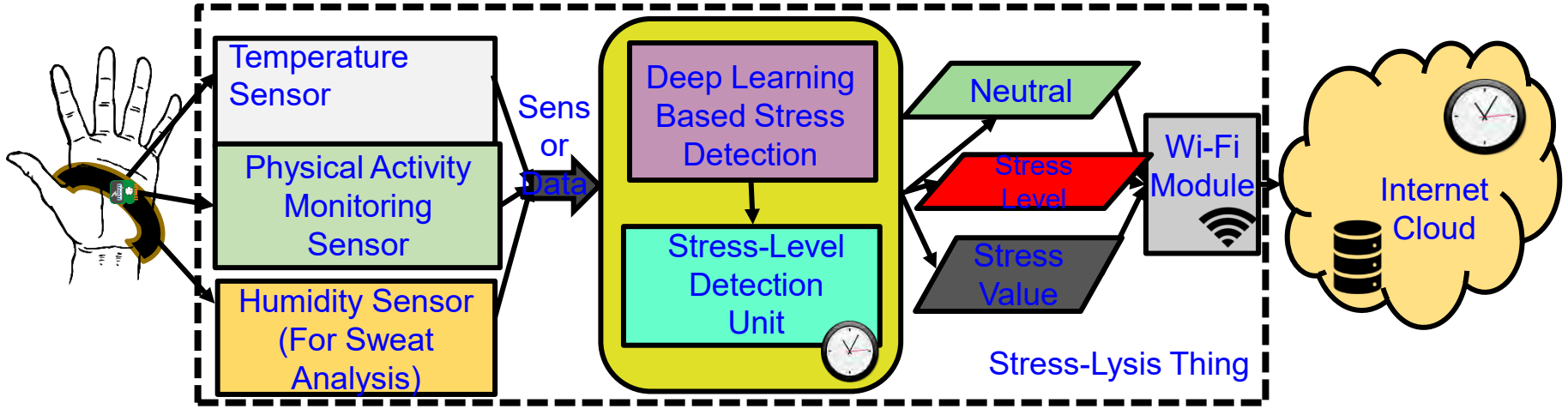


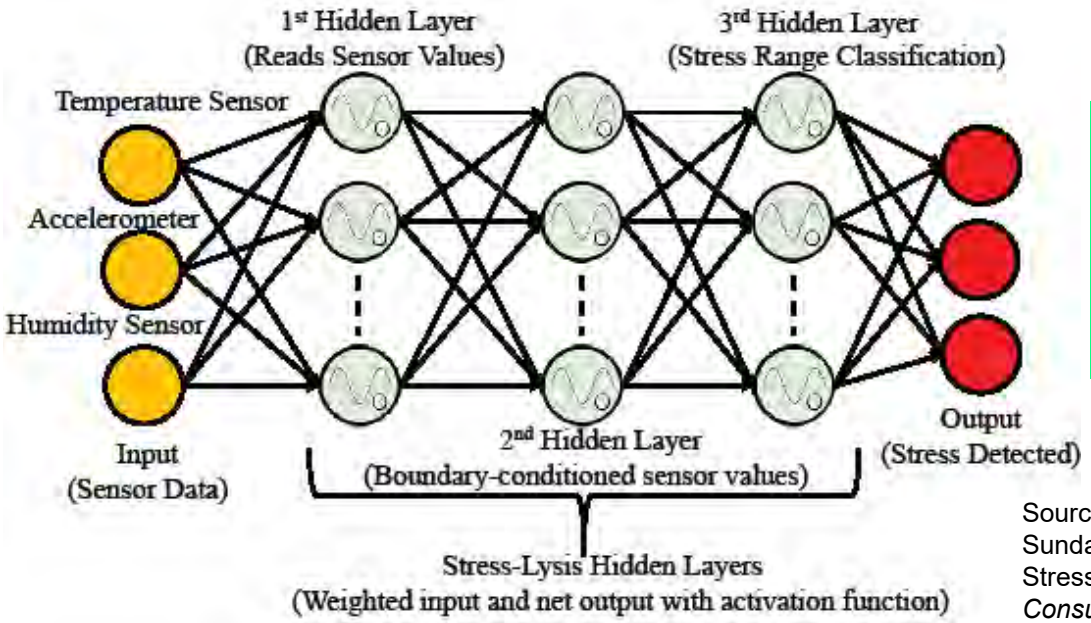
Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature ℉	98-100	90-97	80-90



Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

Stress-Lysis: From Physiological Signals

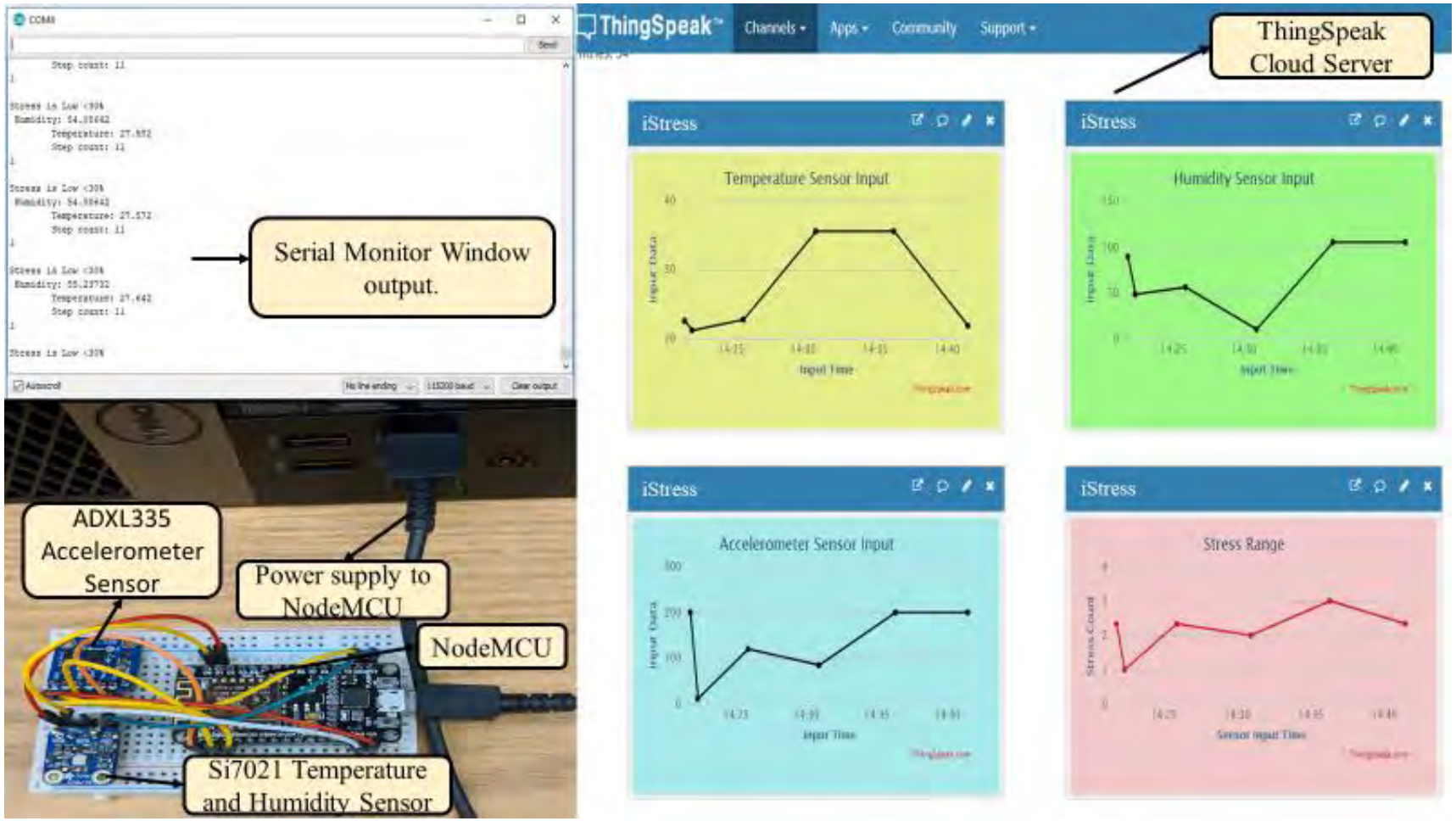




Stress-Lysis - DNN has been trained with a total of 26,000 samples per dataset and has accuracy upto 99.7%.

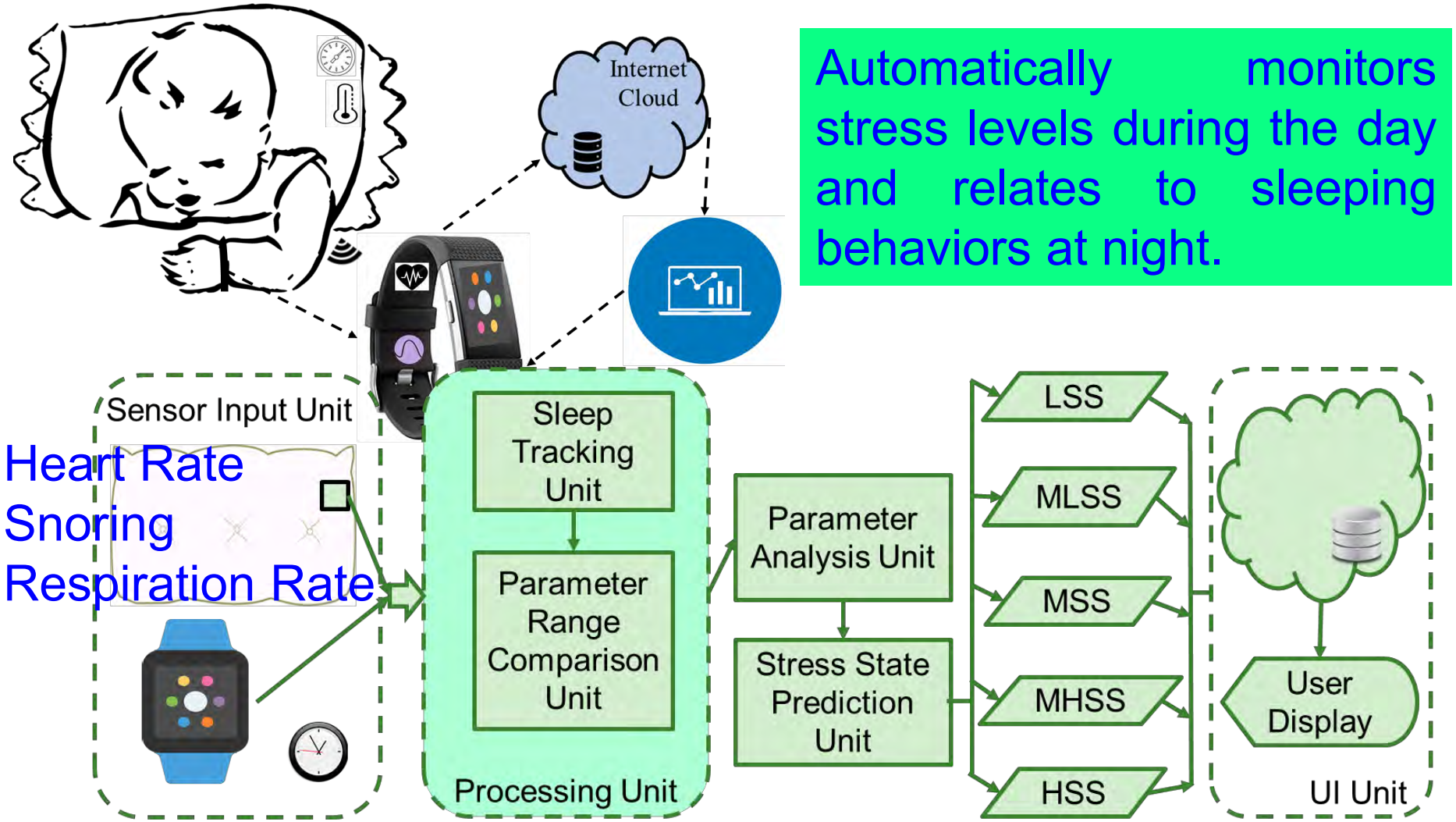
Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

Stress-Lysis: Experiments



Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, and P. Sundaravadivel, "Stress-Lysis: A DNN-Integrated Edge Device for Stress Level Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 4, Nov 2019, pp. 474--483.

Smart Healthcare – Smart-Pillow



Automatically monitors stress levels during the day and relates to sleeping behaviors at night.

Source: Mohanty iSES 2018: "Smart-Pillow: An IoT based Device for Stress Detection Considering Sleeping Habits", in *Proc. of 4th IEEE International Symposium on Smart Electronic Systems (iSES)* 2018.

Smart-Yoga Pillow (SaYoPillow) - Sleeping Pattern

Person On Pillow:
Physiological Sensor Data Monitoring Starts

Person Off Pillow:
Physiological Sensor Data Monitoring Ends

Period 1. Lying on bed but not Sleeping

Period 2: Trying to Sleep

Period 3: Drift from Wakefulness to Sleep

Period 4: Deep Sleep

Period 5: Awake Person

Transitions of a person drifting into non-rapid eye movement (NREM) followed by rapid eye movement (REM) to Awake State.

Data Processing

Secure Data Transfer

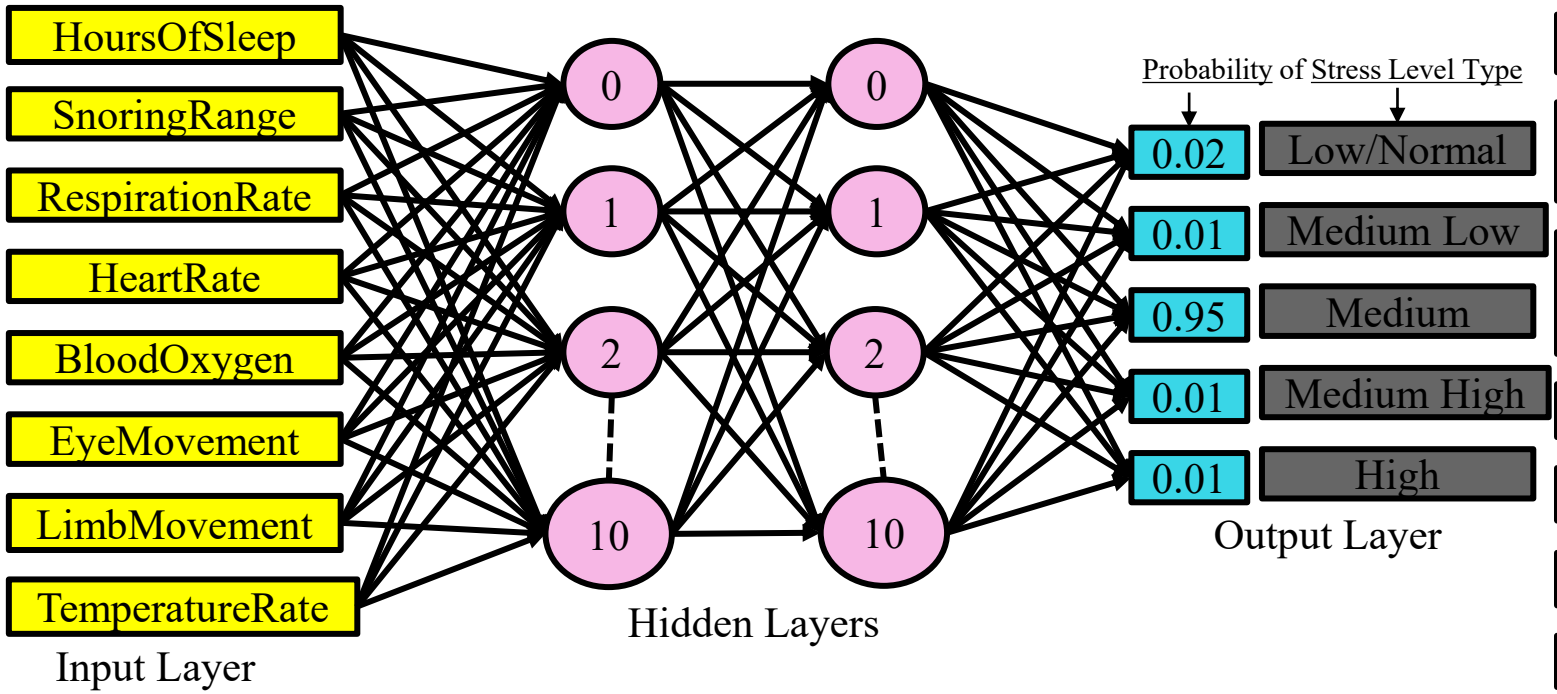
Secure Data Storage

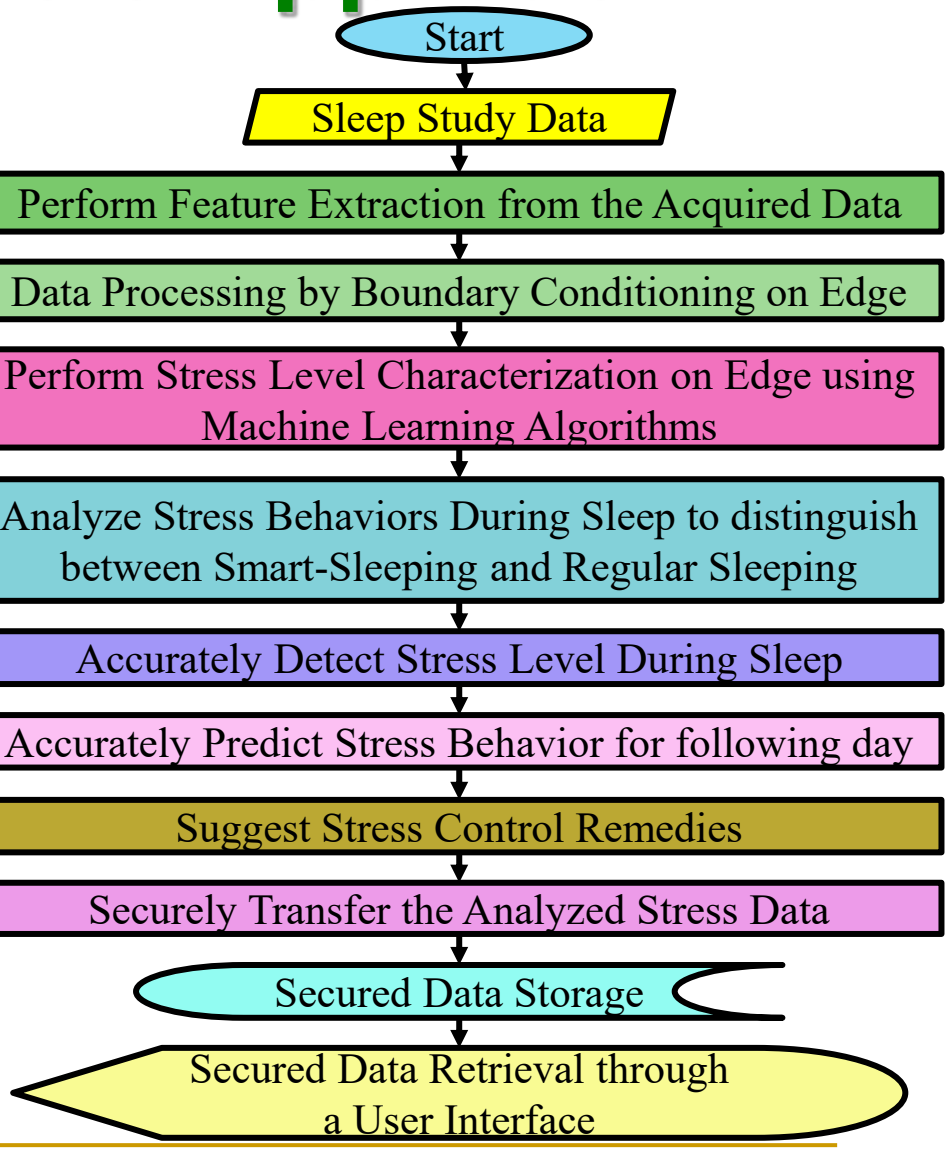
Secure Data Access

User Applications

Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

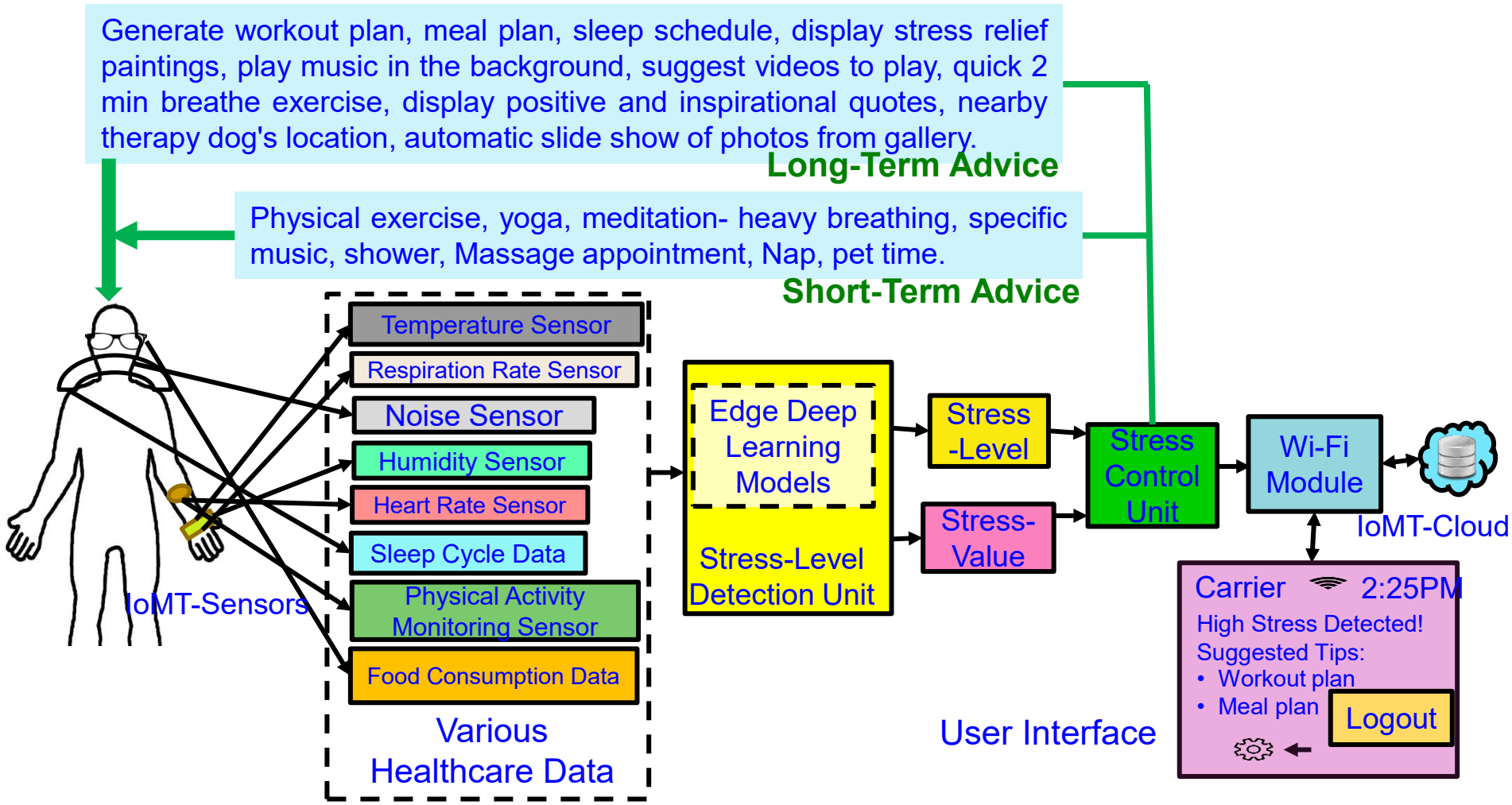
SaYoPillow – Stress Analysis Approach





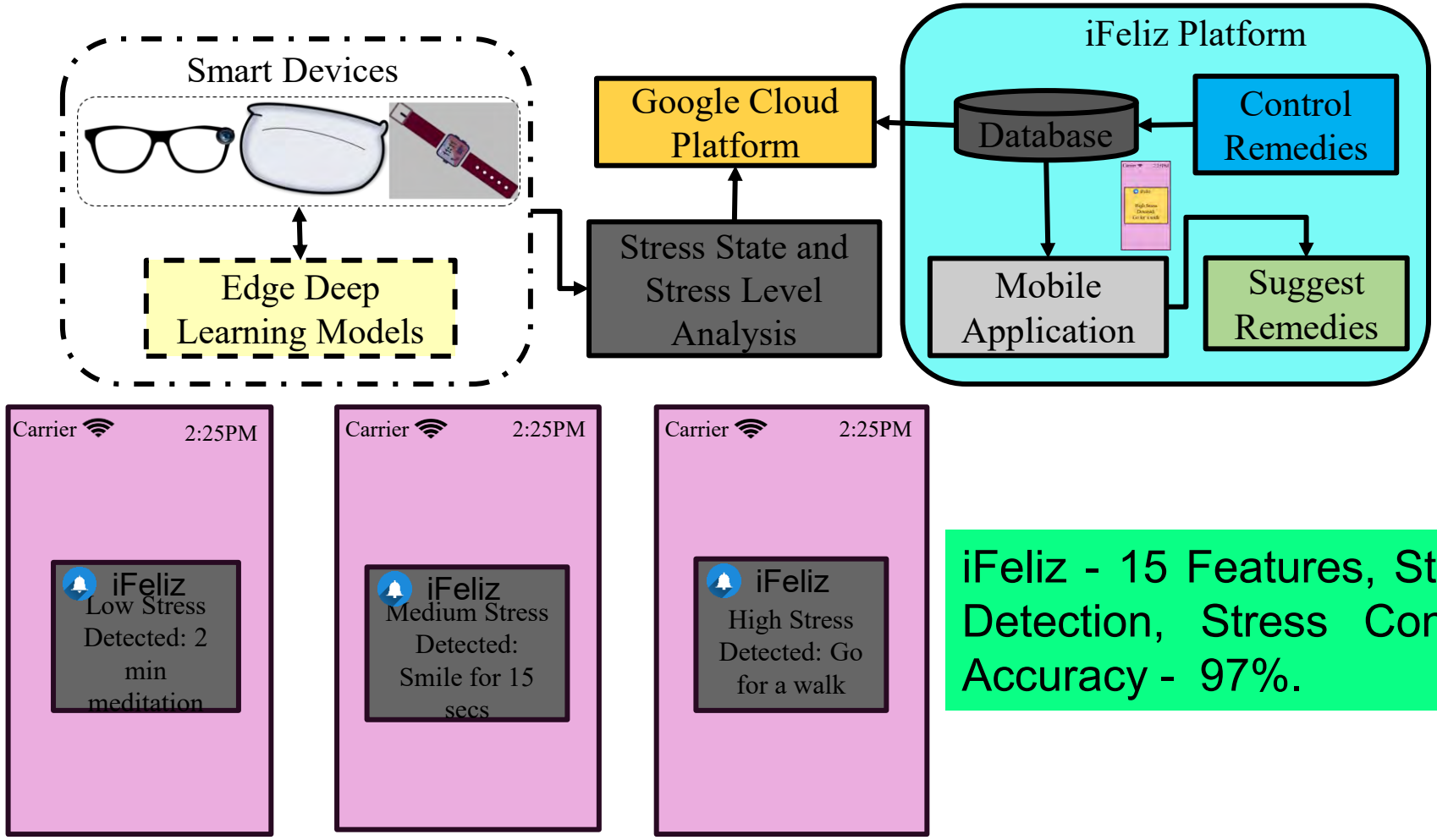
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

iFeliz: Proposed System



Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iFeliz: An Approach to Control Stress in the Midst of the Global Pandemic and Beyond for Smart Cities using the IoMT", in *Proc. of IEEE Smart Cities Conference (ISC2)*, 2020.

iFeliz: Prototyping



iFeliz - 15 Features, Stress Detection, Stress Control, Accuracy - 97%.

Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iFeliz: An Approach to Control Stress in the Midst of the Global Pandemic and Beyond for Smart Cities using the IoMT", in *Proc. of IEEE Smart Cities Conference (ISC2)*, 2020.

Imbalance Diet is a Global Issue

- Imbalanced diet can be either more or fewer of certain nutrients than the body needs.
- In 2017, 11 million deaths and 255 million disability-adjusted life-years (DALYs) were attributable to dietary risk factors.
- Eating wrong type of food is potential cause of a dietary imbalance:

➢ Psychiatric disorders	➢ Obesity
➢ Coronary heart disease	➢ Tooth decay
➢ High blood pressure	➢ Diabetes

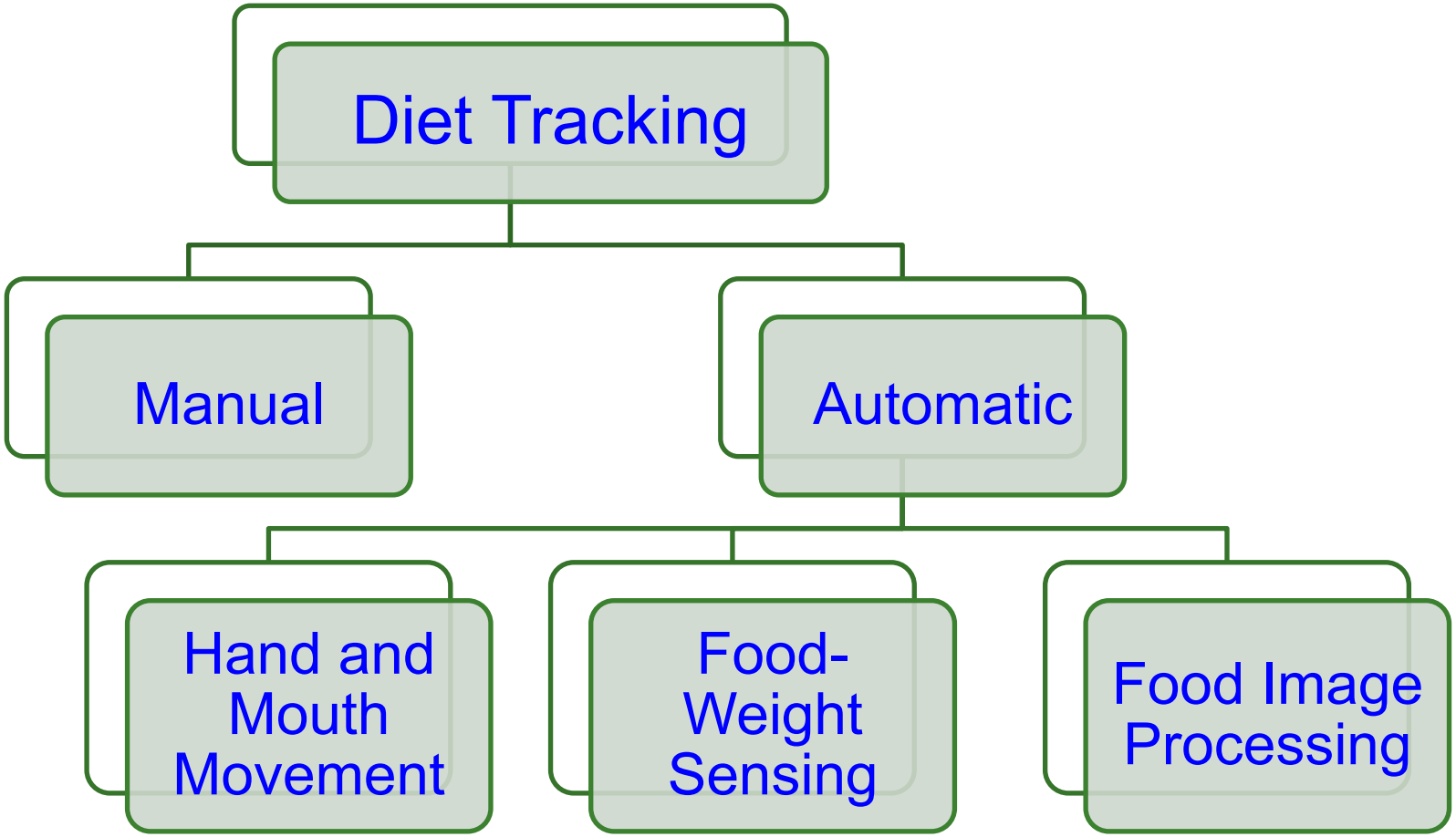
Source: https://obesity-diet.nutritionalconference.com/events-list/imbalanced-diet-effects-and-causes
https://www.thelancet.com/article/S0140-6736(19)30041-8/fulltext

Food Tracking Apps

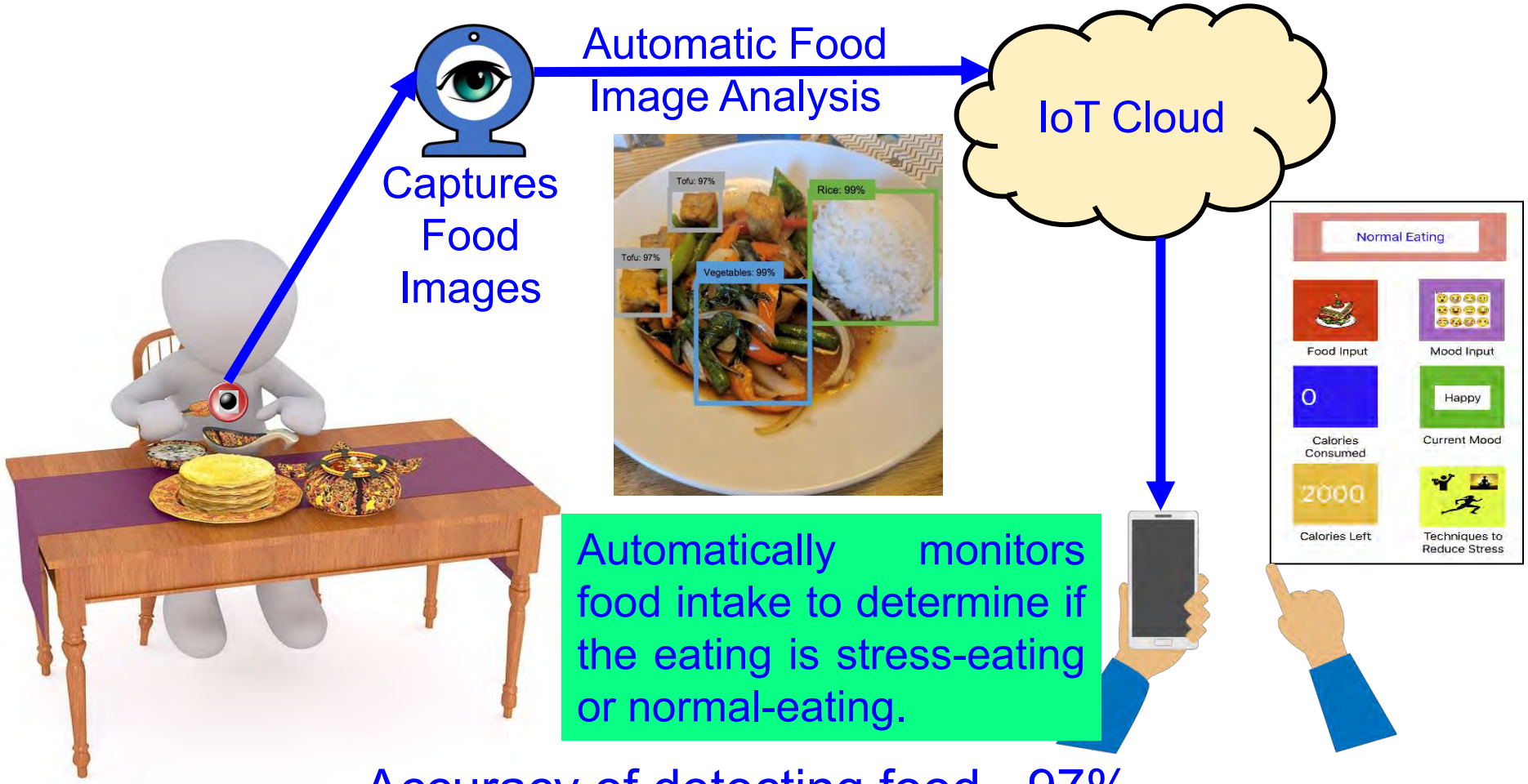
Table 1. Overview of popular food tracking approaches and their capabilities.

App Name	Downloads	Reviews	Rating	Image	Food-Label in Image			Manual	Scanning	Speech	Database search	Calories	Nutrition
				Input Method									
					Auto	Manual	Crowd Sourced						
MyFitnessPal	50 M	2 M	4.6					X	X			X	
FatSecret	10 M	268 k	4.5					X	X			X	X
My Diet Coach	10 M	144 k	4.4					X				X	
Lose it	10 M	77 k	4.4	X				X	X			X	
MyPlate	1 M	31 k	4.6					X	X			X	X
mynetdiary	1 M	31 k	4.5					X				X	X
Macros	500 k	3 k	4.5					X	X			X	
Cron-o-meter	100 k	1 k	4.2					X					
Eating Habit	100 k	549	4	X		X						X	
21 day Fix	100 k	470	3.7					X				X	
Bite Snap	50 k	2k	4.7	X								X	X
MealLogger	50 k	225	3.5	X				X				X	X
EatRight	10 k	220	4.5					X				X	
Keto Meal Plan	10 k	19	2.6								X		
YouAte	10 k			X									
KudoLife	1 k	11	3.4								X	X	X
Calorific	19		3.2								X		
Ate				X				?				?	?
Foodlog				X	X			X				X	

Diet Tracking Approaches



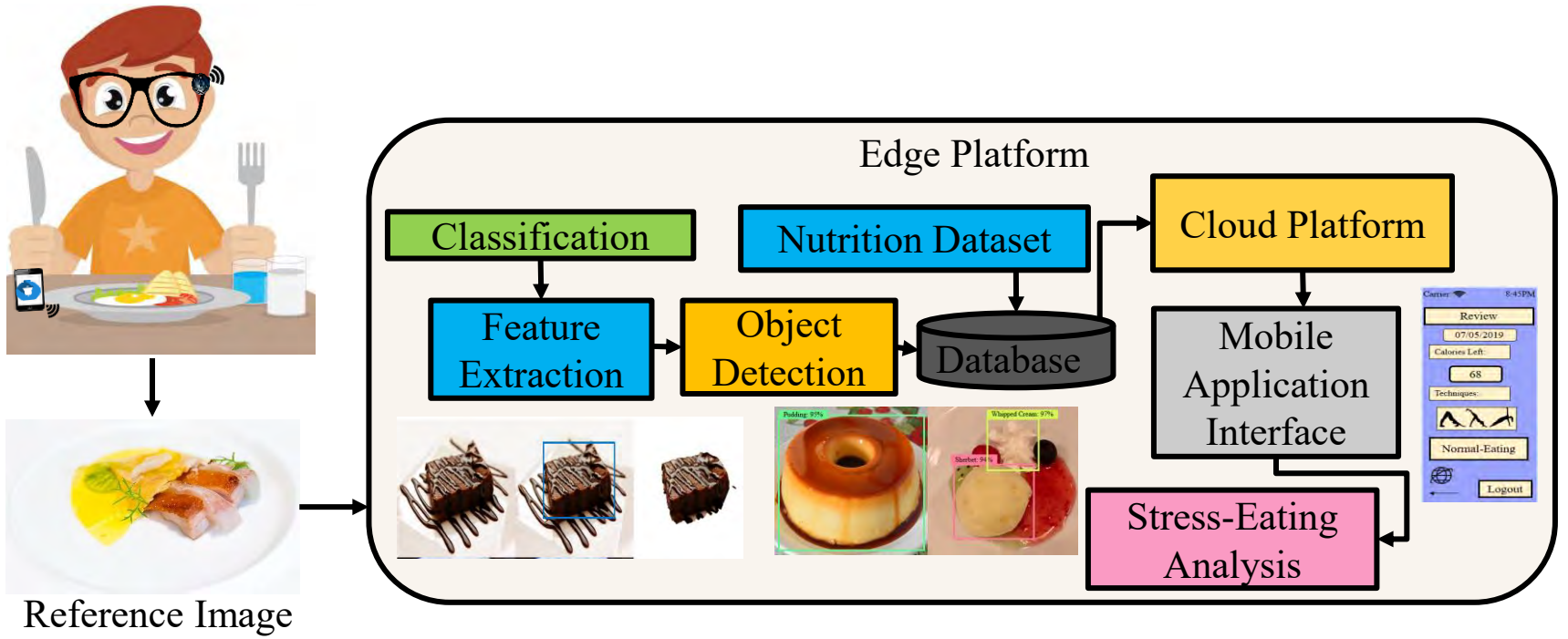
Smart Healthcare – Diet Monitoring



Accuracy of detecting food - 97%

Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 2, May 2020, pp. 115--124.

Smart Healthcare – iLog



iLog- Fully Automated Detection System with 98% accuracy.

Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 2, May 2020, pp. 115--124.

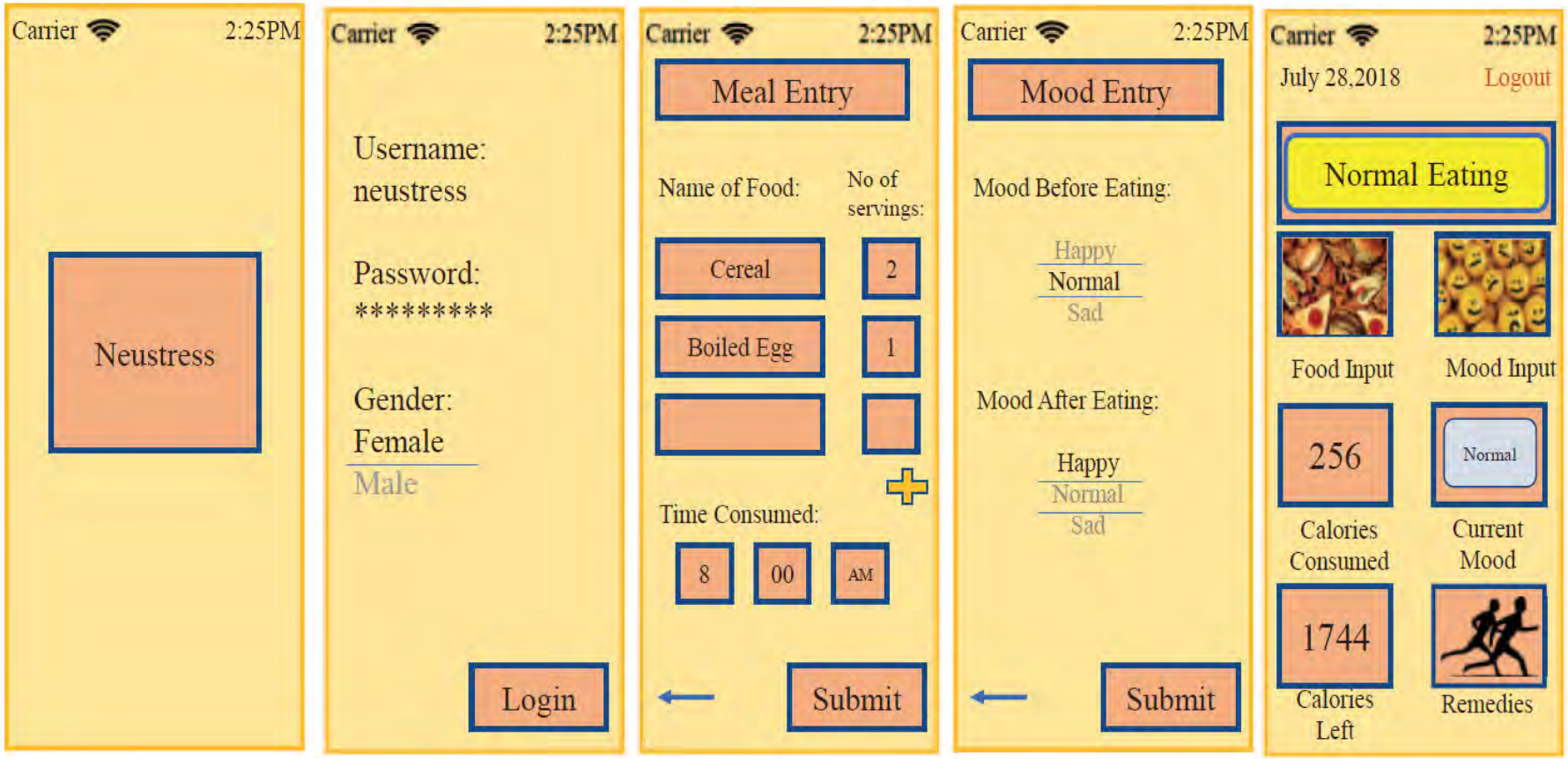
Smart Healthcare – iLog

The data collected is sent to the Firebase Database in which the calorie count is generated by using a dataset with calories and sugars count of individual items from data.gov.

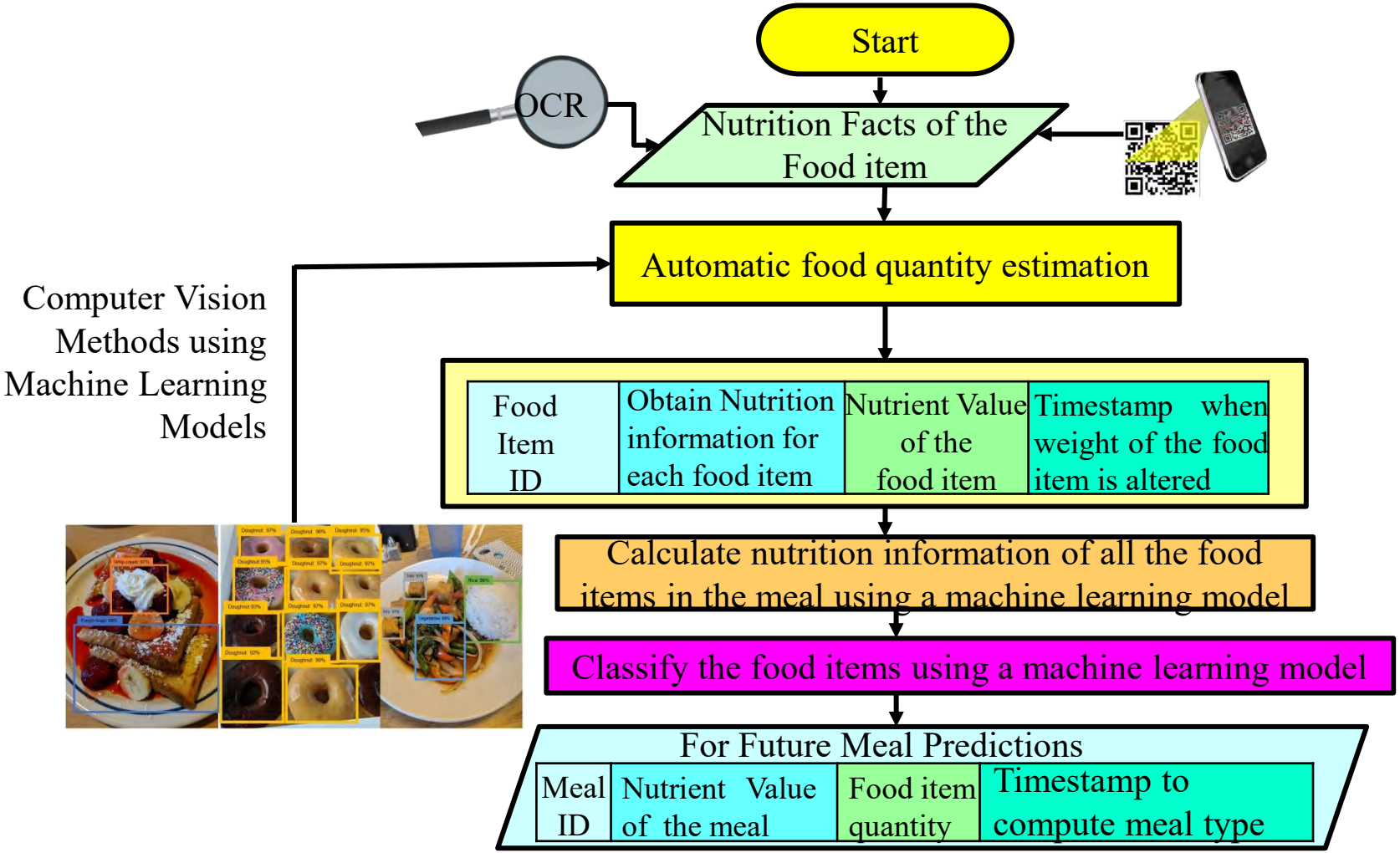
Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, “iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT”, *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 2, May 2020, pp. 115--124.

Implementation- Normal Eating

✓ Wearable Approach

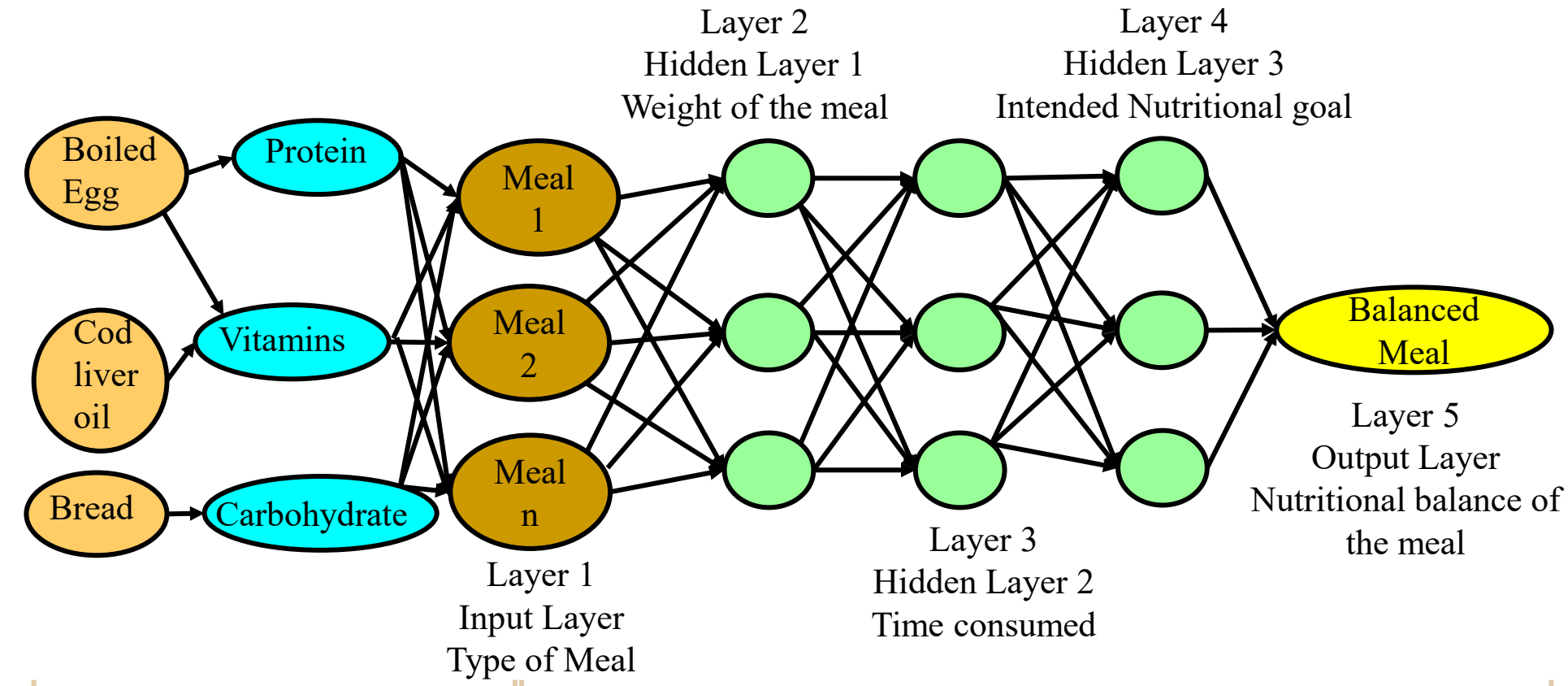


Smart Healthcare – Diet Prediction



Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, **S. P. Mohanty**, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", *IEEE Transactions on Consumer Electronics*, Vol 64, Issue 3, Aug 2018, pp. 390-398.

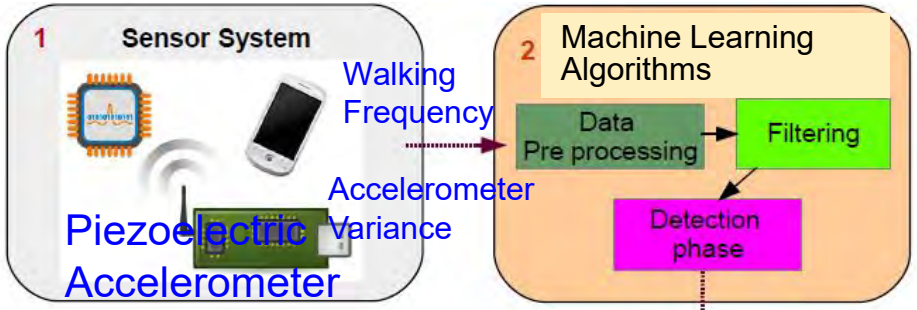
Smart Healthcare – Diet Prediction



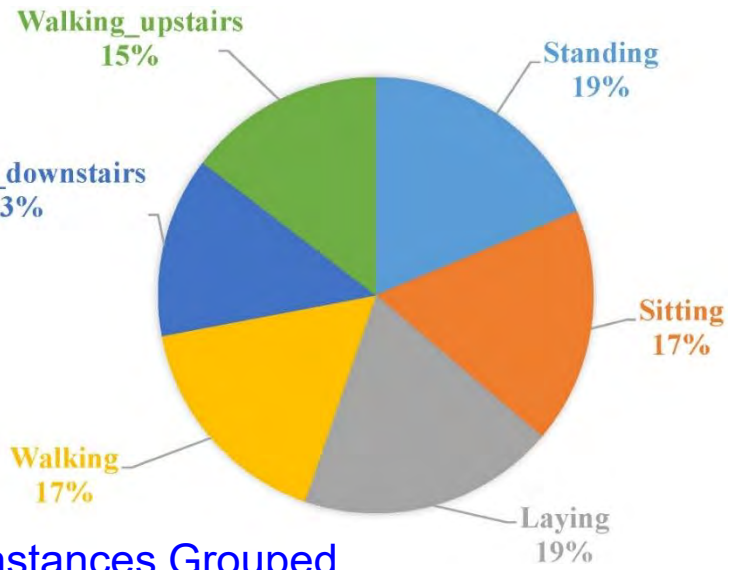
Prediction (Automated) accuracy of Smart-Log - 98.6%

Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, S. P. Mohanty, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 64, Issue 3, August 2018, pp. 390--398.

Smart Healthcare - Smart-Walk



Automated Physiological Monitoring System



10291 Instances Grouped Under 6 Activities - Kaggle

Research Works	Method	Features considered	Activities	Accuracy (%)
This Work	Adaptive algorithm based on feature extraction (WEKA)	Step detection and Step length estimation	Walking, sitting, standing, etc.	97.9

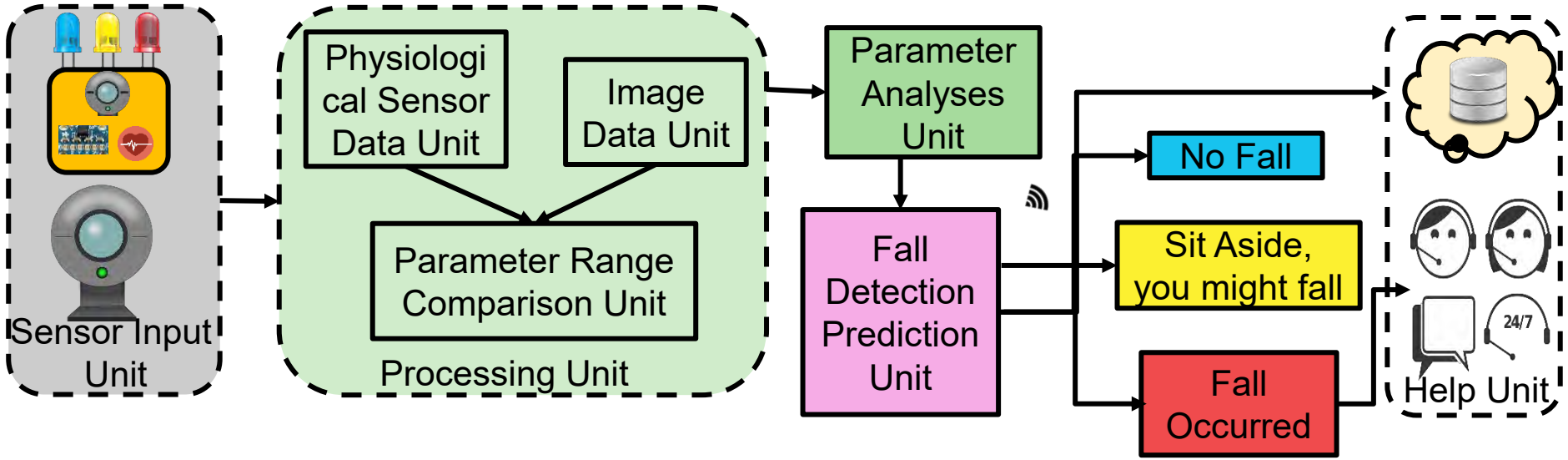
Source: Mohanty ICCE 2018

Elderly Fall Automatic Detection is Needed to Improve Quality of Life

- Elderly Fall: Approximately a third of elderly people 65 years or older fall each year.
- Fall Caused → Over 800,000 hospital admissions, 2.8 million injuries and 27,000 deaths have occurred in the last few years.

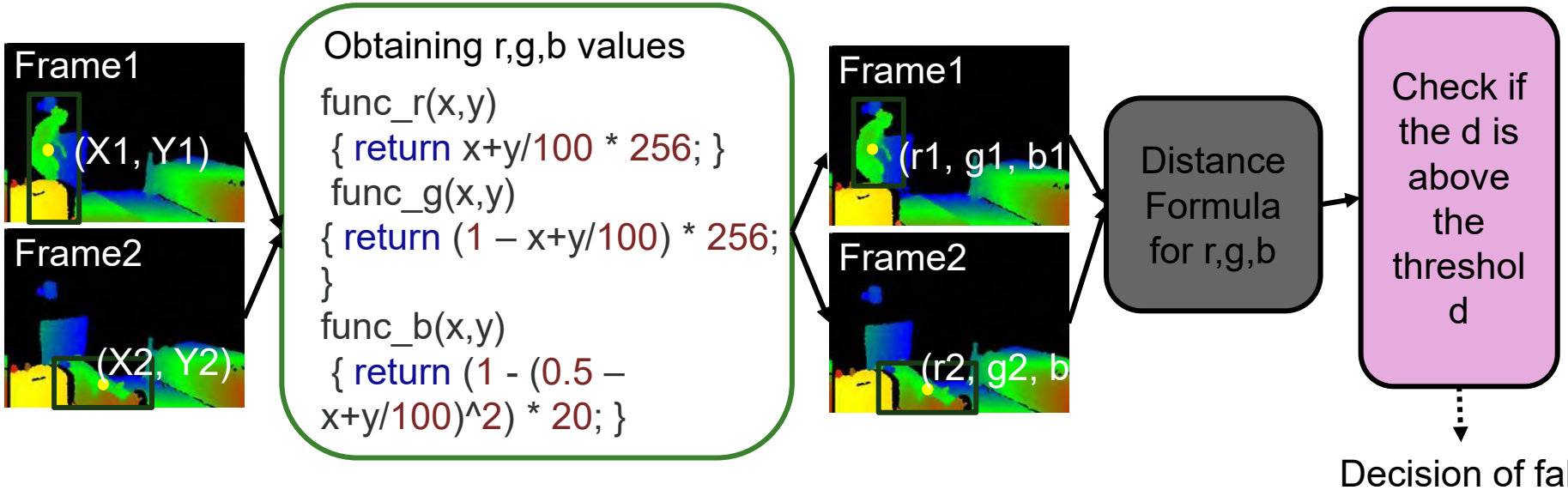
Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

Good-Eye: Our Multimodal Sensor System for Elderly Fall Prediction and Detection



Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

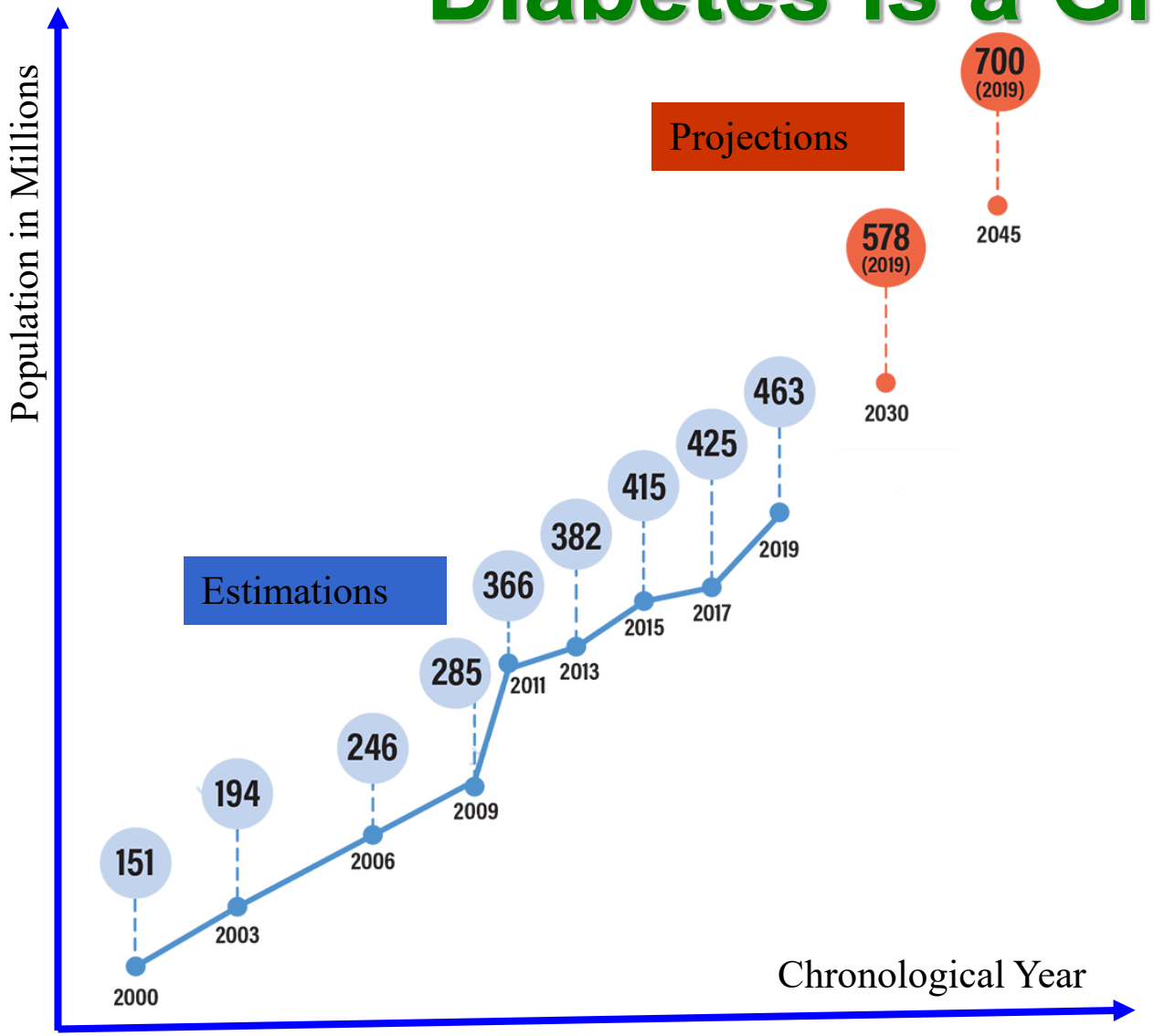
Good-Eye: Elderly Fall Detection



Good-Eye: Fall detection and prediction Accuracy - 95%.

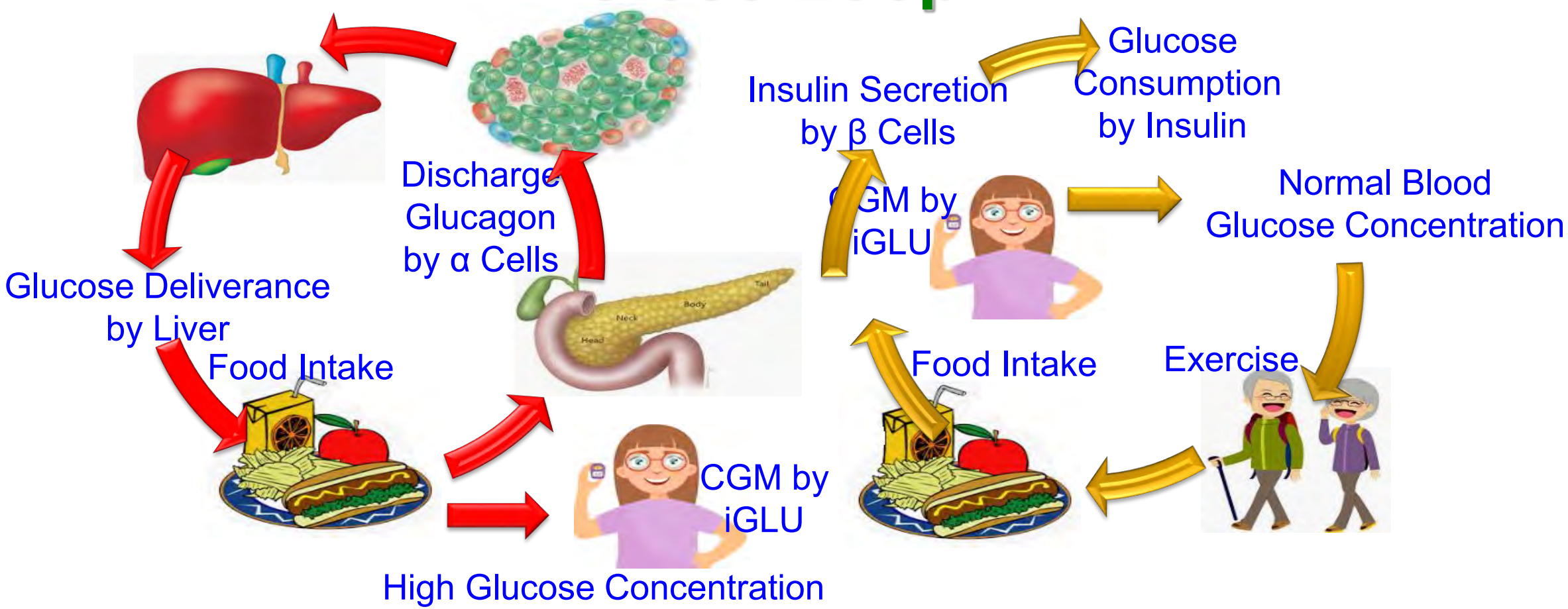
Source: L. Rachakonda, A. Sharma, S. P. Mohanty, and E. Kougianos, "Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Device for Full-Proof Prediction and Detection of Fall of Adults", in *Proceedings of the 2nd IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2019, pp. 273--288.

Diabetes is a Global Crisis



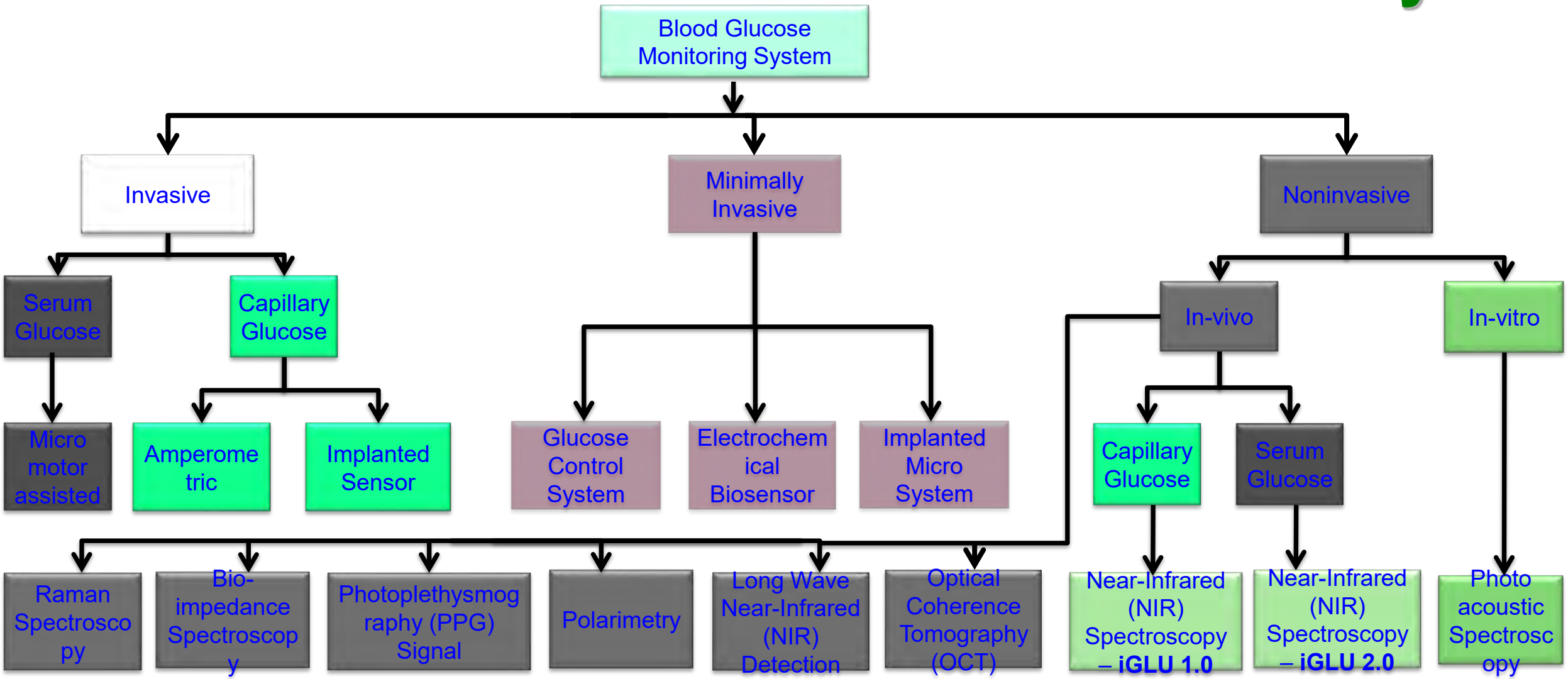
Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

Glucose Generation and Consumption – Close Loop



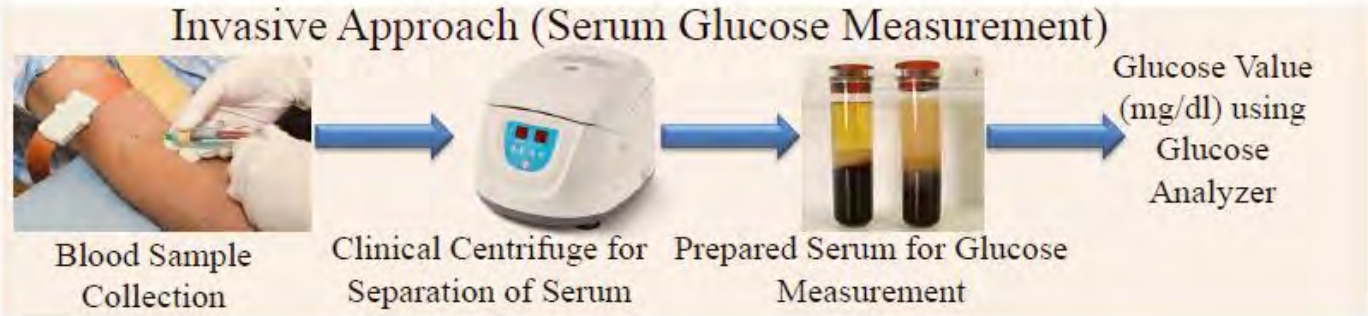
Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

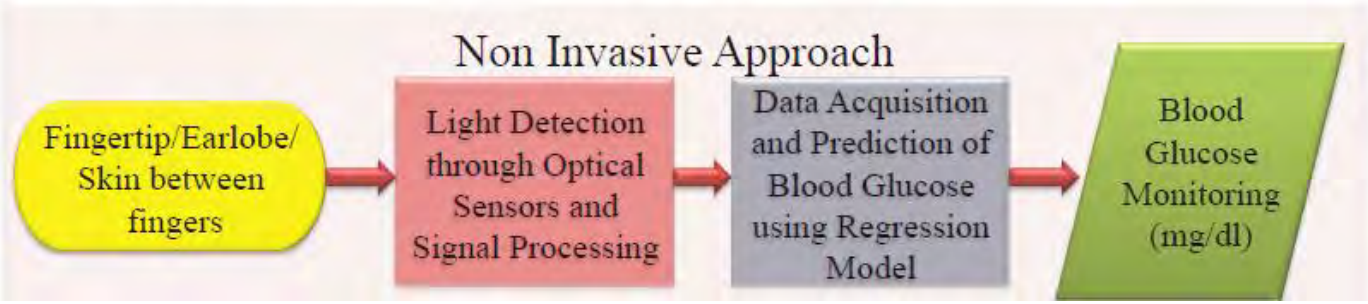
Glucose-Level Measurement - Taxonomy



Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

Blood Glucose Monitoring – Invasive Vs Noninvasive





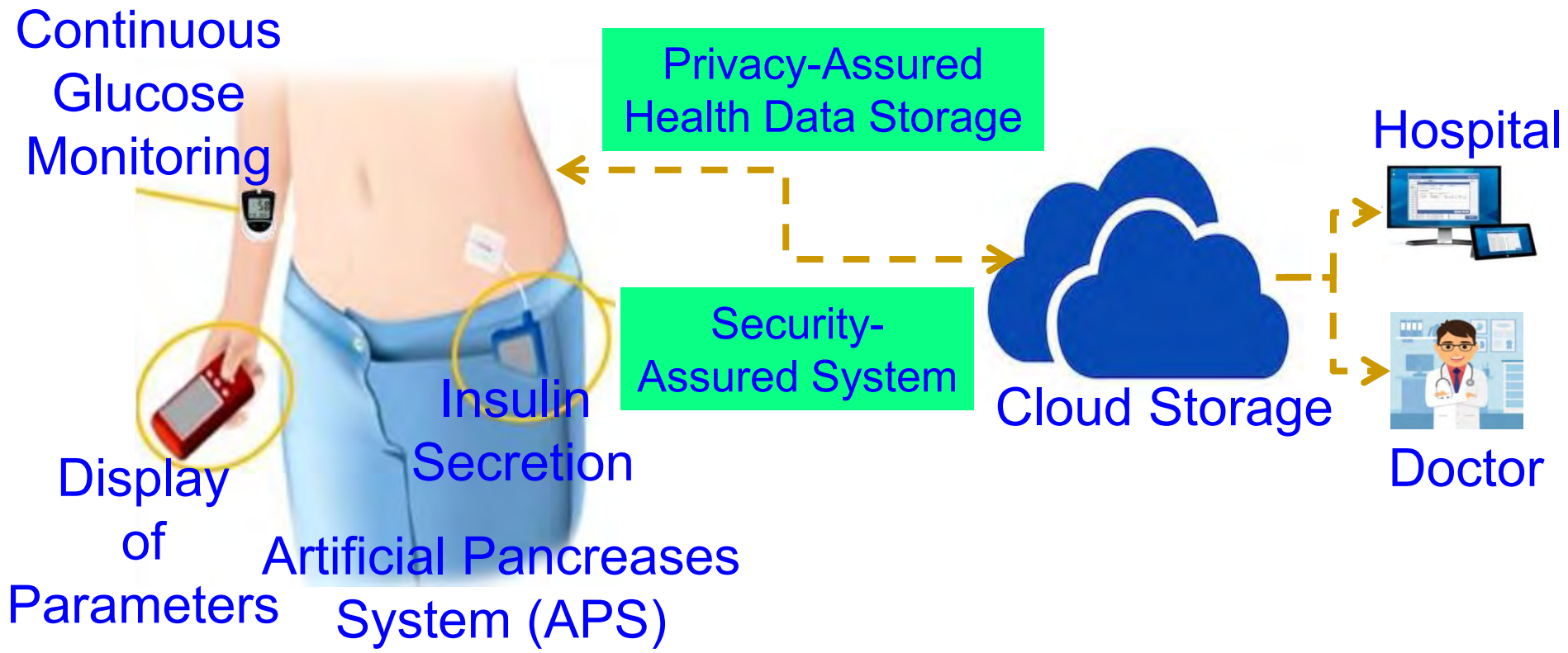
Traditional – Finger Pricking

Invasive Approach – Processing Blood/Serum

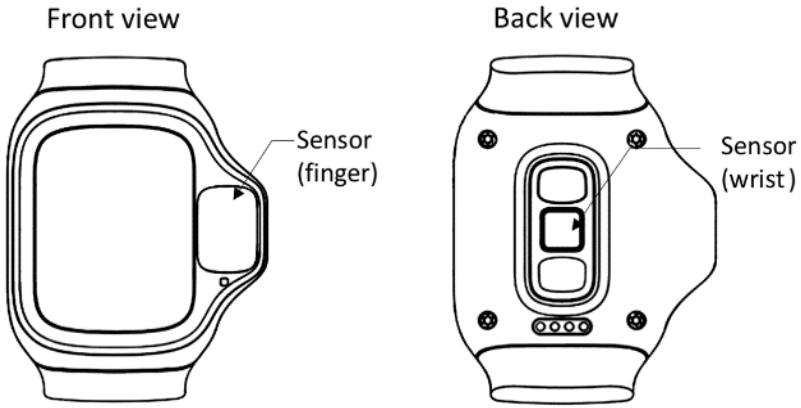
Noninvasive – Wearable

Noninvasive Approach – Processing Light

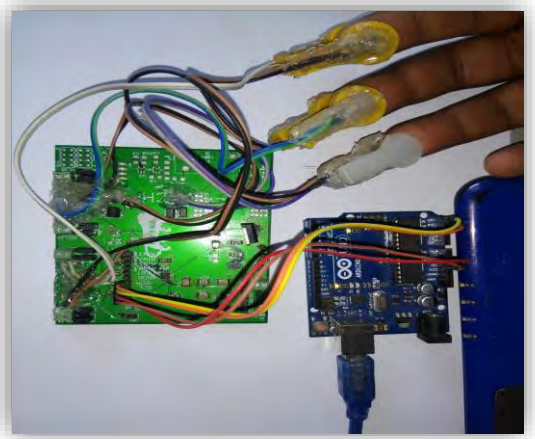
Our Vision – iGLU (Intelligent Noninvasive Monitoring and Control)



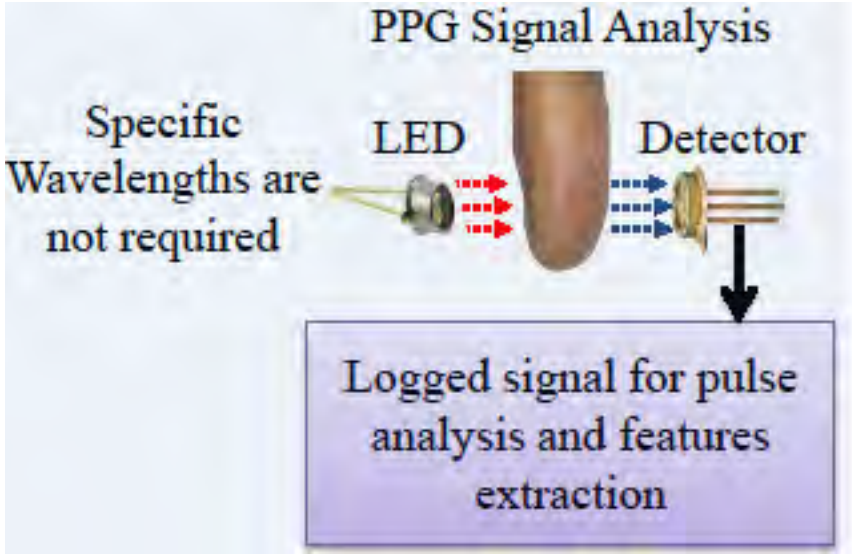
Noninvasive Glucose-Level Monitoring

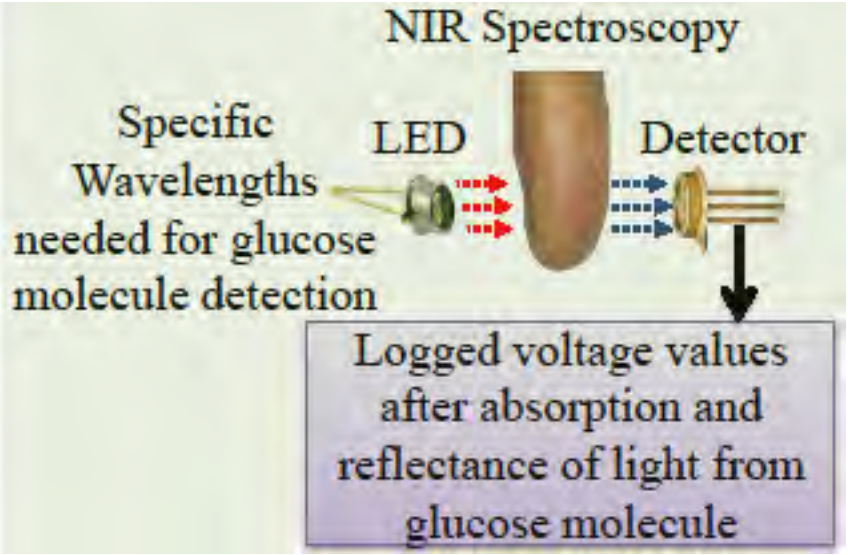


Photoplethysmogram (PPG)

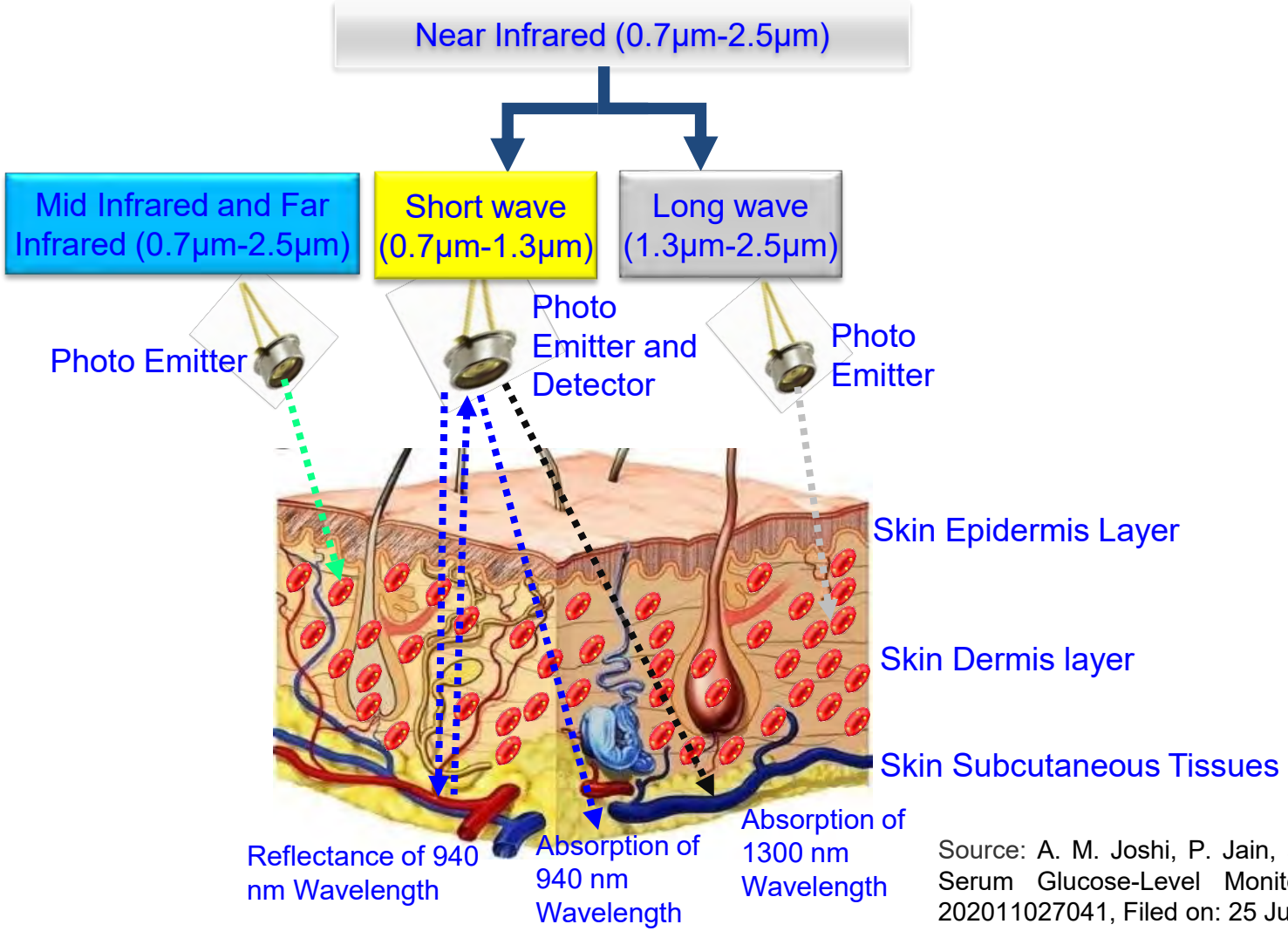


Near Infrared (NIR)



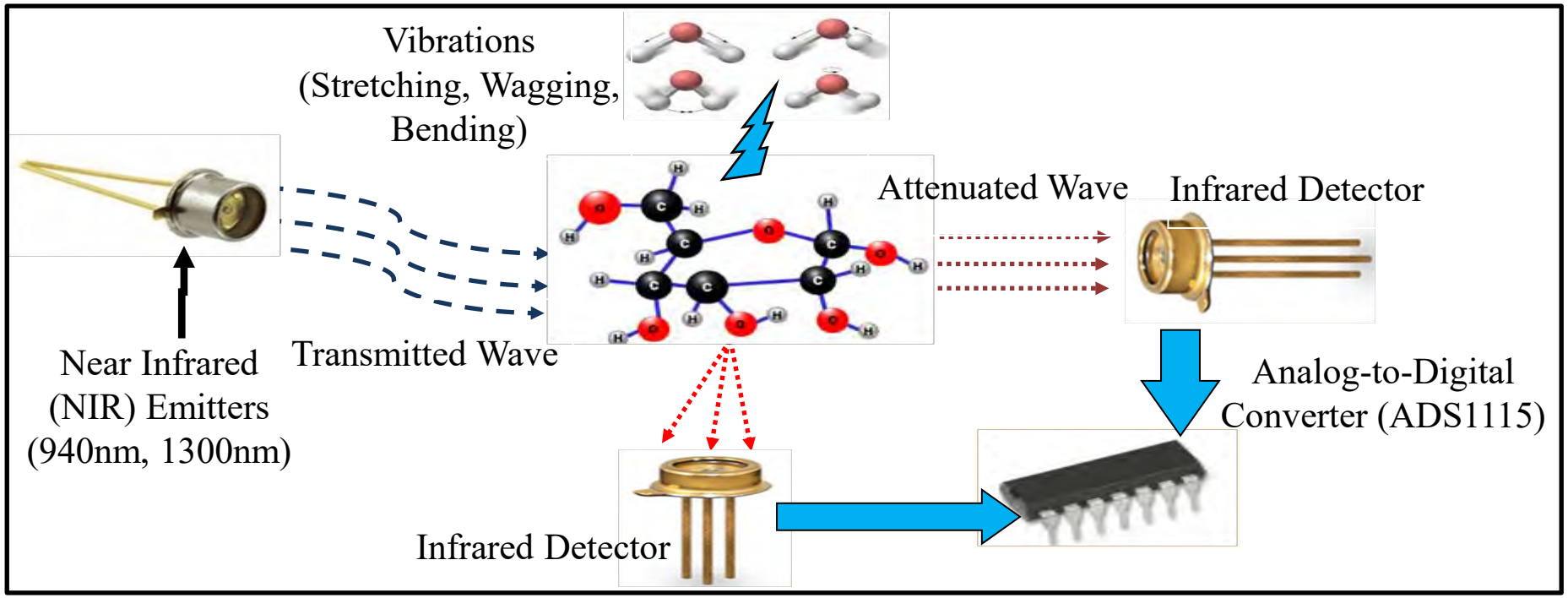


Unique Near Infrared Spectroscopy for iGLU



Source: A. M. Joshi, P. Jain, and S. P. Mohanty, A Device For Non-Invasive Blood and Serum Glucose-Level Monitoring and Control, India Patent Application Number: 202011027041, Filed on: 25 June 2020.

iGLU 1.0 - Capillary Glucose

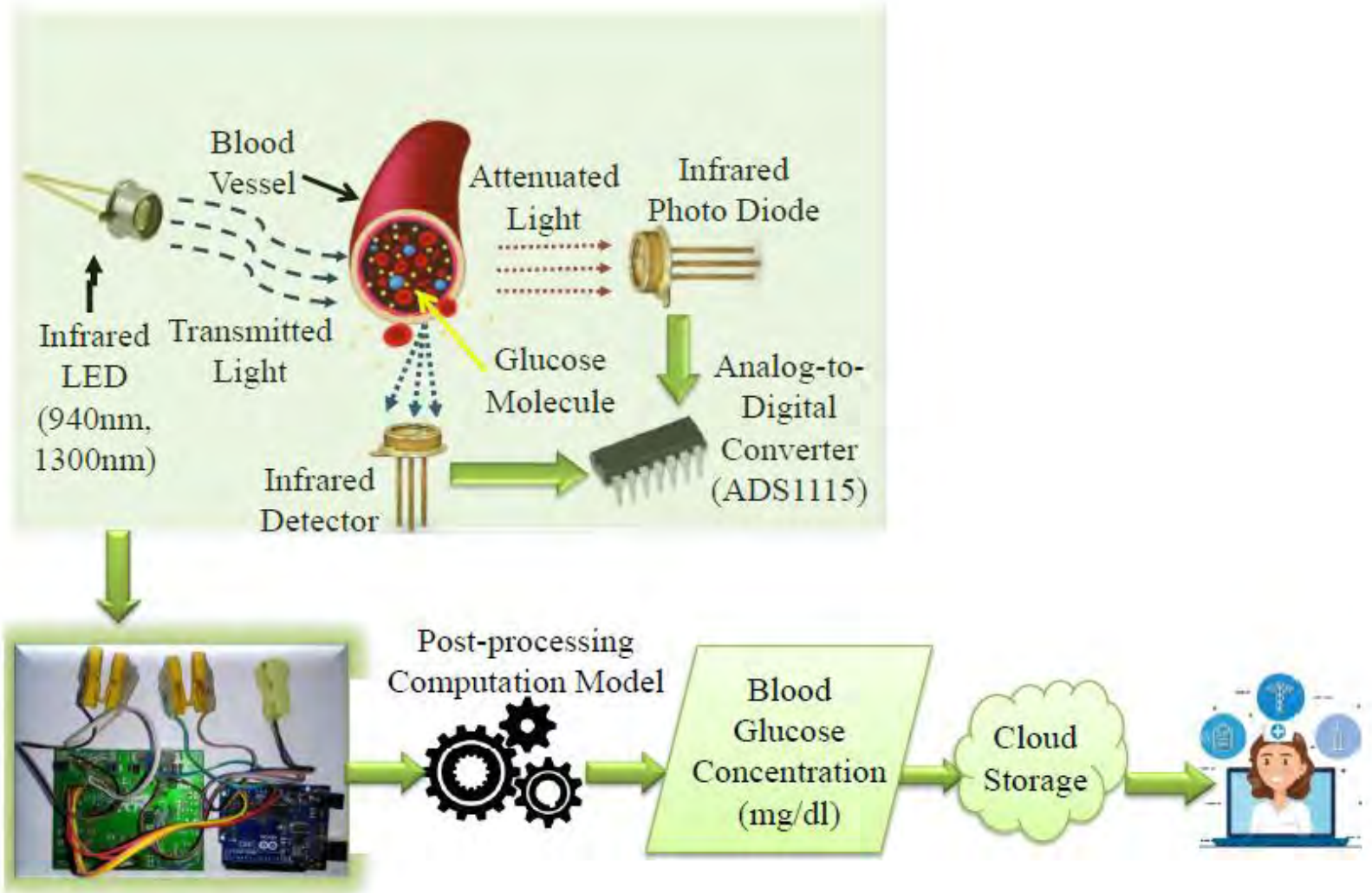


Clinically tested in an hospital.

Cost - US$ 20
Accuracy - 100%

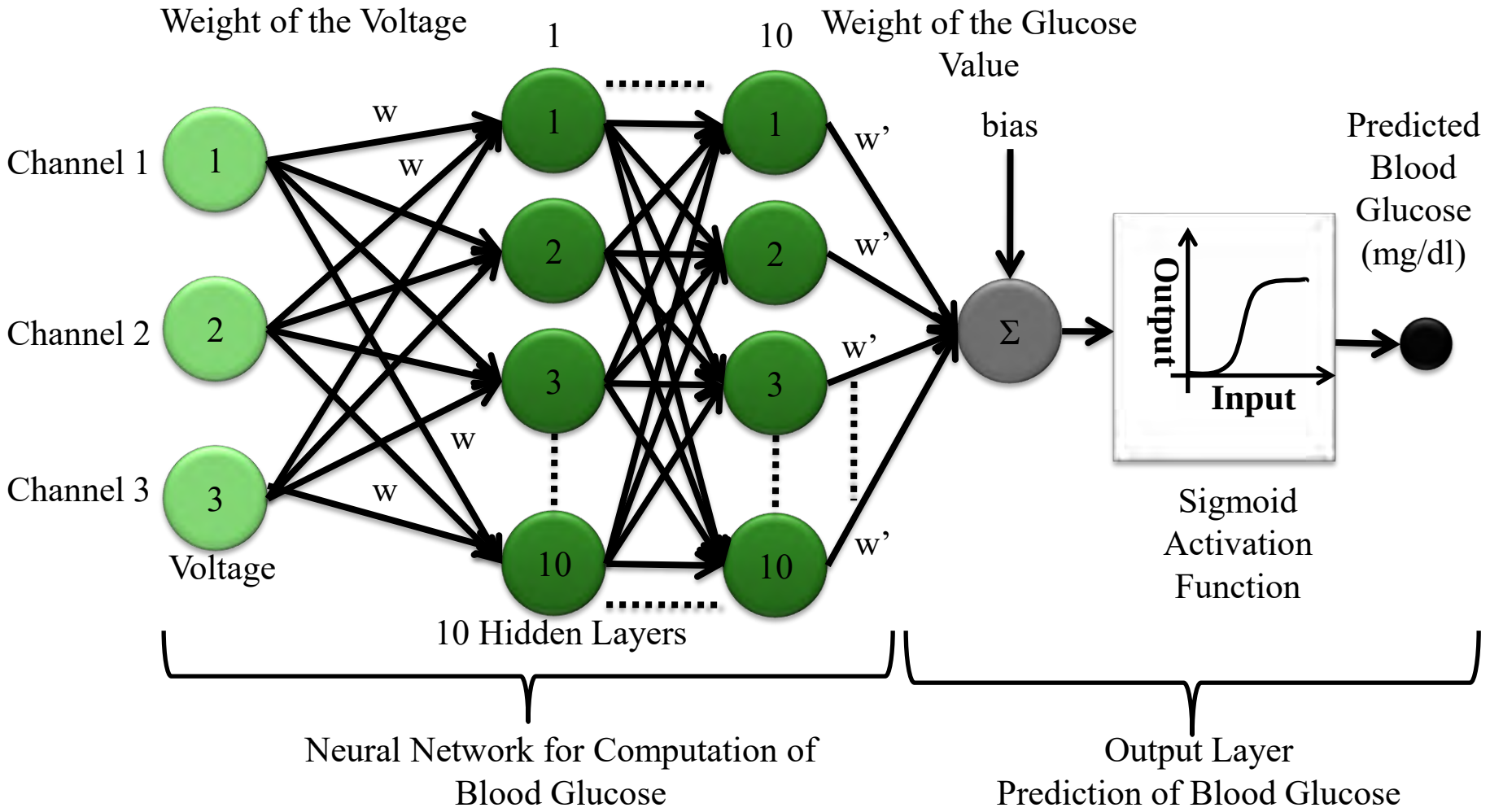
Source: P. Jain, A. M. Joshi, and S. P. Mohanty, "iGLU: An Intelligent Device for Accurate Non-Invasive Blood Glucose-Level Monitoring in Smart Healthcare", *IEEE Consumer Electronics Magazine (MCE),* Vol. 9, No. 1, January 2020, pp. 35-42.

iGLU 2.0 - Serum Glucose

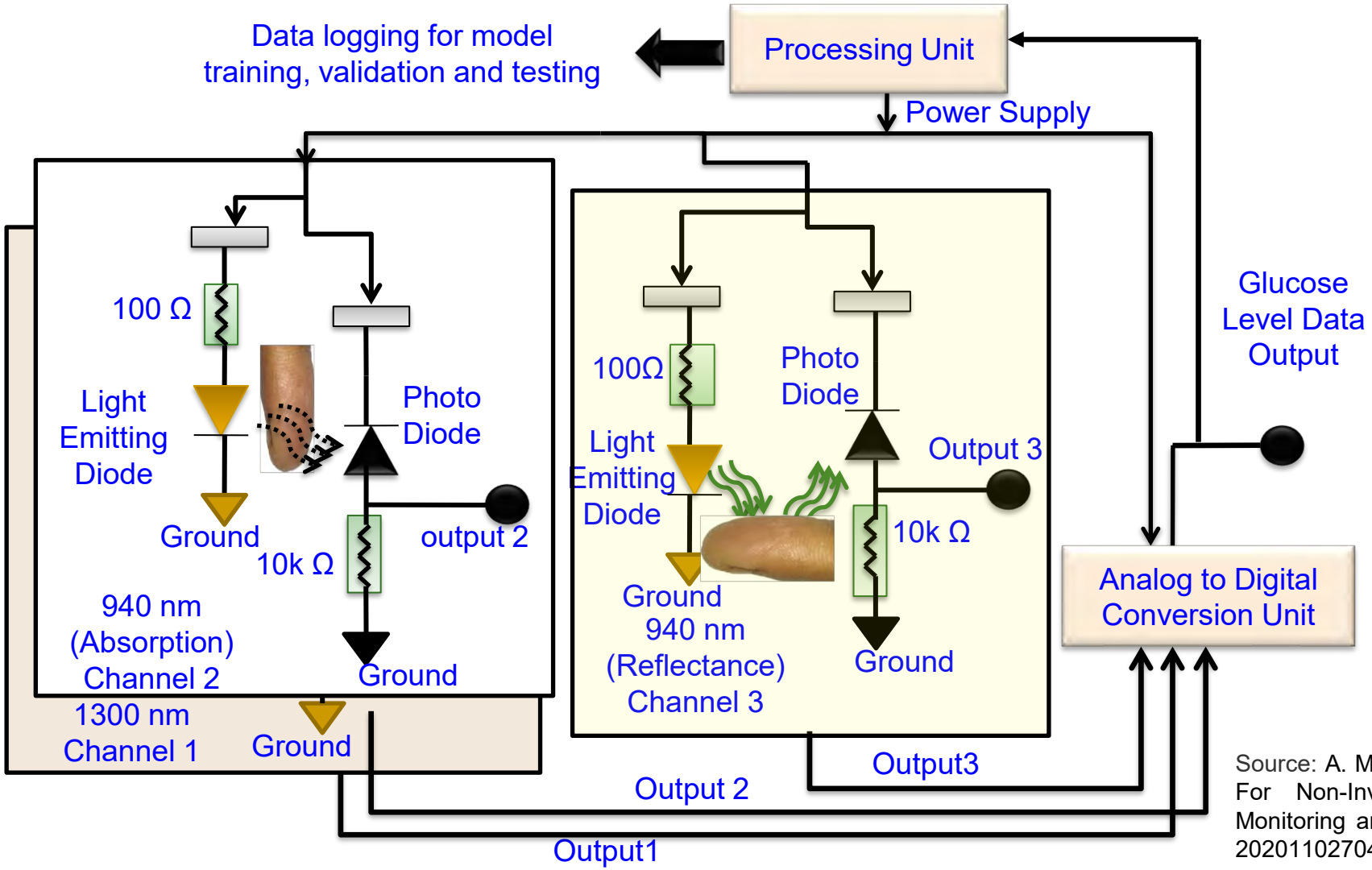


Source: P. Jain, A. M. Joshi, N. Agrawal, and S. P. Mohanty, "iGLU 2.0: A New Non-invasive, Accurate Serum Glucometer for Smart Healthcare", *arXiv Electrical Engineering and Systems Science*, arXiv:2001.09182, January 2020, 19-pages.

DNN Based Glucose Prediction

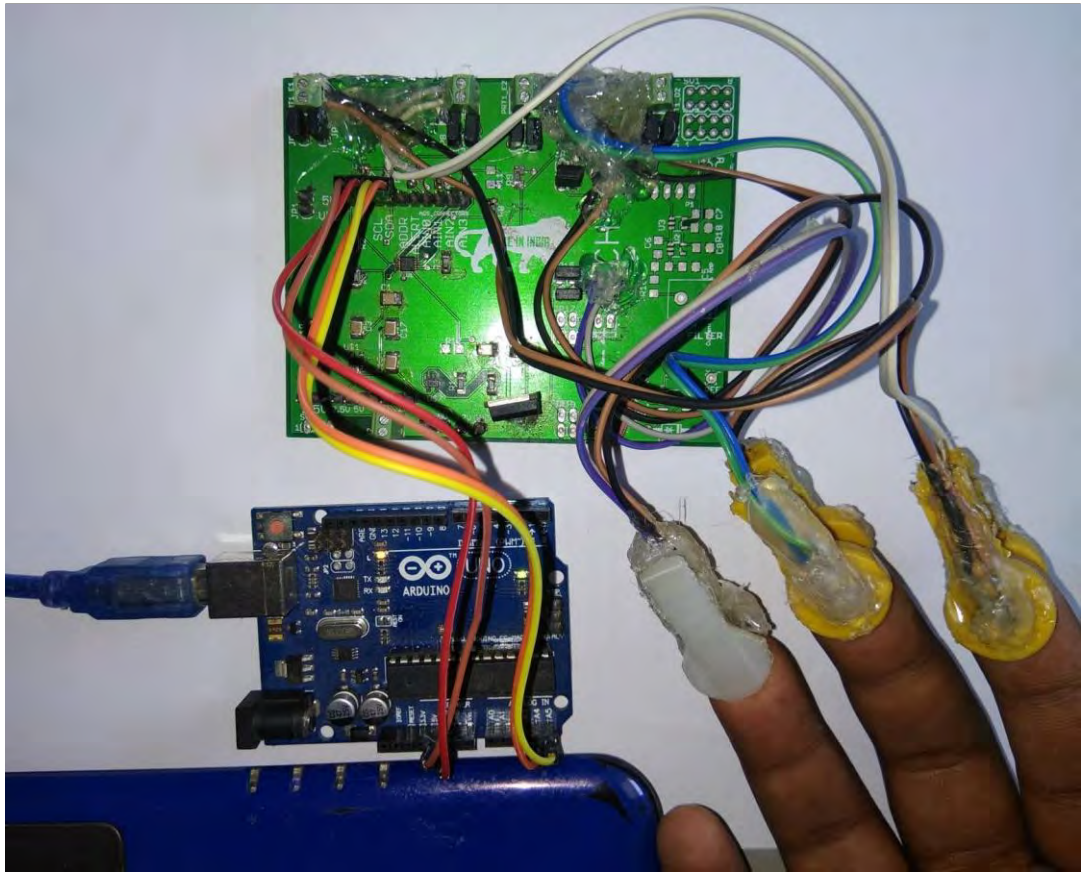


iGLU – Design Implementation



Source: A. M. Joshi, P. Jain, and S. P. Mohanty, A Device For Non-Invasive Blood and Serum Glucose-Level Monitoring and Control, India Patent Application Number: 202011027041, Filed on: 25 June 2020.

iGLU – Real-Life Testing



Clinically tested in an hospital.

Cost - US$ 20
Accuracy - 100%

Non-invasive Detection of Alcohol Concentration based on Photoplethysmogram (PPG) Signals

- Roughly speaking, the more alcohol one consumes, the faster the heart beats. This motivates this research to exploit the relationship between BAC and heartbeat.

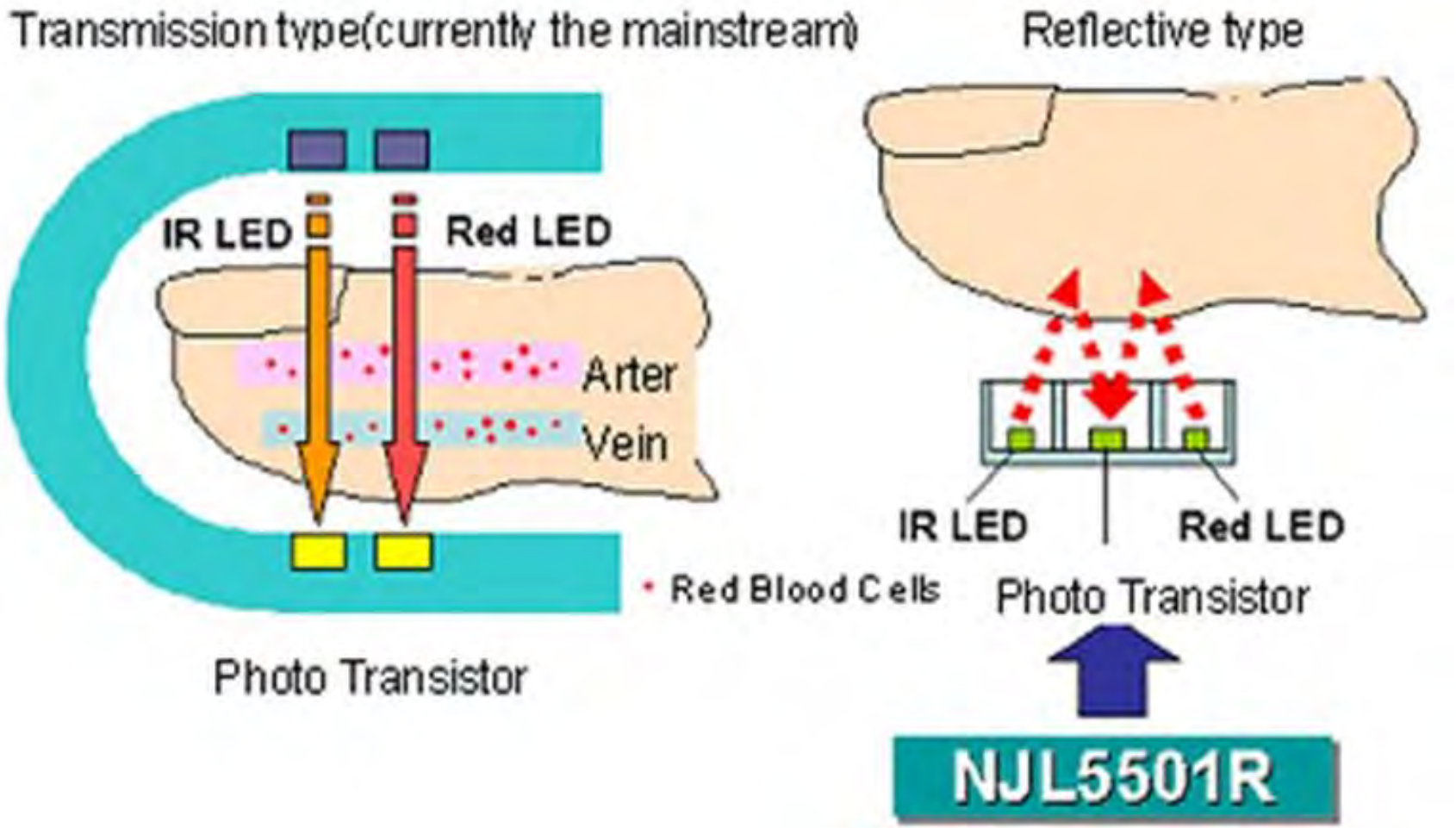
Source: Y. Chen, C. Lin, Y. Lin, and C. Zhao, "Non-invasive detection of alcohol concentration based on photoplethysmogram signals," *IET Image Processing*, vol. 12, no. 2, pp. 188 193, 2018.

Blood Pressure Monitoring using PPG

- Suboptimal blood pressure (BP) is the number one risk factor for death throughout the world.
- One major reason is the lack of proper monitoring and feedback on the treatment. In patients with hypertension, rapid BP change can occur with physical activity, emotion and stress, it is thus crucial for hypertensive people to monitor their BP continuously and get timely medical intervention.
- Our aim is to provide a theoretical explanation of PPG waveforms, and design an algorithm to estimate BP accurately from PPG signal, so that a wearable, continuous, and cuffless device can be developed and hypertensive population can use this device to better manage their BP in all conditions.

Source: Xing X, Sun M, "Optical blood pressure estimation with photoplethysmography and FFT-based neural networks", *Biomedical Optics Express,* 2016, Vol.7 No.8 pp:3007-3020 doi:10.1364/BOE.7.003007.

Photoplethysmograph (PPG) …



Source: http://www.ee.columbia.edu/~kinget/EE6350_S15/08_PPG1_Girish_Oliver/overview.html

Photoplethysmograph (PPG) …

Green LED - 540 nm wavelength
– Preferred for wearables

Source: https://www.wareable.com/fitbit/fitbit-red-light-optical-sensor-technology-2034

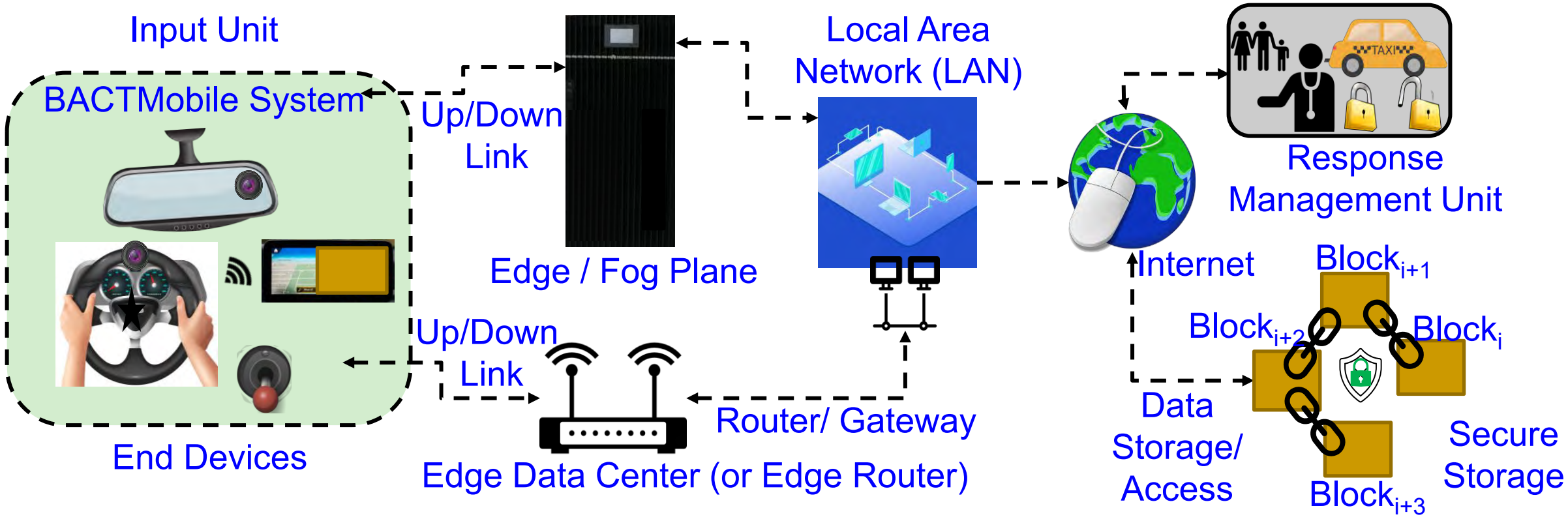
The body absorbs green really well, it's great for reducing signal distortion, but it doesn't penetrate deep. A lot of it is absorbed by your body so you don't get anything deeper than heart rate.

Red LED - 645 nm wavelength
- Preferred for hospitals and health industry

Source: https://willem.com/blog/2017-11-15_collecting-health-data-with-biostrap/

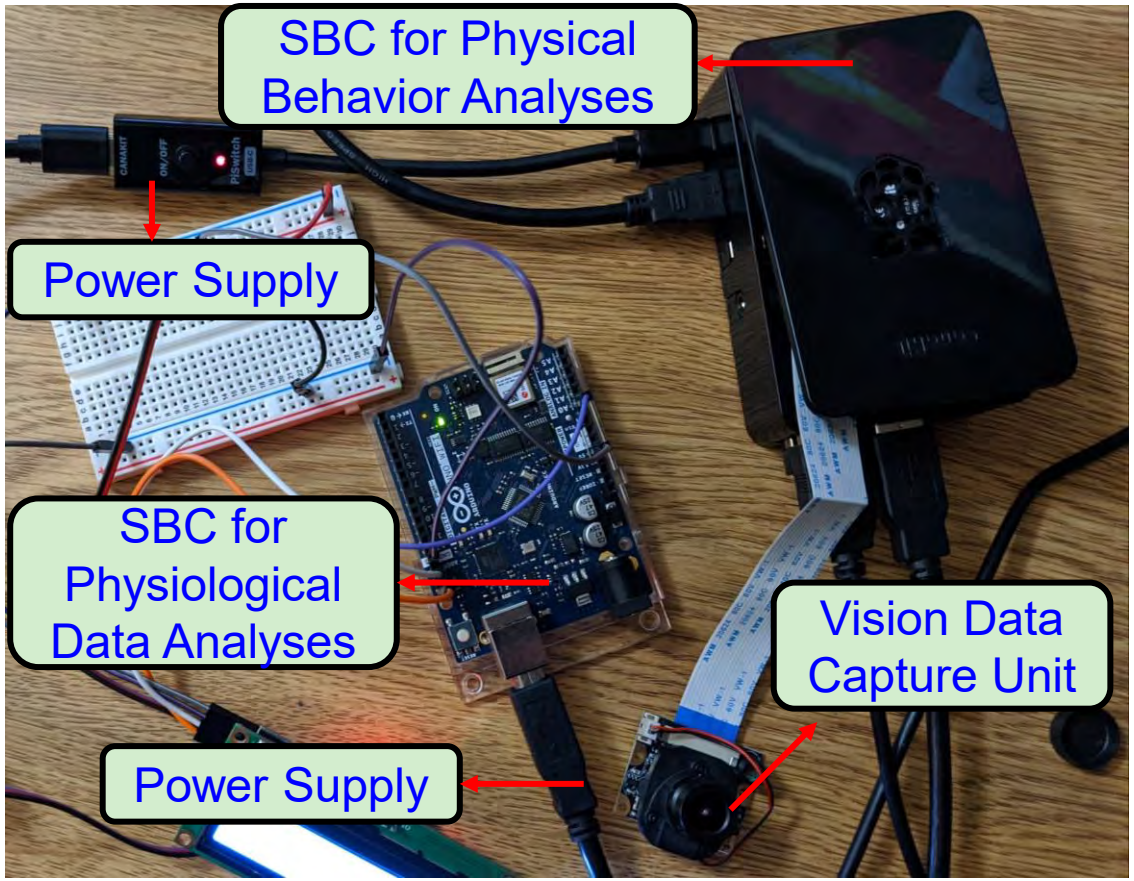
The body is a poor absorber of red light allowing the light to pass much deeper into the body and a larger volume of tissues to help provide more insightful data and could lead to improved accuracy with biometric data like heart rate.

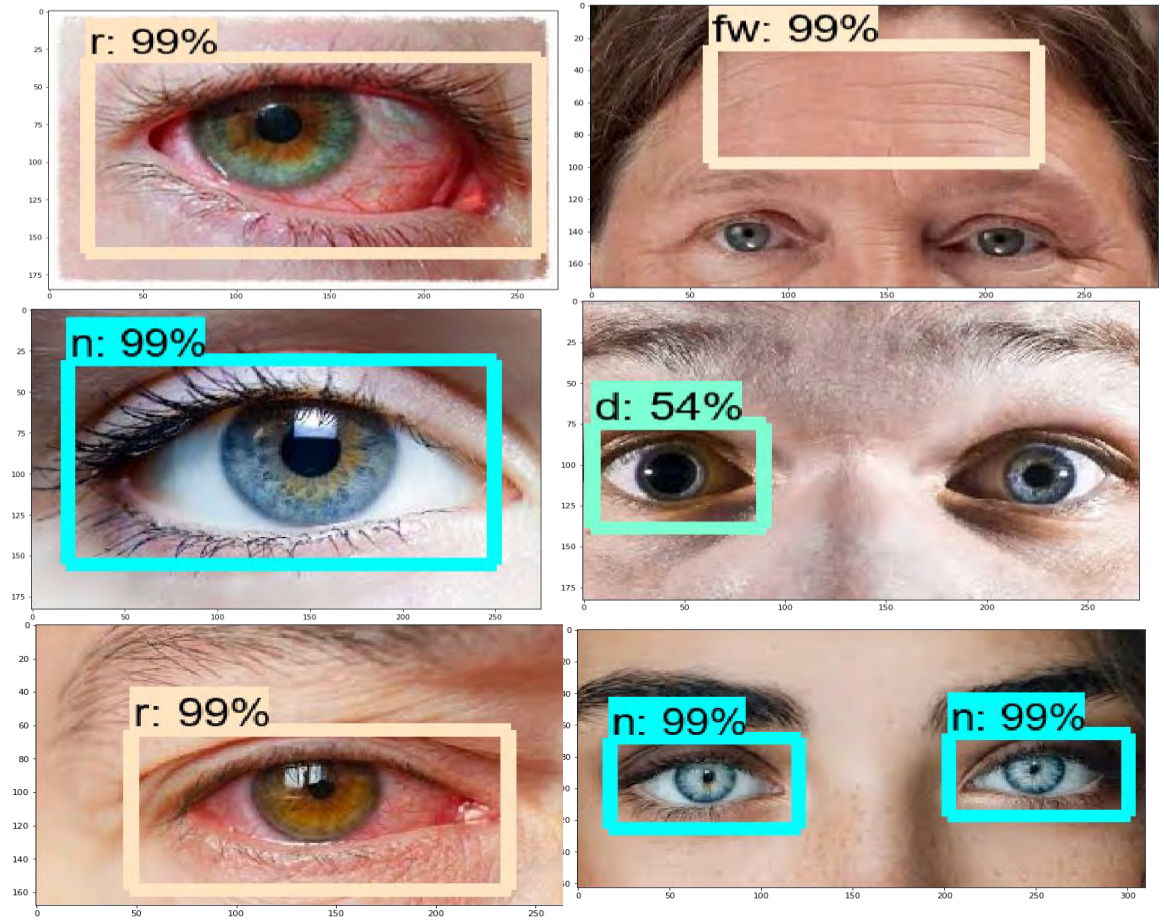
Our Smart Blood Alcohol Concentration Tracking Mechanism in Healthcare CPS - BACTmobile



Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

Our Smart Blood Alcohol Concentration Tracking Mechanism in Healthcare CPS - BACTmobile





Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

Epileptic Seizure

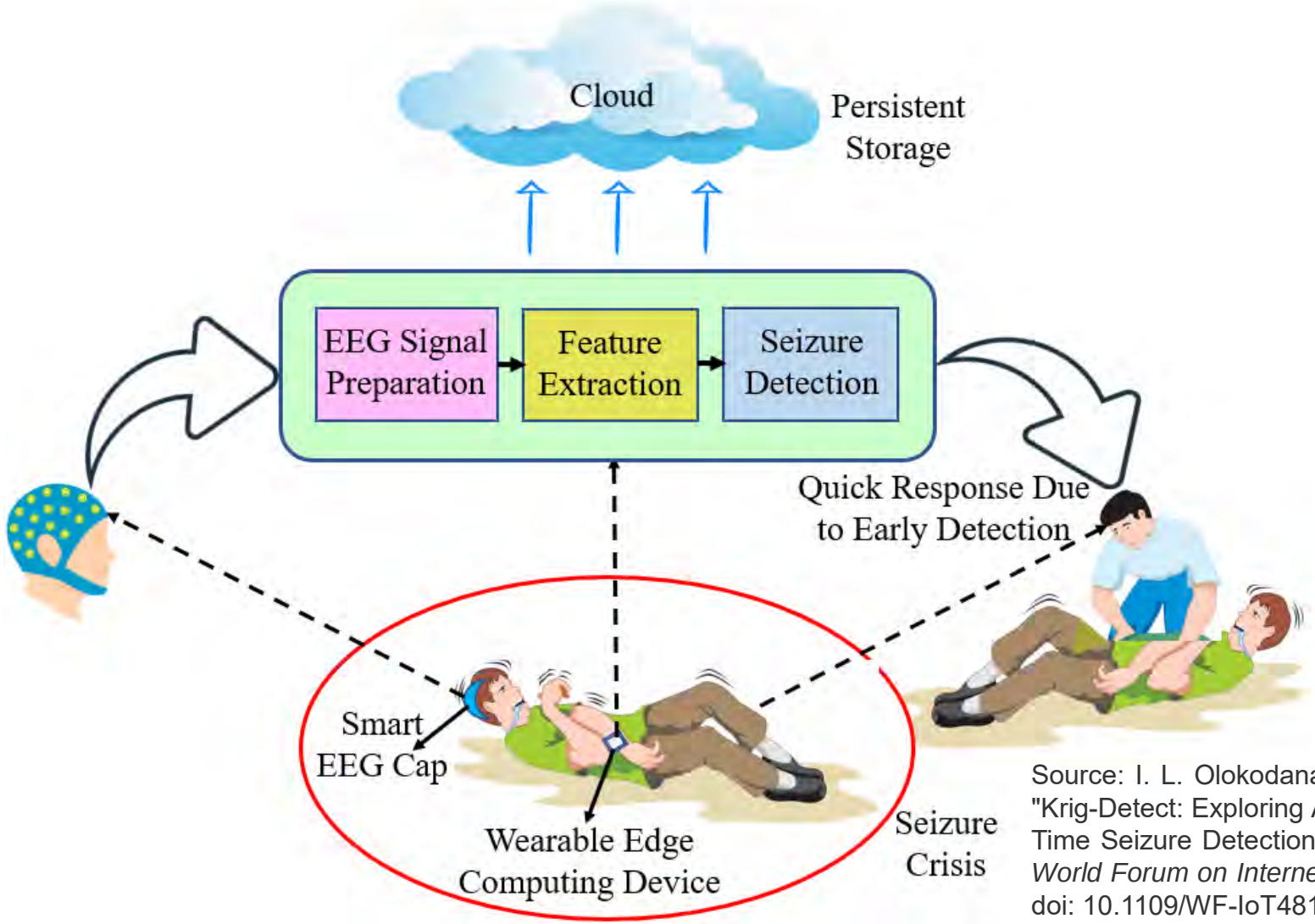
- A seizure is an abnormal activity in the nervous system which causes its sufferers to lose consciousness and control.

Epileptic Seizure Has Global Impact

- Up to 1% of the world's population suffers from epilepsy.
- Epilepsy is the fourth most common neurological disease after migraine, stroke, and Alzheimer's.
- Individuals can suffer a seizure at any time with potentially disastrous outcomes including a fatal complication called "Sudden Unexpected Death in Epilepsy" (SUDEP).

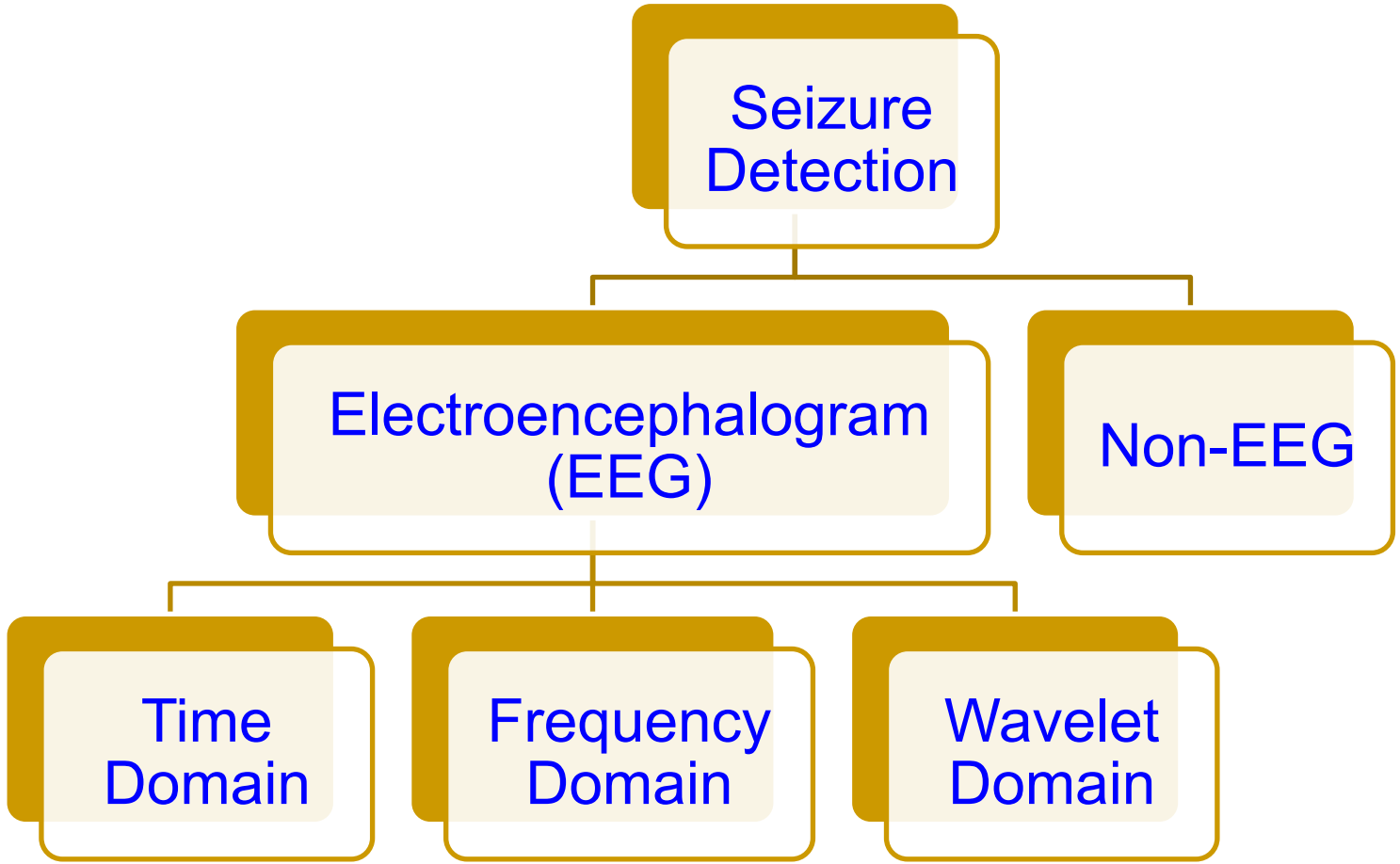
Source: https://www.epilepsy.com/learn/about-epilepsy-basics/epilepsy-statistics

Epileptic Seizure - Research Vision



Source: I. L. Olokodana, S. P. Mohanty and E. Kougianos, "Krig-Detect: Exploring Alternative Kriging Methods for Real-Time Seizure Detection from EEG Signals," *2020 IEEE 6th World Forum on Internet of Things (WF-IoT)*, 2020, pp. 1-6, doi: 10.1109/WF-IoT48130.2020.9221260.

Seizure Detection Methods



Seizure Detection Methods – Non-EEG

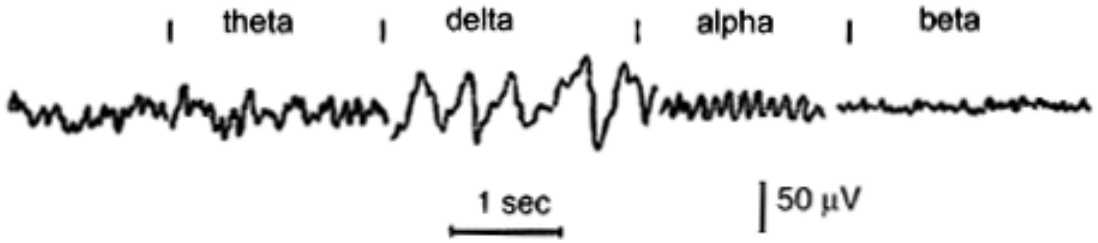
			DETECTION METHODS							
			Audio	Video	Electro-magnetic waves	ACM/ gyro/ magneto	Electrodes	Plethys-mograph (volume)	Pressure	Tempe-rature
NON-EEG SEIZURE MANIFESTATIONS	Motor	Body	bed noise	optical or thermal camera	radio, infrared or microwaves	bed or body attached	EMG		pressure mat for bed vacancy	
		Eye(lid)		optical camera			EOG/EMG			
	Auto-nomic	HR	PCG	thermal camera	radio or microwaves (BCG)	BCG	ECG	PPG		
		BP						PPG		
		SpO_2			infrared waves of oximeter					
		Respira-tion	neck	thermal camera	radio or microwaves chest, infrared waves of oximeter/ capnograph	ACM/ magneto chest	EMG, EDR, impedance pneumograph chest, electrodes for pO_2/CO_2	RIP chest	pneumo-tachograph airflow	thermo-couple airflow
		Sweating					ohm/ galvanometer			
		Vomiting/ salivation/ coughing	audio phone				humidity meter			
		Inconti-nence					humidity meter			
	Vocalizations		audio phone							
	Fever			thermal camera	radio waves					sticker

ACM = accelerometer, BP = blood pressure,
ECG = electrocardiography,
EDR = ECG-derived respiration,
EMG = electromyography,
EOG = electro-oculography,
gyro = gyroscope, HR = heart rhythm, magneto = magnetometer,
PCG = phonocardiography,
pO_2/CO_2 = partial pressure oxygen/carbon dioxide,
PPG = photoplethysmography,
RIP = Respiratory Inductance Plethysmography, SpO_2 = blood oxygenation.

Source: https://www.seizure-journal.com/article/S1059-1311(16)30114-5/fulltext

Brain Electroencephalogram (EEG) Signal

Source: https://www.medicine.mcgill.ca/physio/vlab/biomed_signals/eeg_n.htm



- Signal Intensity: EEG activity is quite small, measured in microvolts (μV).
- Signal Frequency: Main frequencies of the human EEG waves are:
  1. Delta (<3 Hz)
  2. Theta (3.5 to 7.5 Hz)
  3. Alpha (7.5 and 13 Hz)
  4. Beta (>14 Hz)

Inside an EEG System

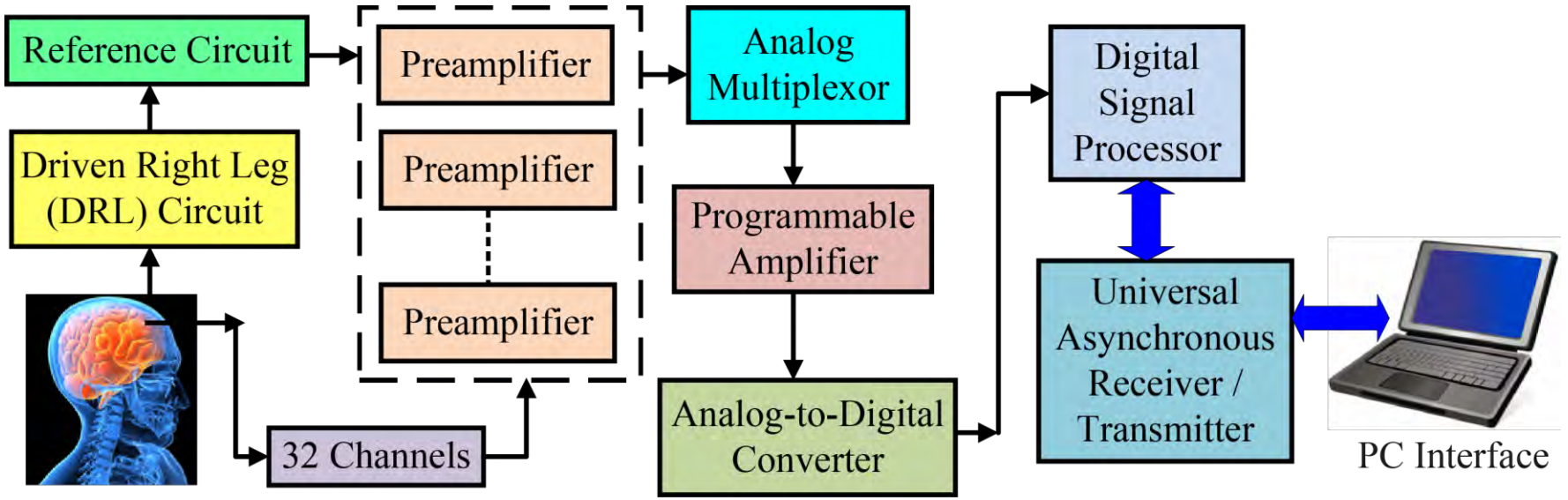
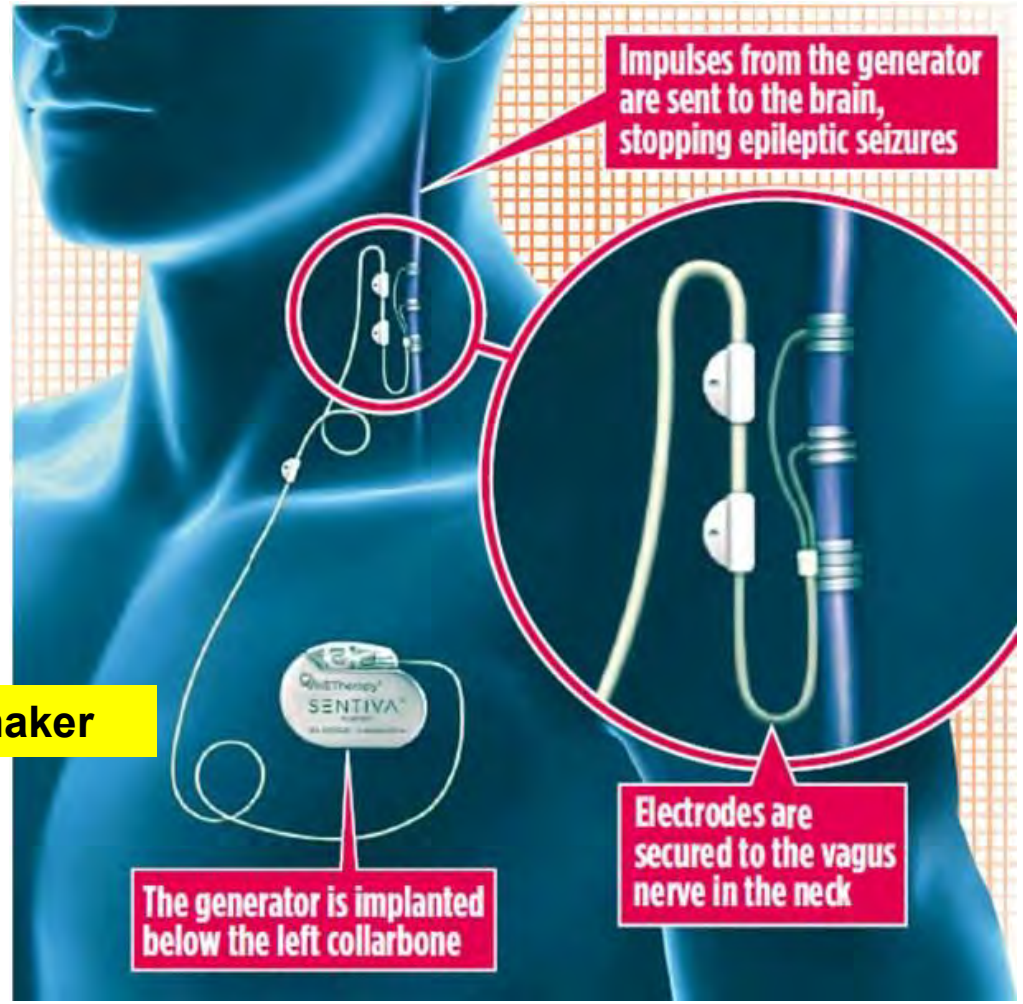


Figure 2.16 Block diagram of a EEG [151].

Seizure Control Devices

Brain Pacemaker



Source: https://www.dailymail.co.uk/health/article-5851595/Game-changer-brain-pacemaker-stops-epileptic-fits-tracks.html

IBM's Implantable Seizure Detector

- The TrueNorth chip is postage stamp-sized and consumes over 1,000 times less power than a conventional processor of similar size.

Source: http://uberveillance.squarespace.com/?category=health_care

Consumer Electronics for Seizure Detection

Source: https://spectrum.ieee.org/the-human-os/biomedical/diagnostics/this-seizuredetecting-smartwatch-could-save-your-life

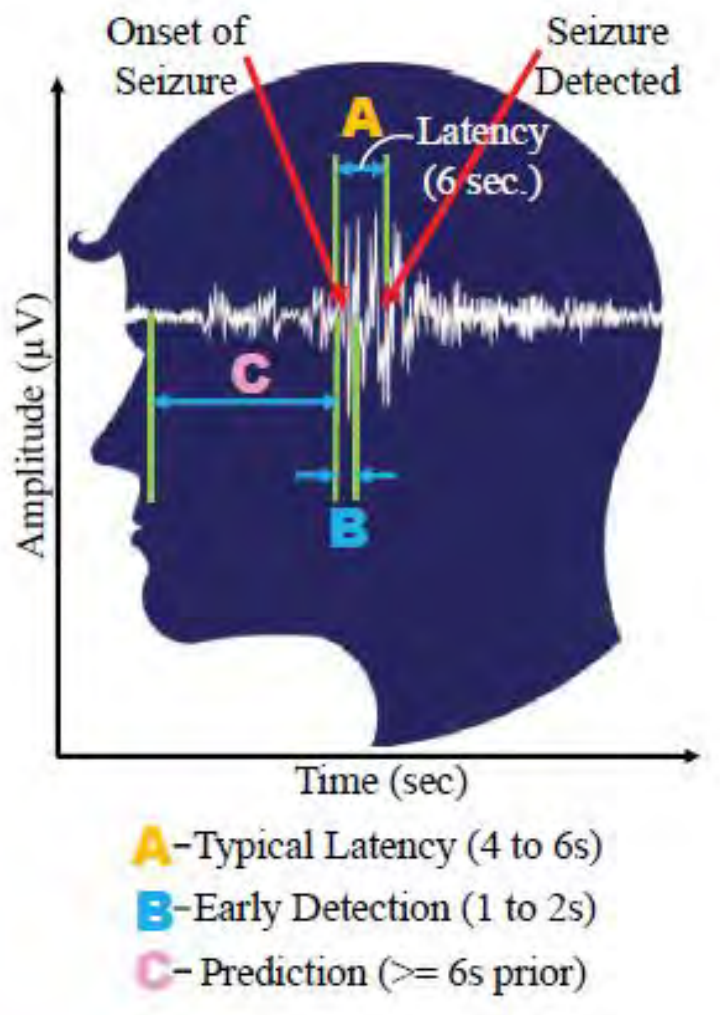
- Embrace2: Smart-band which uses machine learning to detect convulsive Seizures and notifies caregivers.

Source: https://www.empatica.com/embrace2/

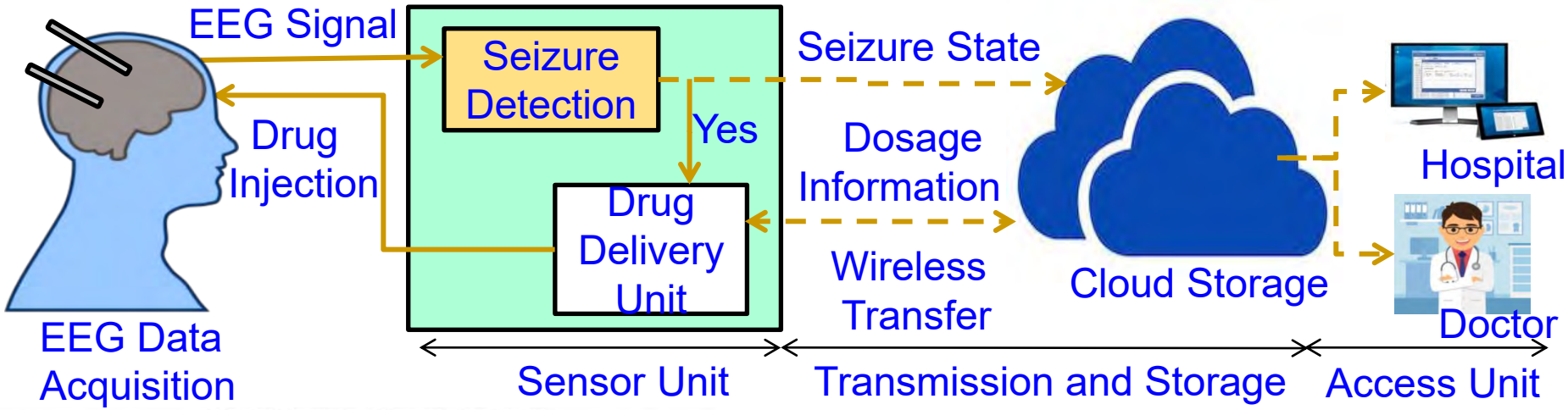
- Medical grade smart watch: It detects generalized clonic-tonic Seizures and notifies physicians.

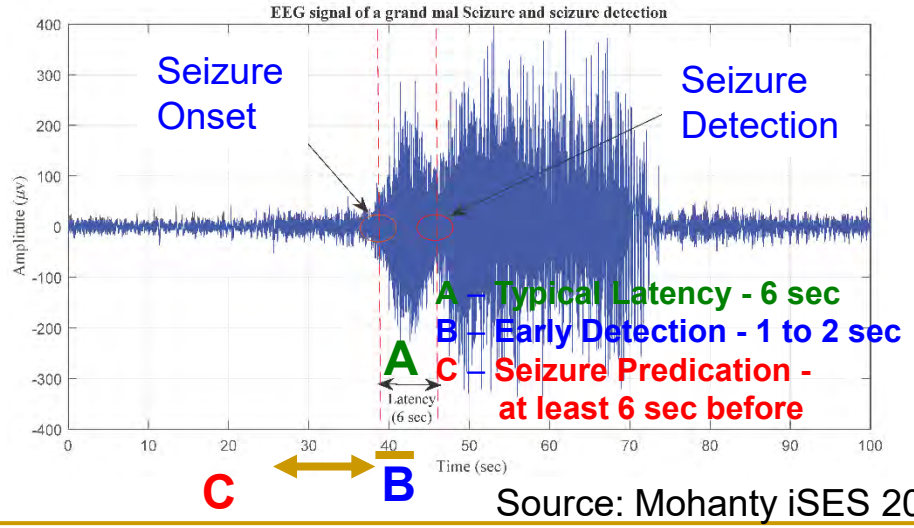
Drawbacks of Existing Works?

- High seizure detection latency.
- Not suitable for real time IoMT deployment.
- Intervention mechanism after detection is lacking.



Smart Healthcare – Seizure Detection and Control



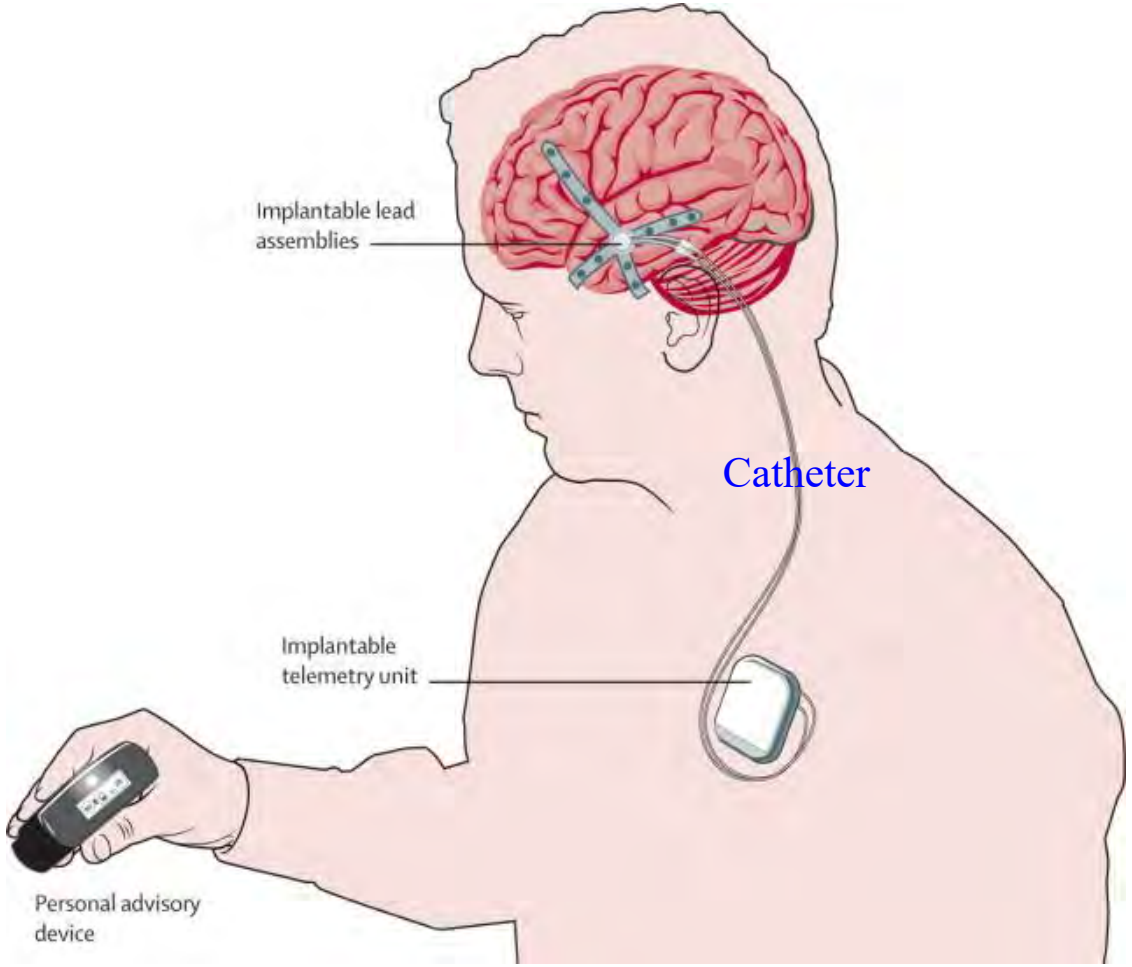


Automated Epileptic Seizure Detection and Control System

Cloud Vs Edge	Latency	Accuracy
Cloud-IoT based Detection	2.5 sec	98.65%
Edge-IoT based Detection	1.4 sec	98.65%

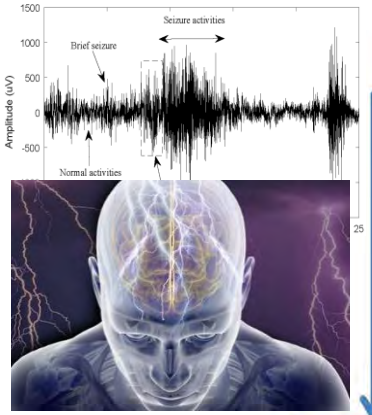
Source: Mohanty iSES 2018, IEEE Smart Cities 2018, and Mohanty ICCE 2019

Implantable for Seizure Detection and Control

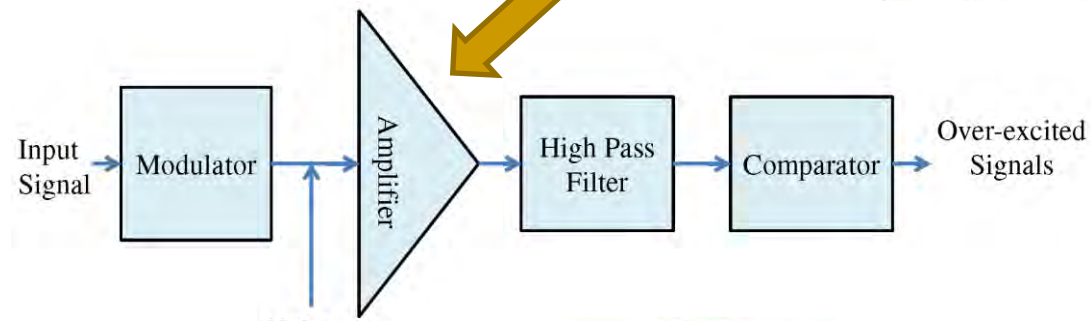


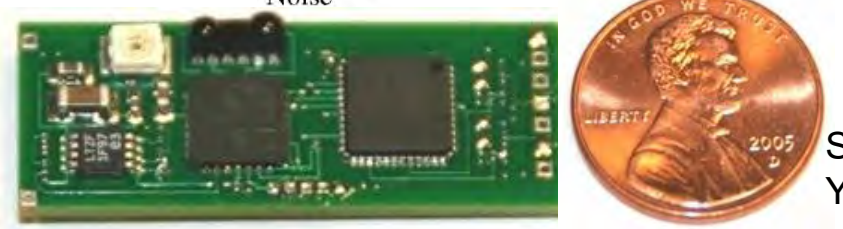
Source: https://www.kurzweilai.net/brain-implant-gives-early-warning-of-epileptic-seizure

Smart Healthcare – Efficient Epileptic Seizure Detector



EEG Signal





Source: Zaveri, Yale University

Parameter	Value
Seizure Frequency (Minimum)	5 Hz
Seizure Frequency (Minimum)	25 HZ
Voltage Level Detector (Avg. Lower Threshold)	210 mV
Voltage Level Detector (Avg. Upper Threshold)	380 mV
Total power consumption	6.18 µW

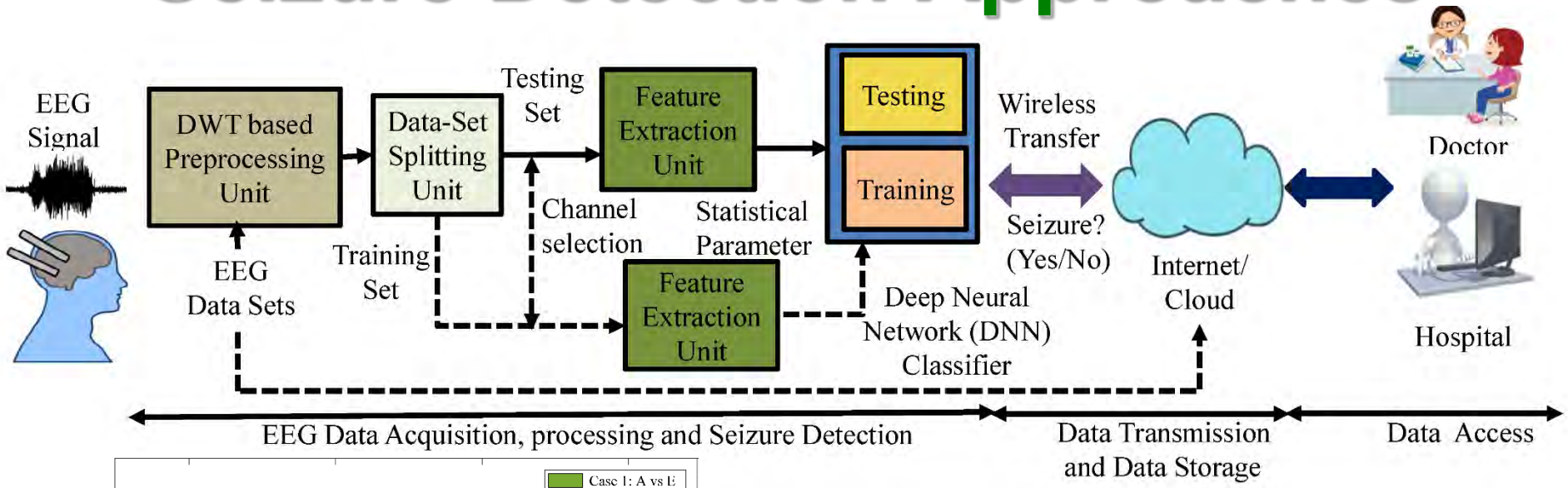
Source: Mohanty ICCE 2018

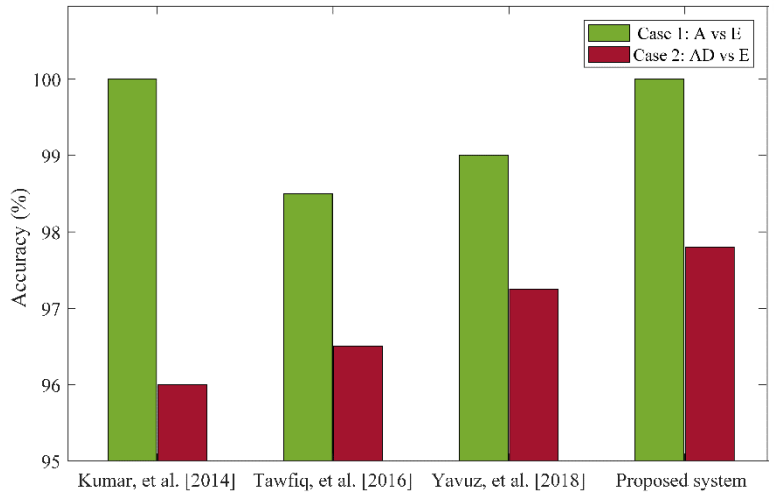
Neuro-Detect: Machine Learning Based Fast and Accurate Seizure Detection

- An accurate seizure detection approach has been proposed.
- This is the first study to propose DWT based Hjorth parameters (HPs) for seizure detection.
- The inclusion of IoT with the proposed system provides universal connectivity with other healthcare applications.

Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 359--368.

Seizure Detection Approaches



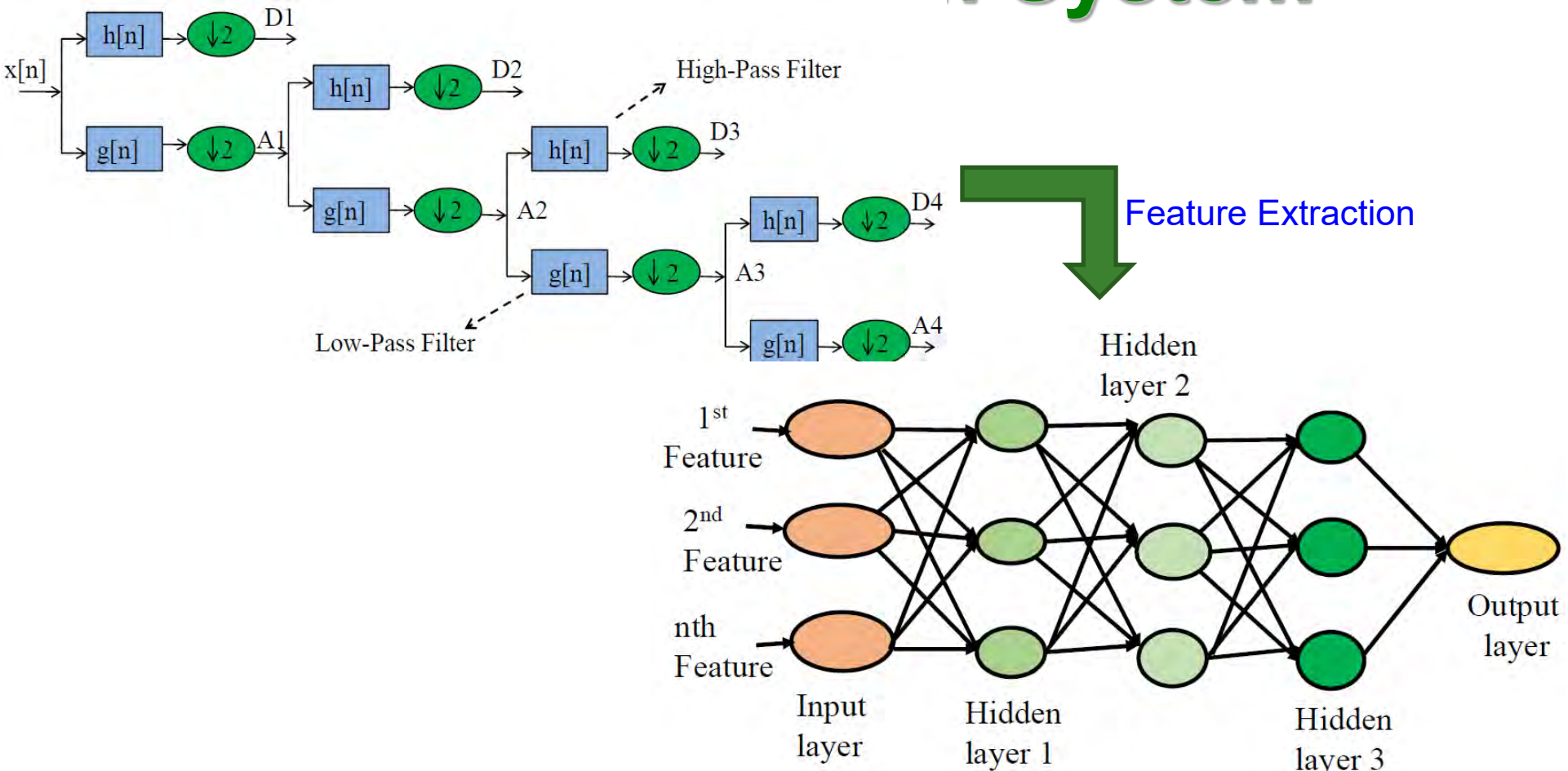


Cloud Vs Edge Computing

Cloud Vs Edge	Latency	Accuracy
Cloud-IoT based Detection	2.5 sec	98.65%
Edge-IoT based Detection	1.4 sec	98.65%

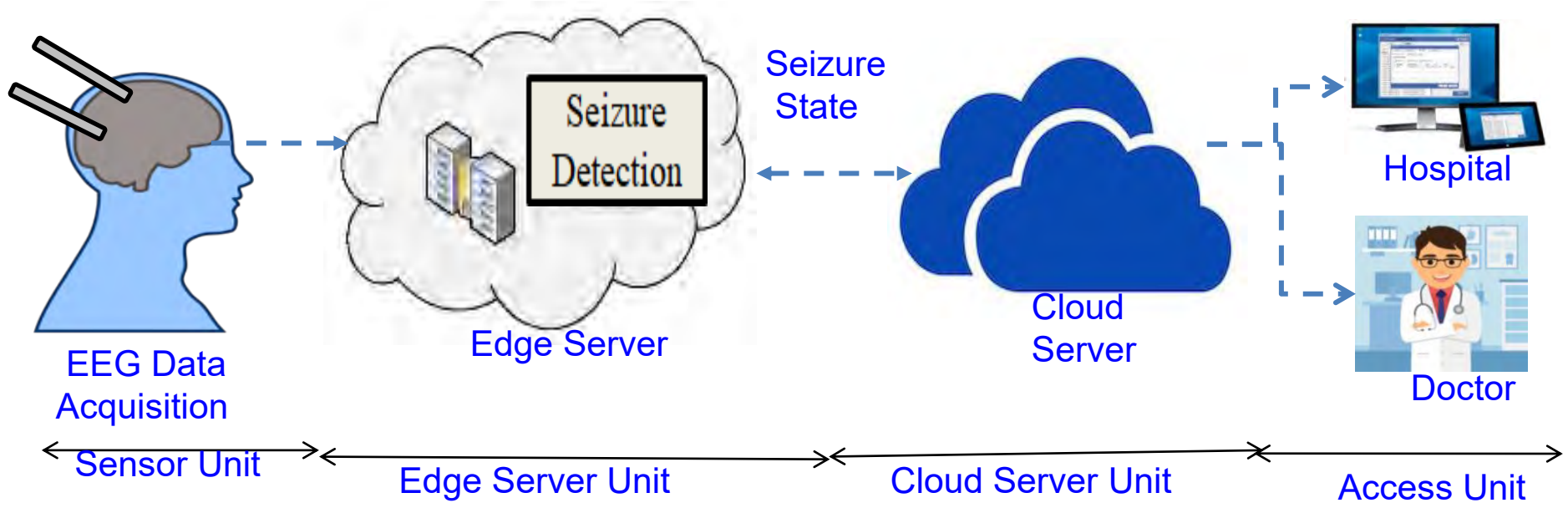
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 3, Aug 2019, pp. 359--368.

Our Neuro-Detect : A ML Based Seizure Detection System



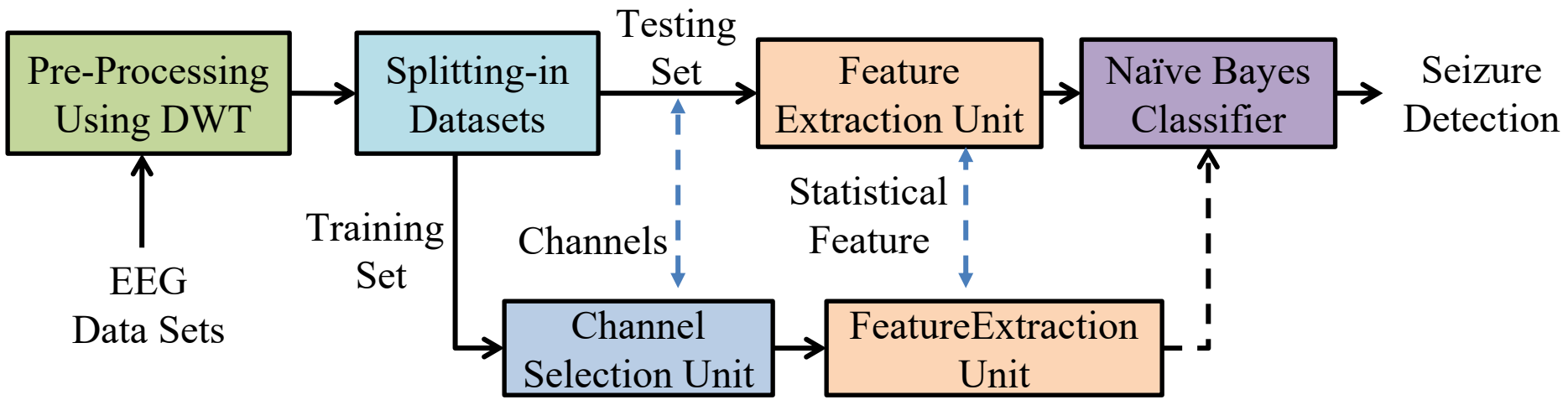
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri , "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, Issue 3, Aug 2019, pp. 359-368.

Seizure Detection – IoT-Edge Computing



Source: A. Sayeed, S. P. Mohanty, E. Kougianos, V. P. Yanambaka and H. Zaveri, "A Robust and Fast Seizure Detector for IoT Edge," in *Proc. IEEE International Symposium on Smart Electronic Systems (iSES) (Formerly iNiS)*, 2018, pp. 156-160, doi: 10.1109/iSES.2018.00042.

Architecture: Epileptic Seizure Detection

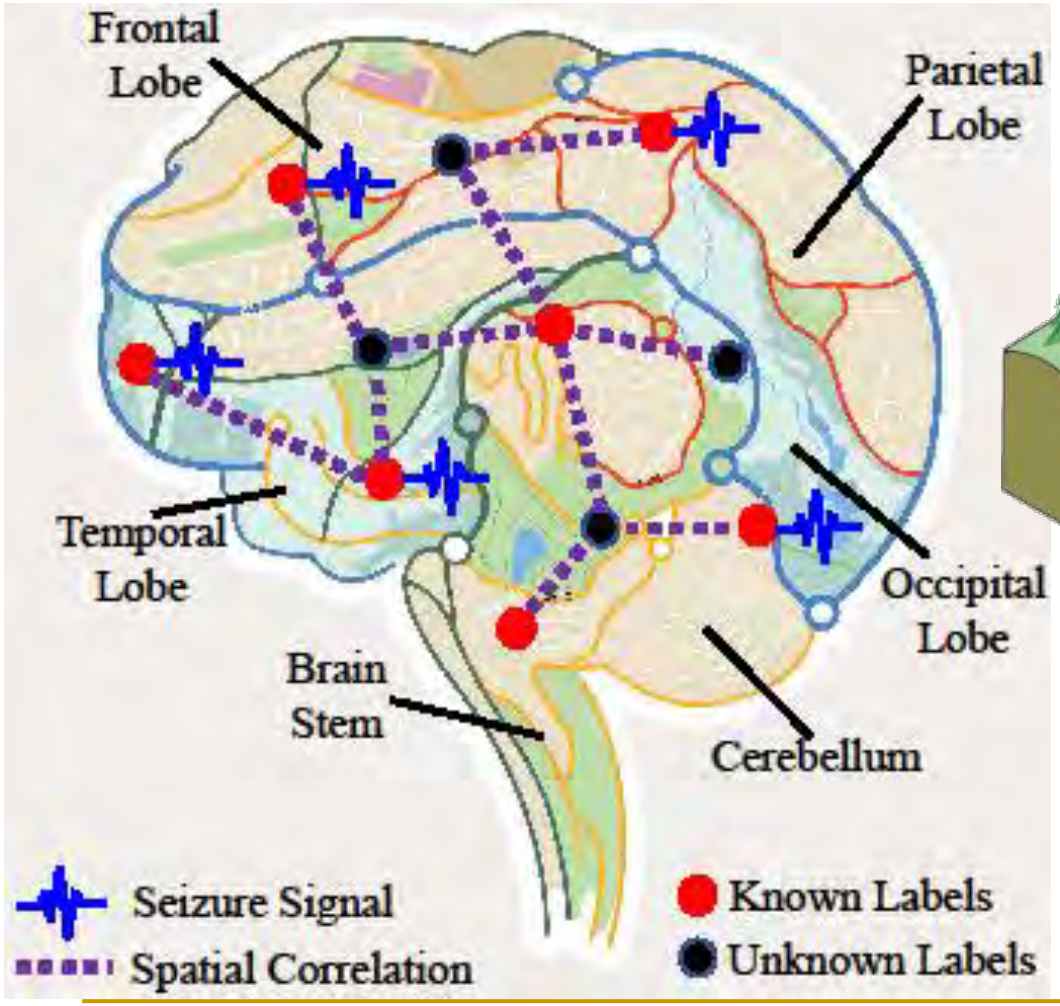


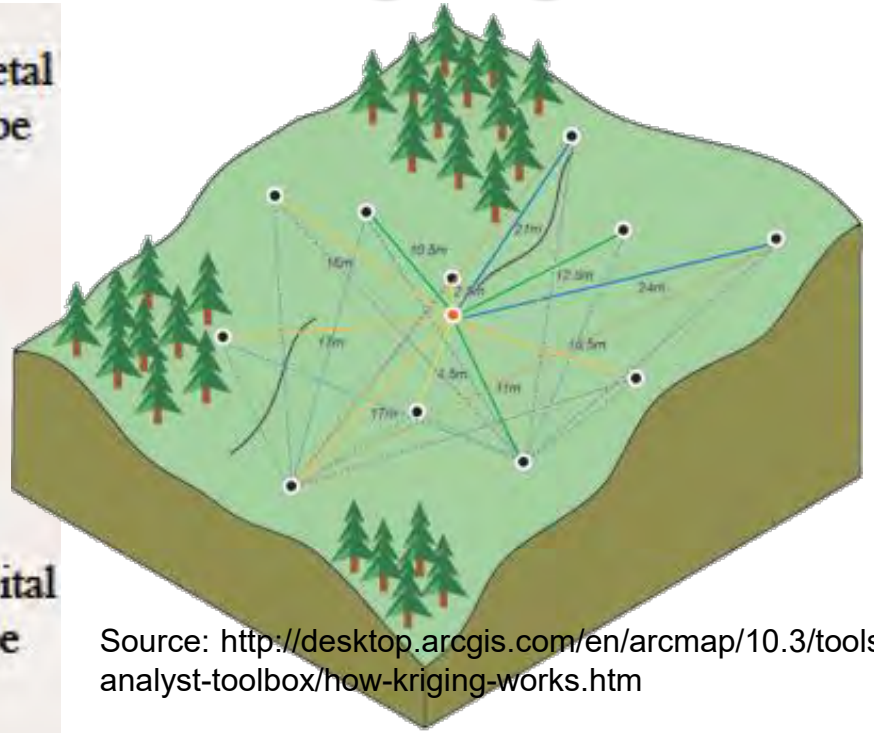
Krig-Detect: Exploring Alternative Kriging Methods for Real-Time Seizure Detection from EEG Signals

- To the best of the authors' knowledge, this is the first work where multiple Kriging methods have been used for real-time seizure detection in an edge computing paradigm.
- A novel achievement of an epileptic seizure detection latency of less than 1 second while maintaining a comparable accuracy with existing models and O(1) time and space complexity for edge computation.

Source: I. L. Olokodana, S. P. Mohanty and E. Kougianos, "Krig-Detect: Exploring Alternative Kriging Methods for Real-Time Seizure Detection from EEG Signals," in *Proc. IEEE 6th World Forum on Internet of Things (WF-IoT)*, 2020, pp. 1-6, doi: 10.1109/WF-IoT48130.2020.9221260.

Smart Healthcare – Brain as a Spatial Map → Kriging Methods





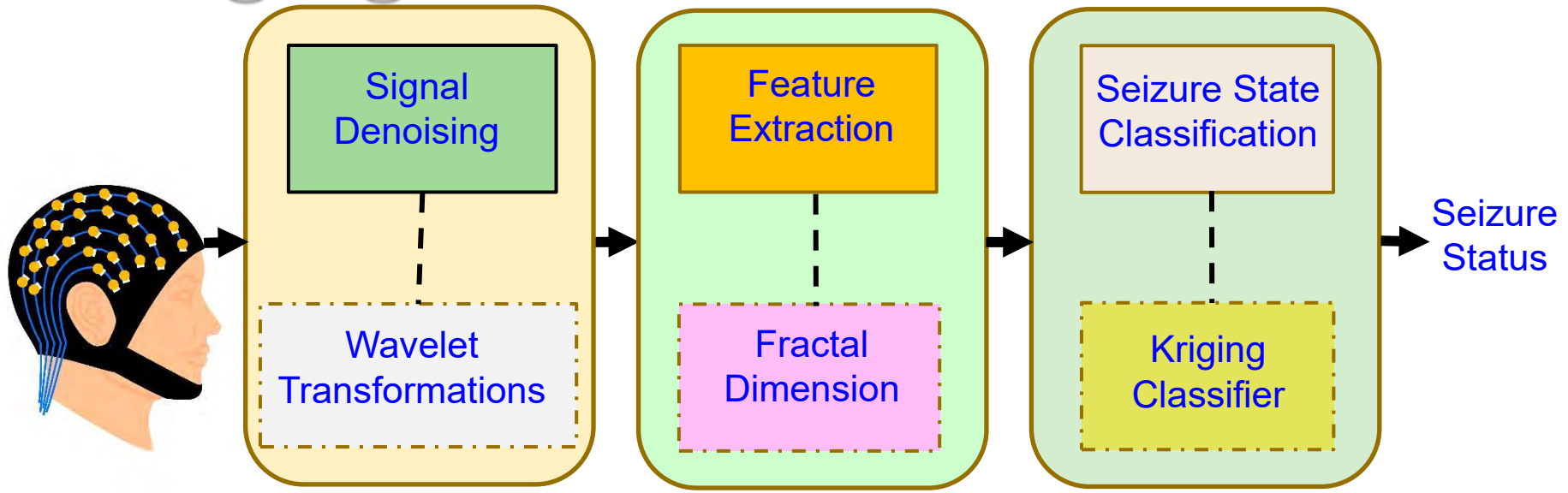
Source: http://desktop.arcgis.com/en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm

Spatial modeling or Variography
- Correlation Function is "Variogram"

Spatial autocorrelation principle - things that are closer are more alike than things farther

Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Ordinary-Kriging Based Real-Time Seizure Detection in an Edge Computing Paradigm", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

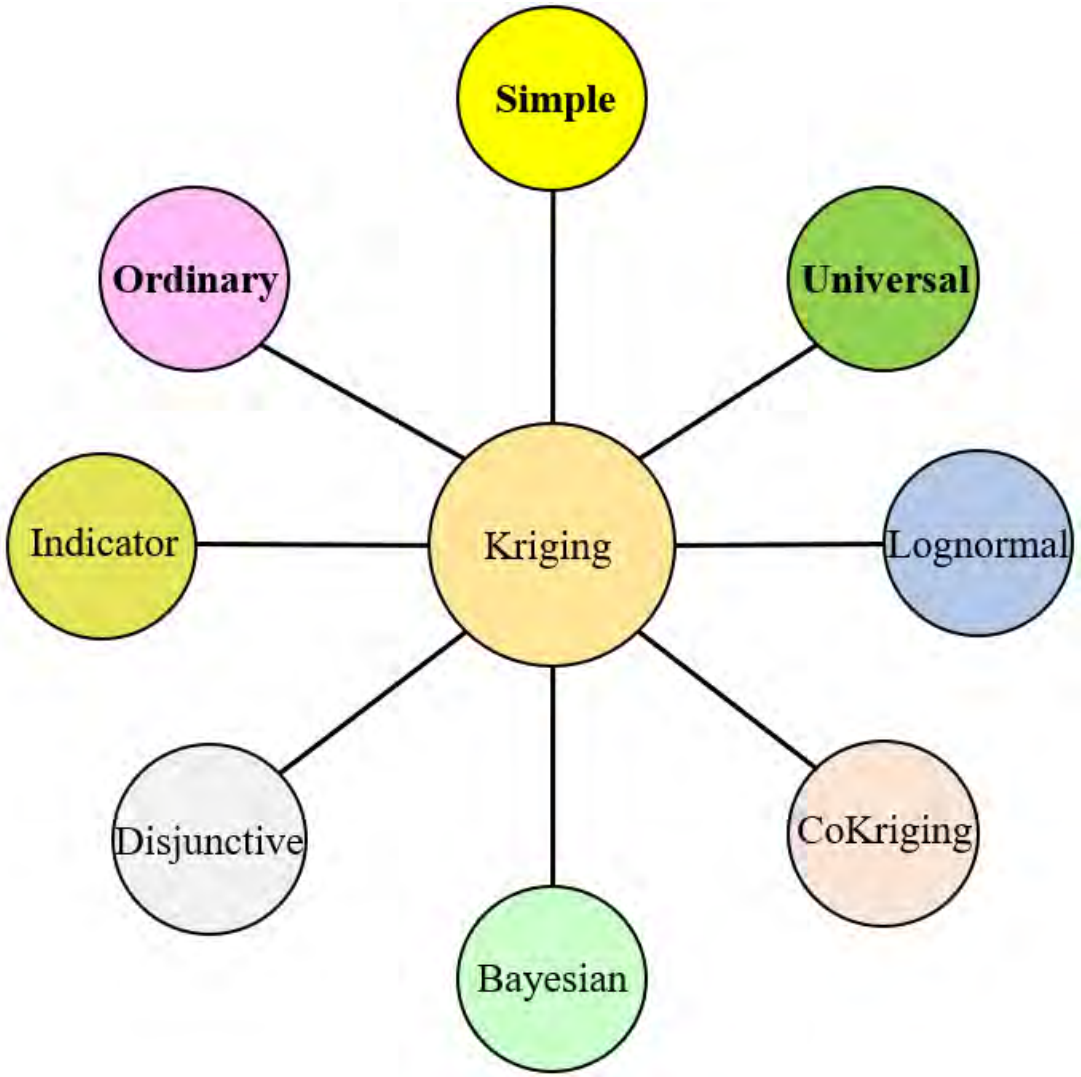
Kriging based Seizure Detection



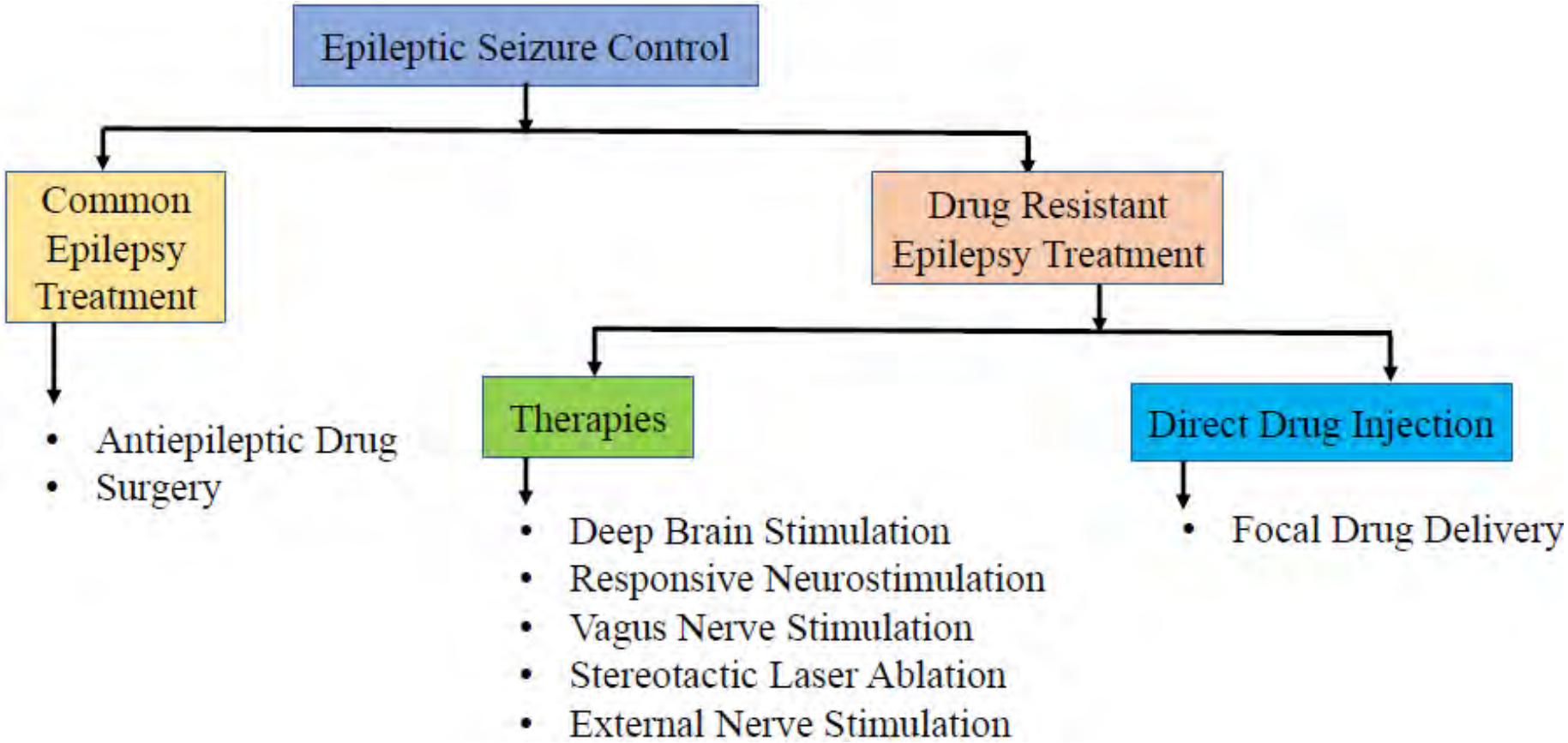
Works	Extracted Features	Classification Algorithm	Sensitivity	Latency
Zandi, et al. 2012 [23]	Regularity, energy & combined seizure indices	Cumulative Sum thresholding	91.00%	9 sec.
Altaf,etal. 2015 [24]	Digital hysteresis	Support Vector Machine	95.70%	1 sec
Vidyaratne, et al. 2017 [25]	Fractal dimension, spatial/ temporal features	Relevance Vector Machine (RVM)	96.00%	1.89 sec
Our Proposed	Petrosian fractal dimension	Kriging Classifier	100.0%	0.85 s

Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Ordinary-Kriging Based Real-Time Seizure Detection in an Edge Computing Paradigm", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020, Accepted.

Kriging Method - Types

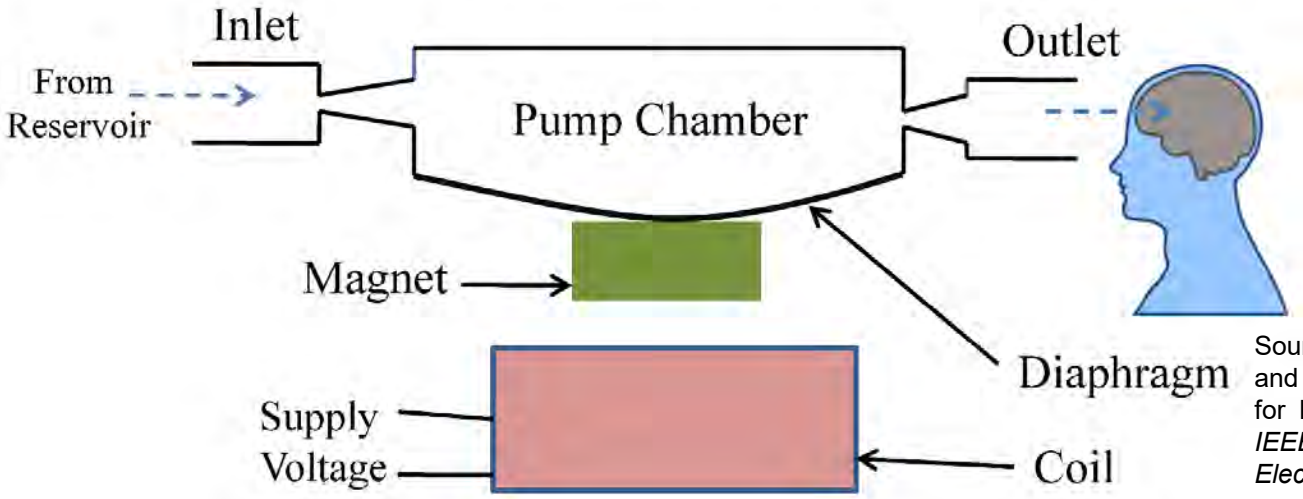


Seizure Control Methods



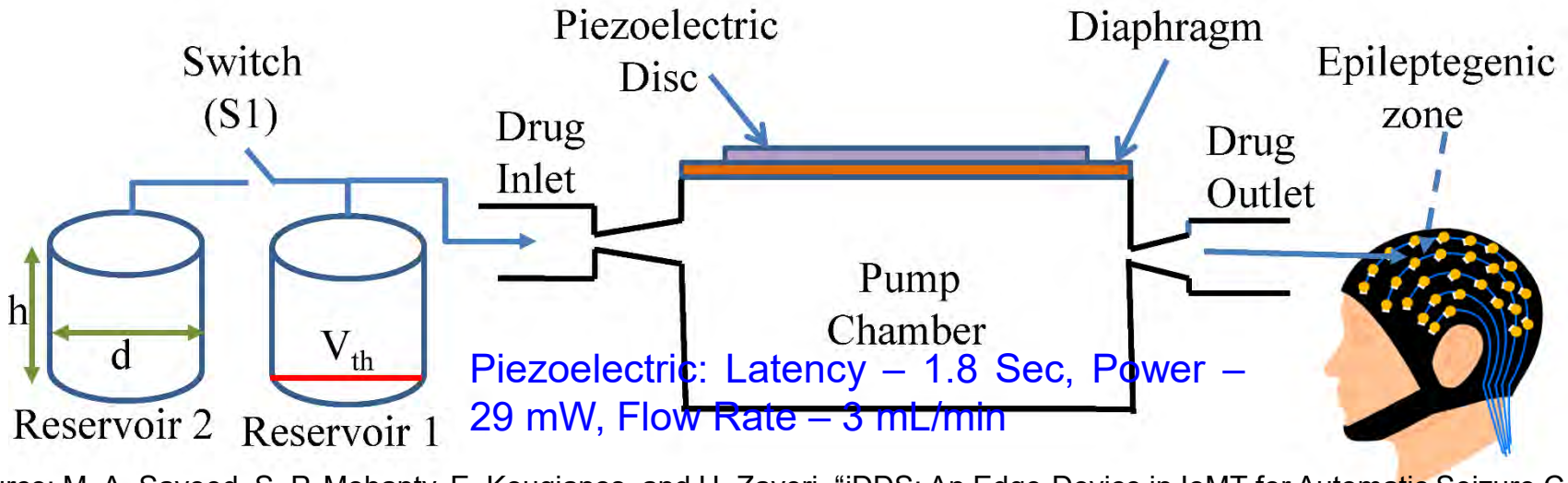
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

Seizure Control Methods



Electromagnetic: Latency – 1.8 Sec, Power – 12.81 mW, Flow Rate – 0.34 mL/min

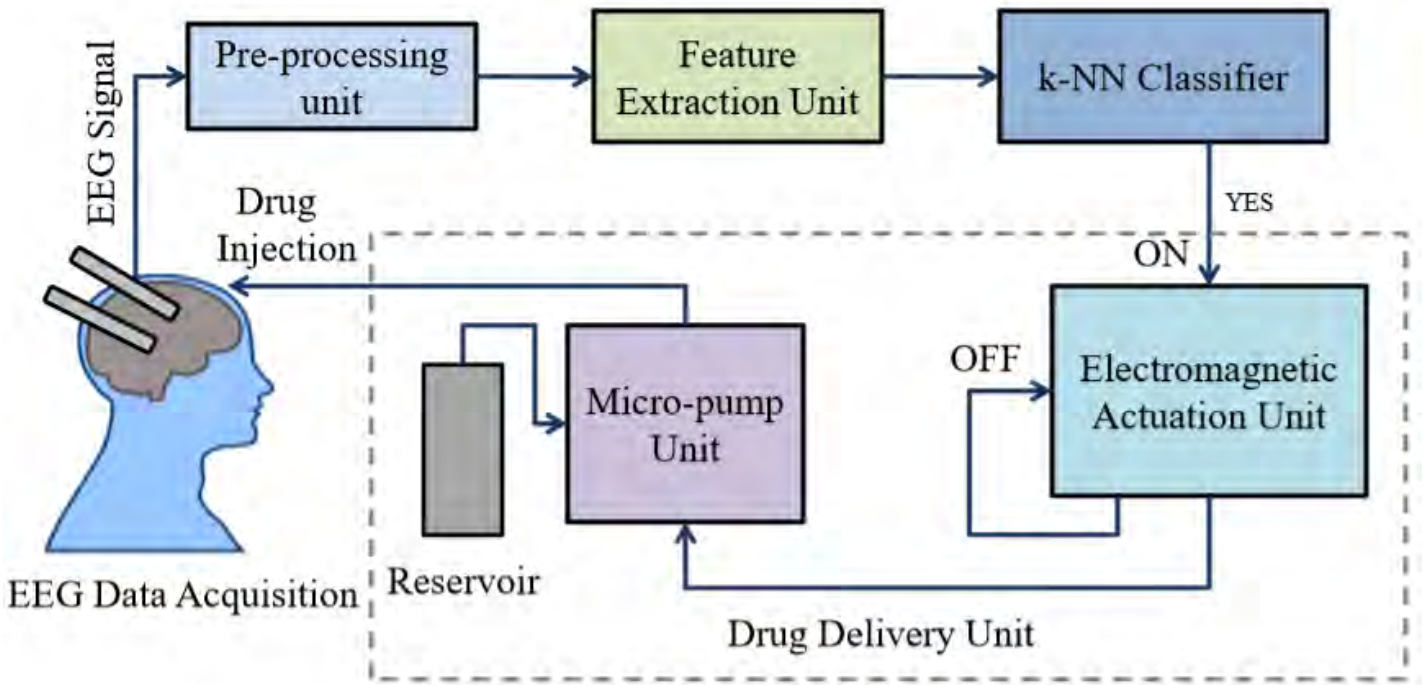
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "An IoT-based Drug Delivery System for Refractory Epilepsy", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.



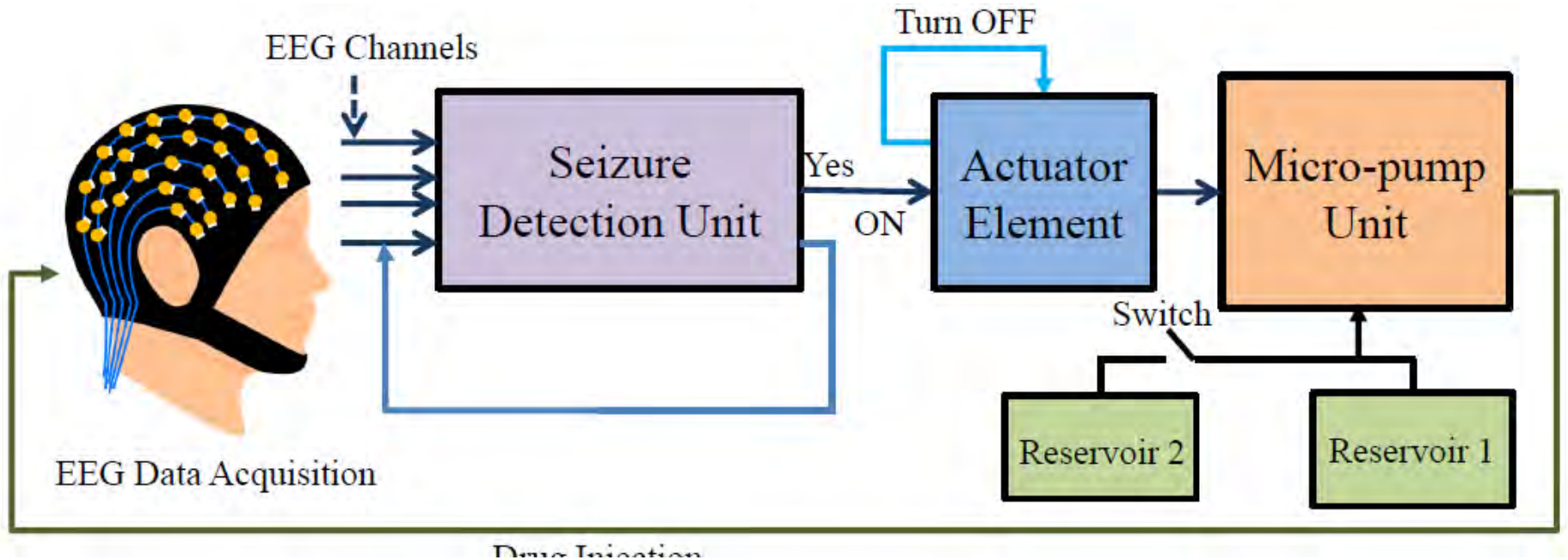
Piezoelectric: Latency – 1.8 Sec, Power – 29 mW, Flow Rate – 3 mL/min

Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

Architecture of the Proposed Drug Delivery System

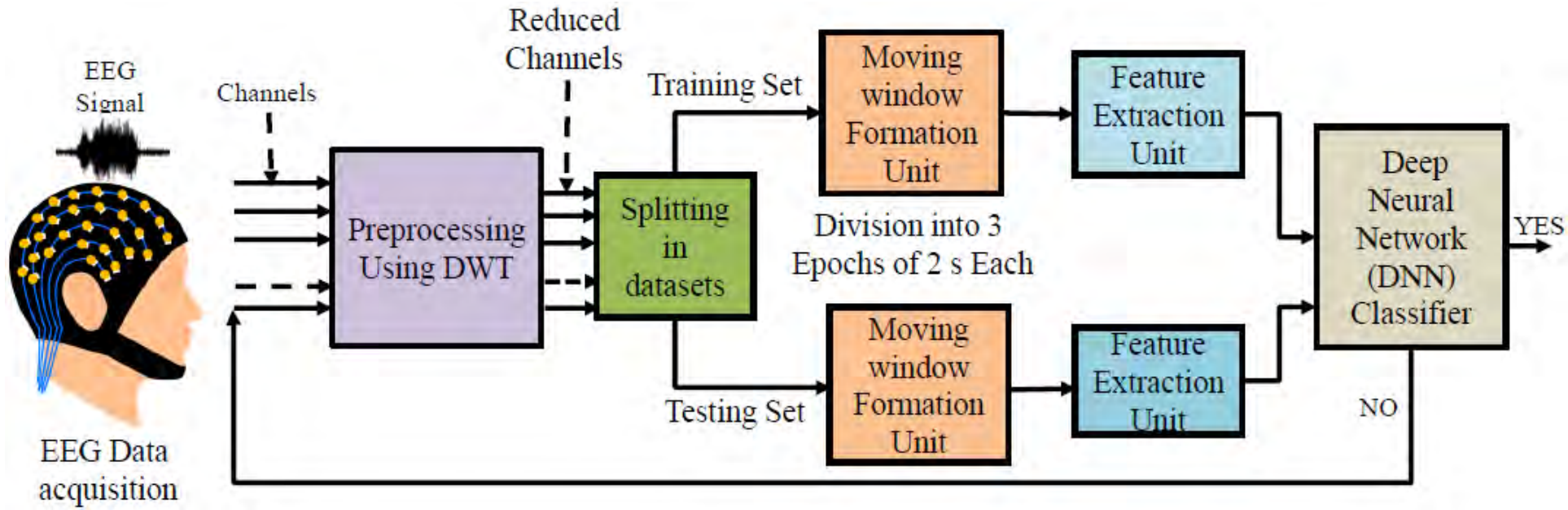


iDDS: An Edge-Device in IoMT for Automatic Seizure Control – Piezoelectric Actuator

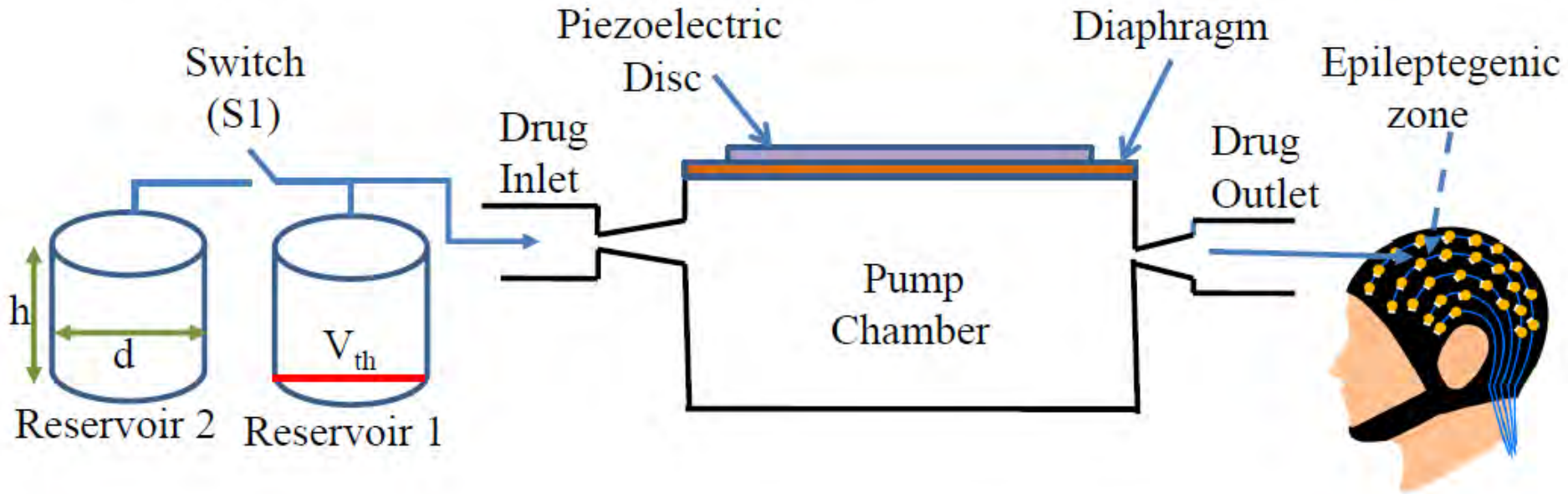


Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos and H. Zaveri, "iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery," *2020 IEEE International Conference on Consumer Electronics (ICCE)*, 2020, pp. 1-6, doi: 10.1109/ICCE46568.2020.9043143.

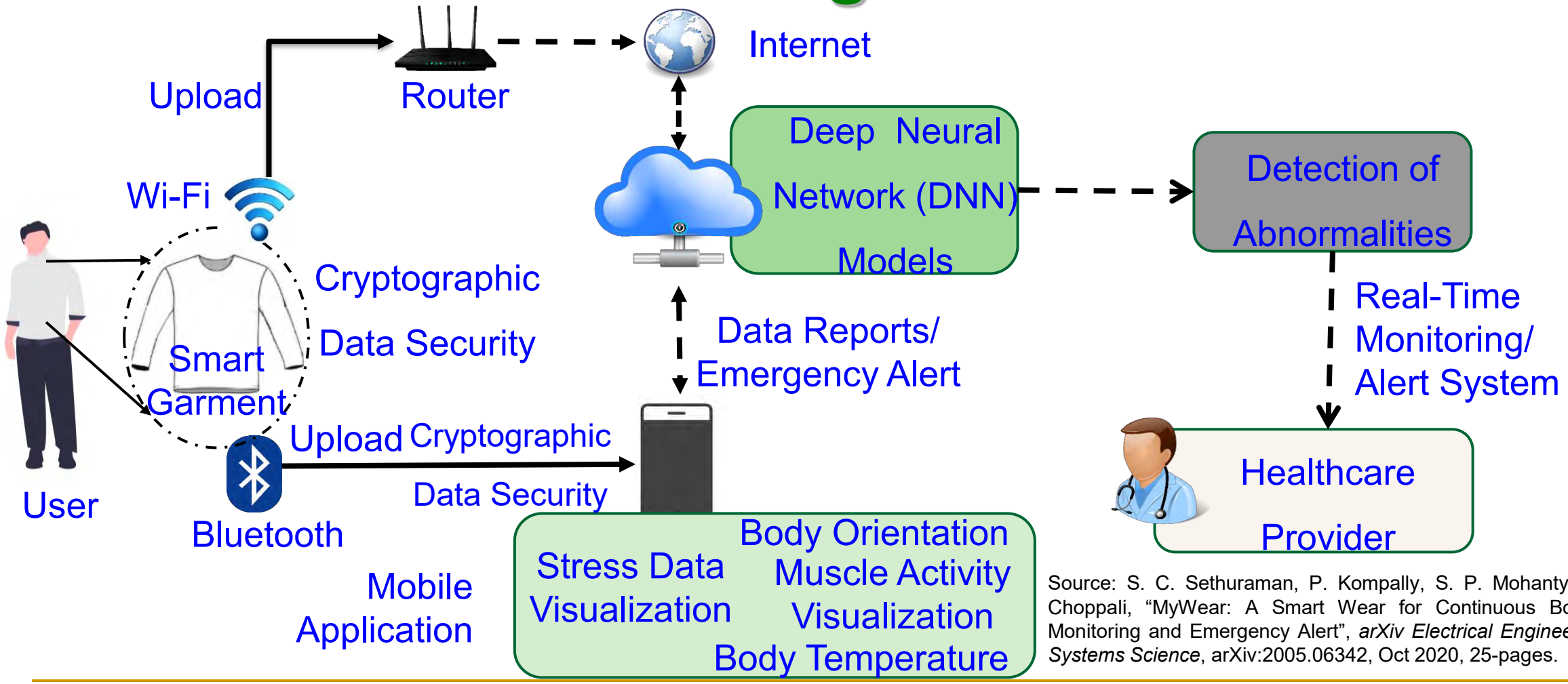
Epileptic Seizure Detection Using DNN Classifier



Drug Delivery Subsystem

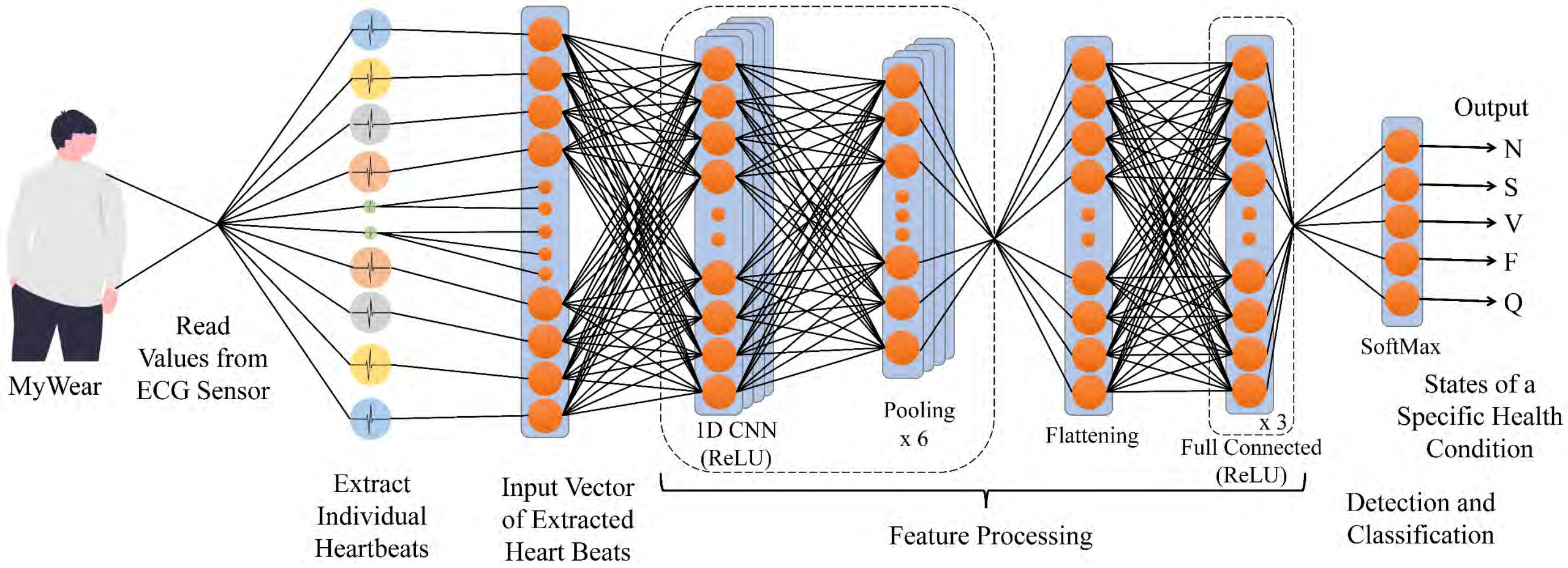


MyWear – A Smart Wear for Continuous Body Vital Monitoring - ECG based



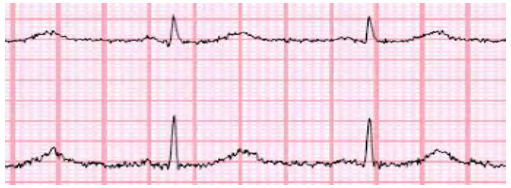
Source: S. C. Sethuraman, P. Kompally, S. P. Mohanty, and U. Choppali, "MyWear: A Smart Wear for Continuous Body Vital Monitoring and Emergency Alert", *arXiv Electrical Engineering and Systems Science*, arXiv:2005.06342, Oct 2020, 25-pages.

MyWear – DNN Model for ECG Data



Source: S. C. Sethuraman, P. Kompally, S. P. Mohanty, and U. Choppali, "MyWear: A Smart Wear for Continuous Body Vital Monitoring and Emergency Alert", *arXiv Electrical Engineering and Systems Science*, arXiv:2005.06342, Oct 2020, 25-pages.

ECG Data → Stress Level



Initialize ECG Sensor

Record and collect ECG for a time window

Compute Time between two successive R peaks

Calculate the Mean of all the obtained RR peaks Interval time

Display the Mean (MeanRR)

Obtain the RR Intervals from ECG

Obtain the Mean of all the RR intervals

Calculate the Standard Deviation

Display Standard Deviation of RR Intervals

Calculate the Successive Differences of two RR Intervals

Compute the Square of the obtained Successive Difference of RR Intervals

Calculate the Mean of the Successive Differences

Calculate the Root of the output Mean of Successive Differences

Obtain the Root Mean Square of Successive Difference (RMSSD) Values

Compare RMSSD value with Stress Chart

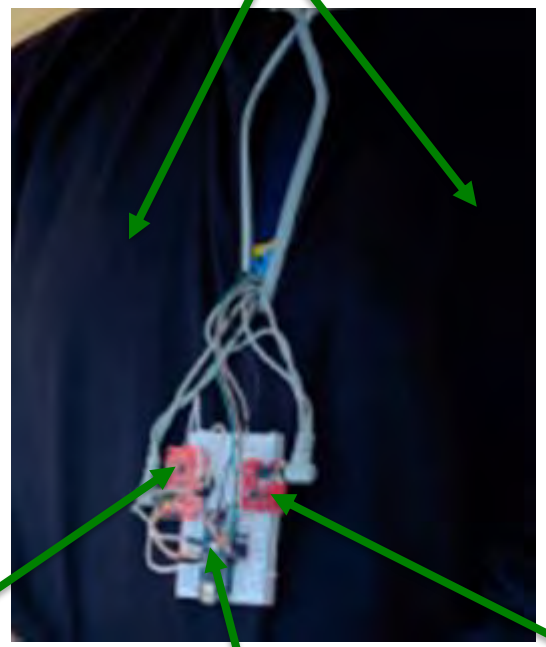
Obtain the Stress Level of the User

Display Stress Level

Source: S. C. Sethuraman, P. Kompally, S. P. Mohanty, and U. Choppali, "MyWear: A Smart Wear for Continuous Body Vital Monitoring and Emergency Alert", *arXiv Electrical Engineering and Systems Science*, arXiv:2005.06342, Oct 2020, 25-pages.

MyWear – Prototyping

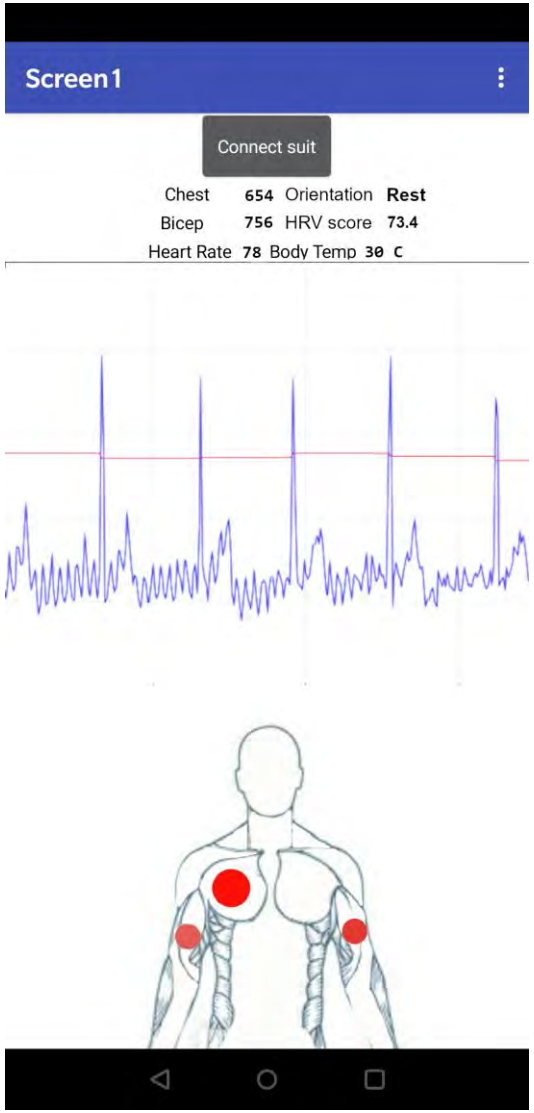
Embedded Electrodes inside MyWear



ECG Sensor

EMG Sensor

Microcontoller



Source: S. C. Sethuraman, P. Kompally, S. P. Mohanty, and U. Choppali, "MyWear: A Smart Wear for Continuous Body Vital Monitoring and Emergency Alert", *arXiv Electrical Engineering and Systems Science*, arXiv:2005.06342, Oct 2020, 25-pages.

Technology for Visually Impaired

Detection Part (Localizes the marker from the other objects)

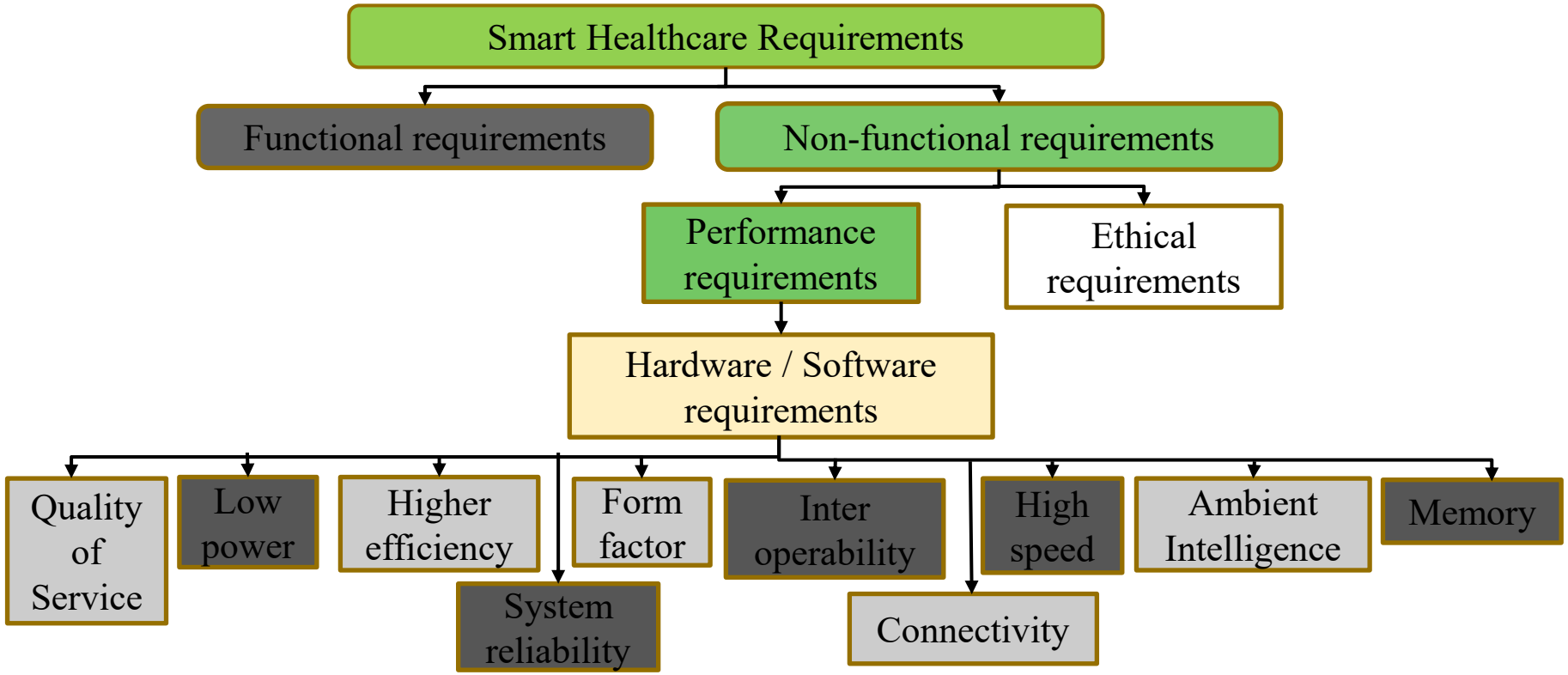
Visual Marker

Recognition Part (QR code)

Source: C. Lee, P. Chondro, S. Ruan, O. Christen and E. Naroska, "Improving Mobility for the Visually Impaired: A Wearable Indoor Positioning System Based on Visual Markers," IEEE Consumer Electronics Magazine, vol. 7, no. 3, pp. 12-20, May 2018.

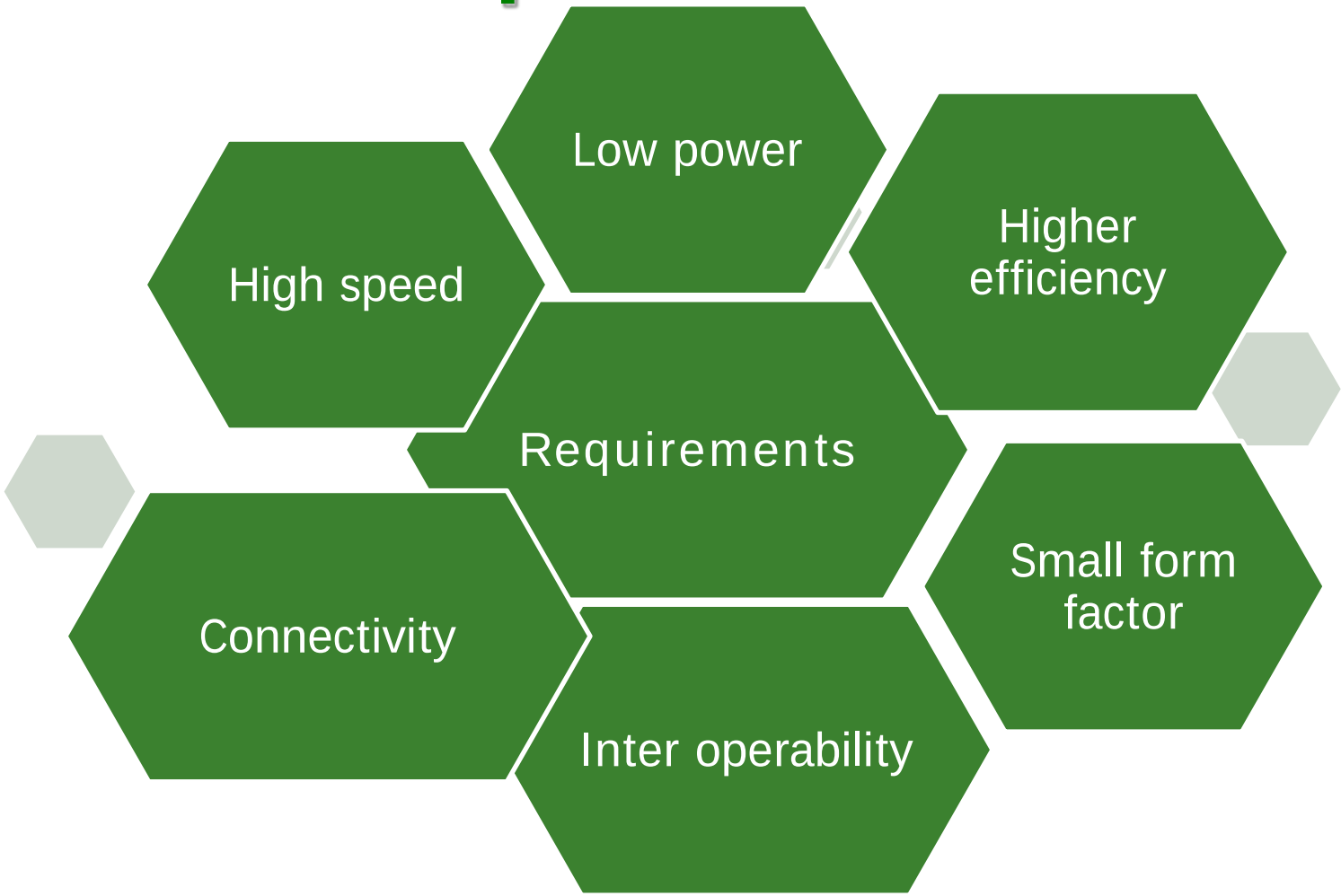
Smart Healthcare – Some Challenges

Smart Healthcare – Requirements



Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", IEEE Consumer Electronics Magazine (CEM), Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare Architecture – Requirements



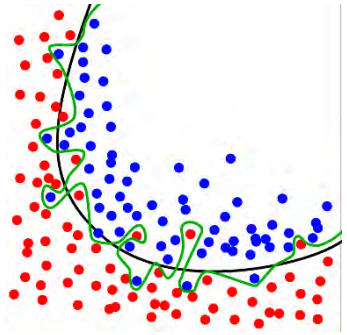
Smart Healthcare – Data Quality

Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Machine Learning Challenges

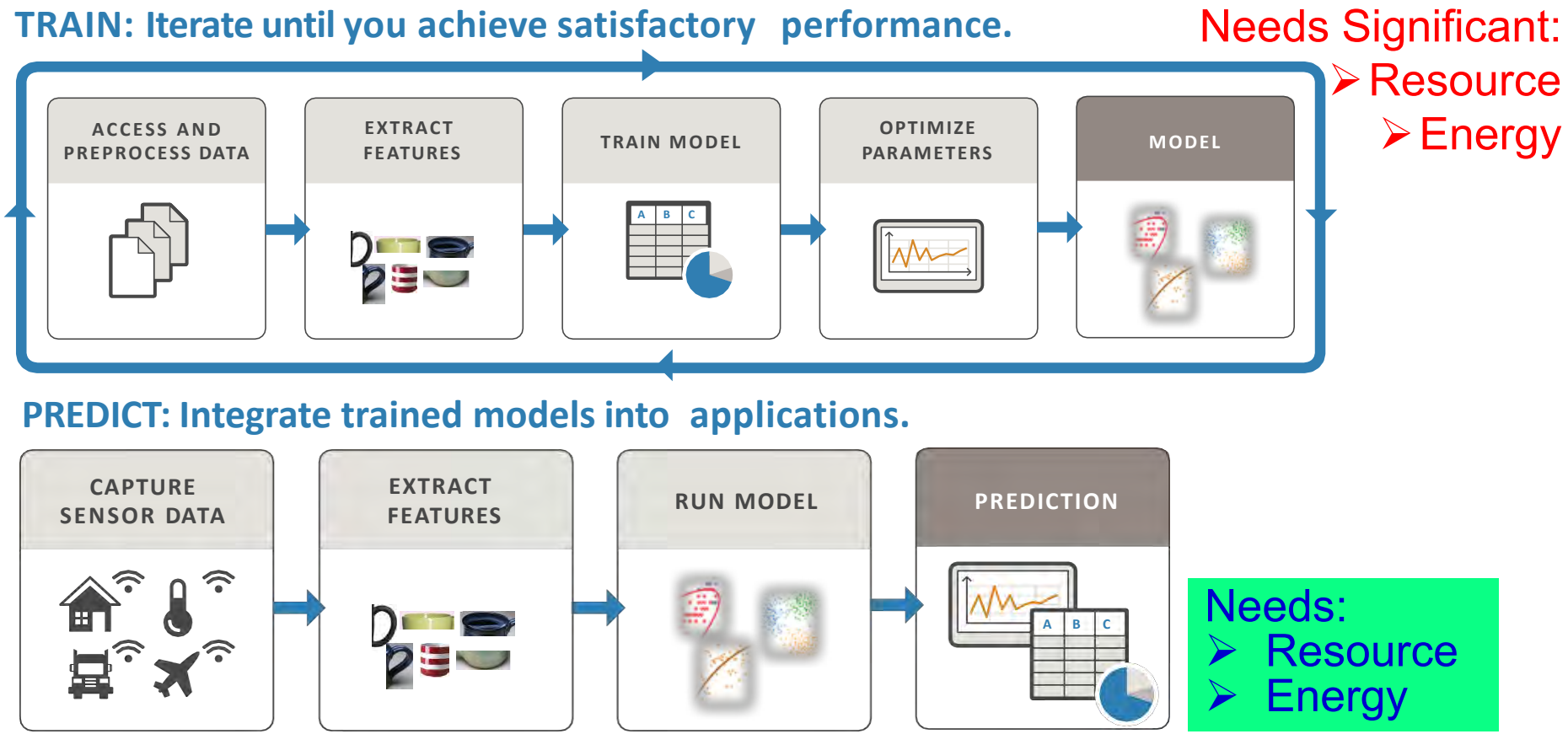
Machine Learning Issues

- High Energy Requirements
- High Computational Resource Requirements
- Large Amount of Data Requirements
- Underfitting/Overfitting Issue
- Class Imbalance Issue
- Fake Data Issue



Source: Mohanty ISCT Keynote 2019

Deep Neural Network (DNN) - Resource and Energy Costs

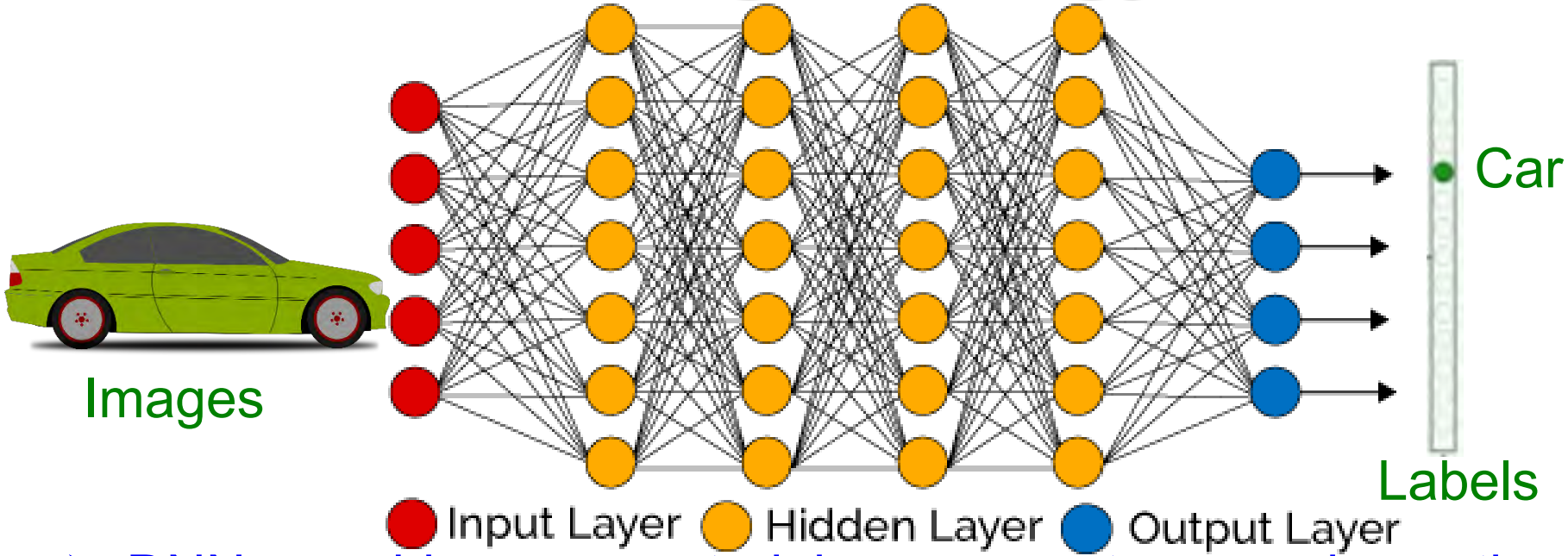


Needs Significant:
- Resource
- Energy

Needs:
- Resource
- Energy

Source: https://www.mathworks.com/campaigns/offers/mastering-machine-learning-with-matlab.html

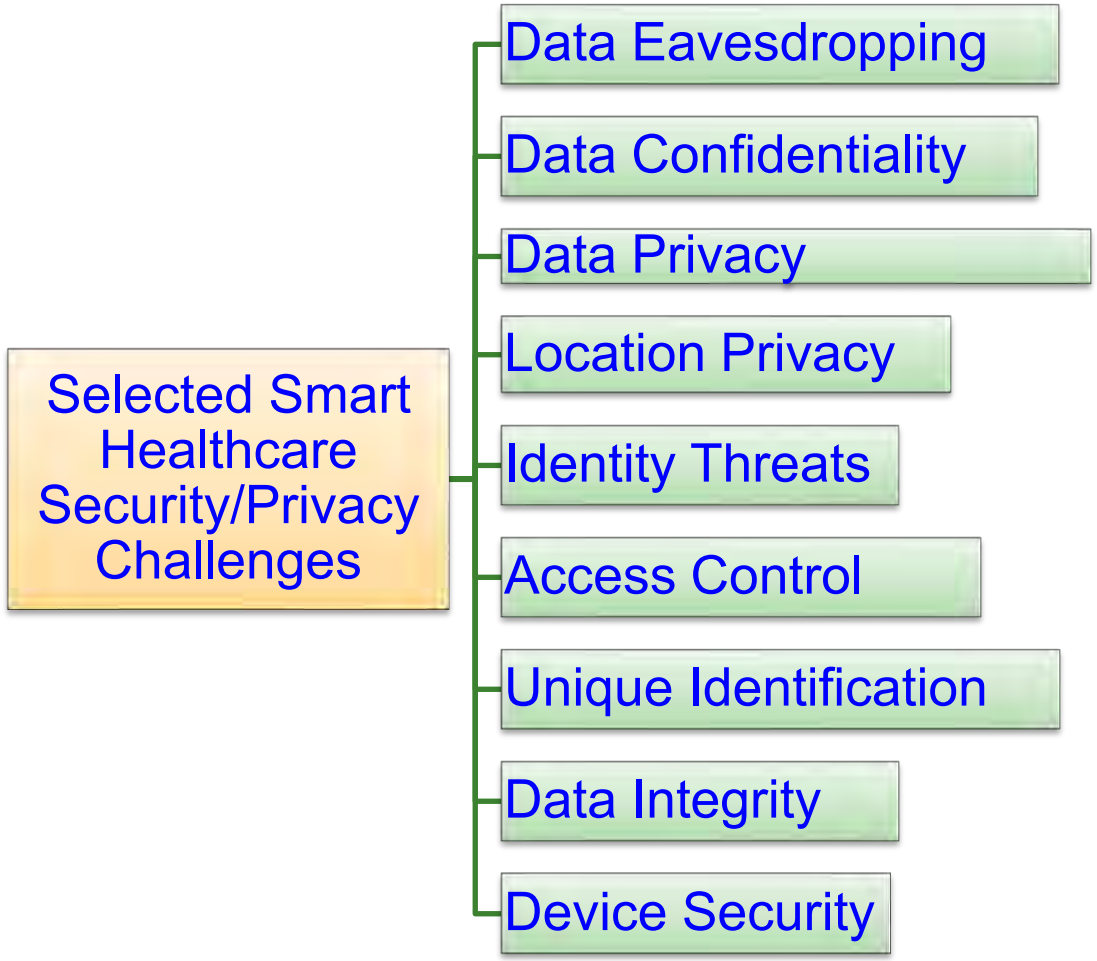
DNN Training - Energy Issue



- DNN considers many training parameters, such as the size, the learning rate, and initial weights.
- High computational resource and time: For sweeping through the parameter space for optimal parameters.
- DNN needs: Multicore processors and batch processing.
- DNN training happens mostly in cloud not at edge or fog.

Source: Mohanty iSES 2018 Keynote

Smart Healthcare - Security Challenges



Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - Security Requirements

Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", IEEE Consumer Electronics Magazine (CEM), Volume 7, Issue 1, January 2018, pp. 18-28.

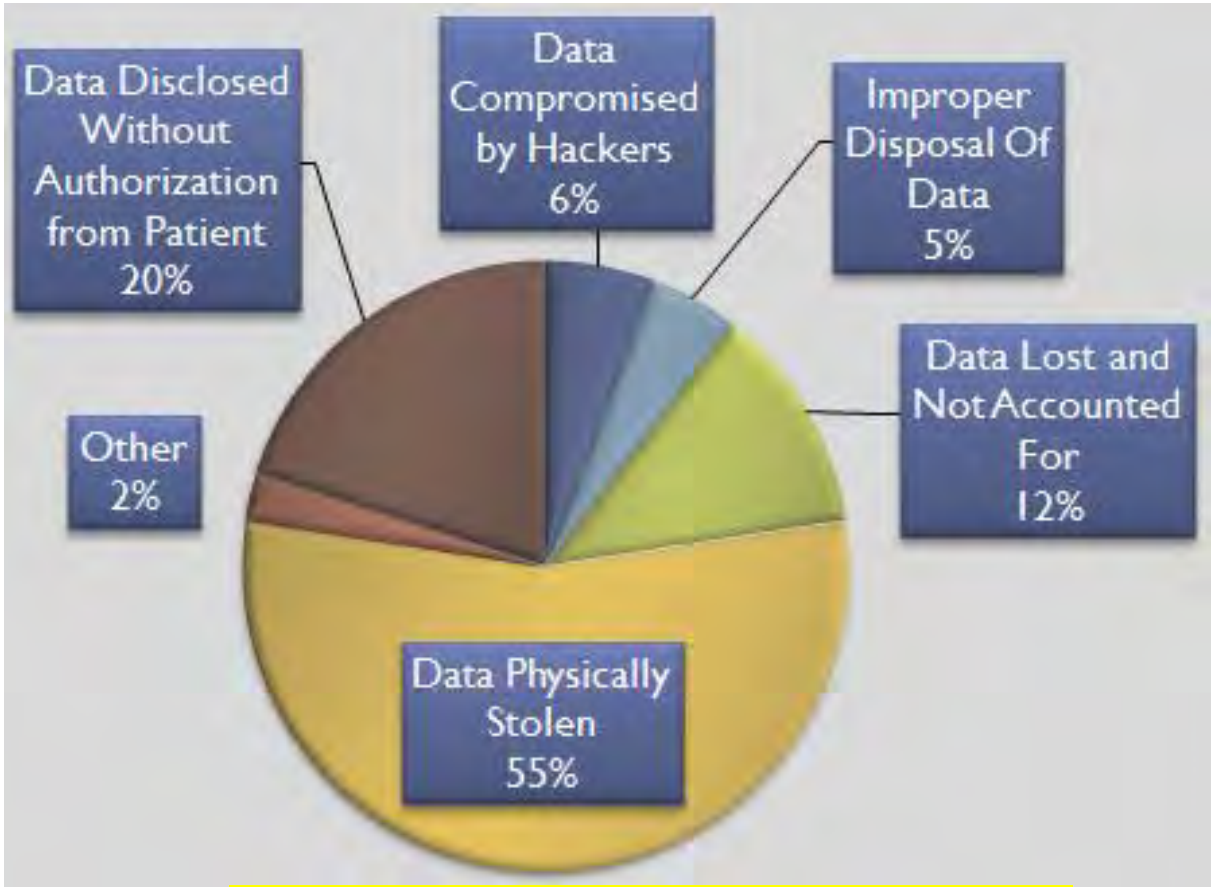
Information Privacy

Source: http://ciphercloud.com/three-ways-pursue-cloud-data-privacy-medical-records/

Source: http://blog.veriphyr.com/2012/06/electronic-medical-records-security-and.html

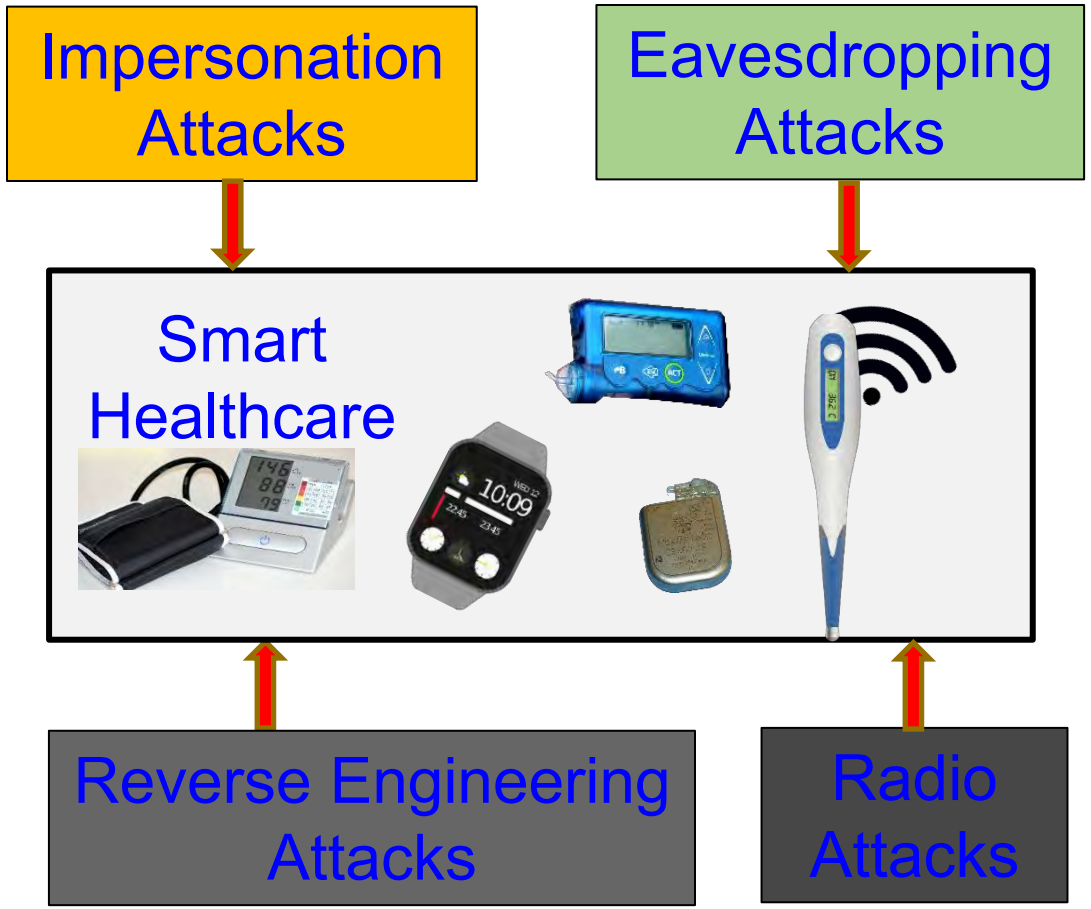
Health Insurance Portability and Accountability Act (HIPPA)

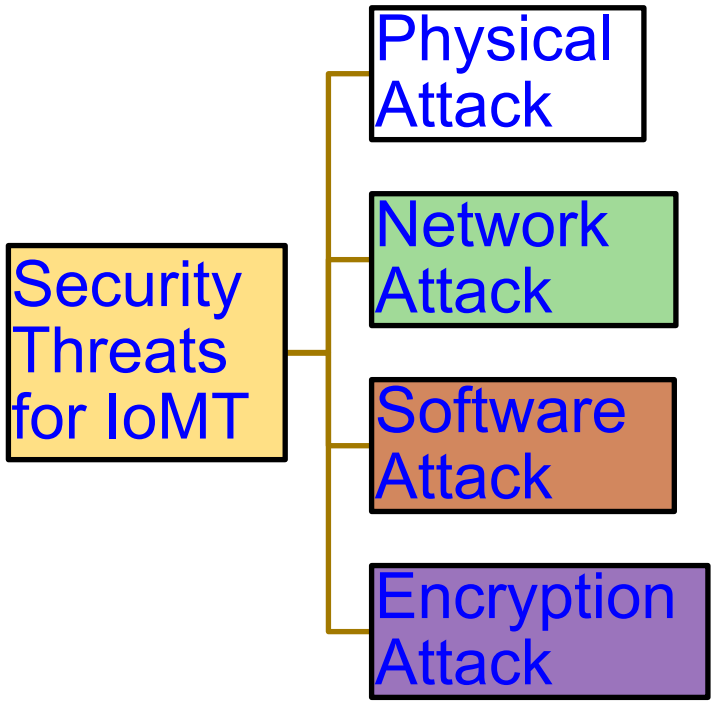
HIPAA
Health Insurance Portability and Accountability Act



HIPPA Privacy Violation by Types

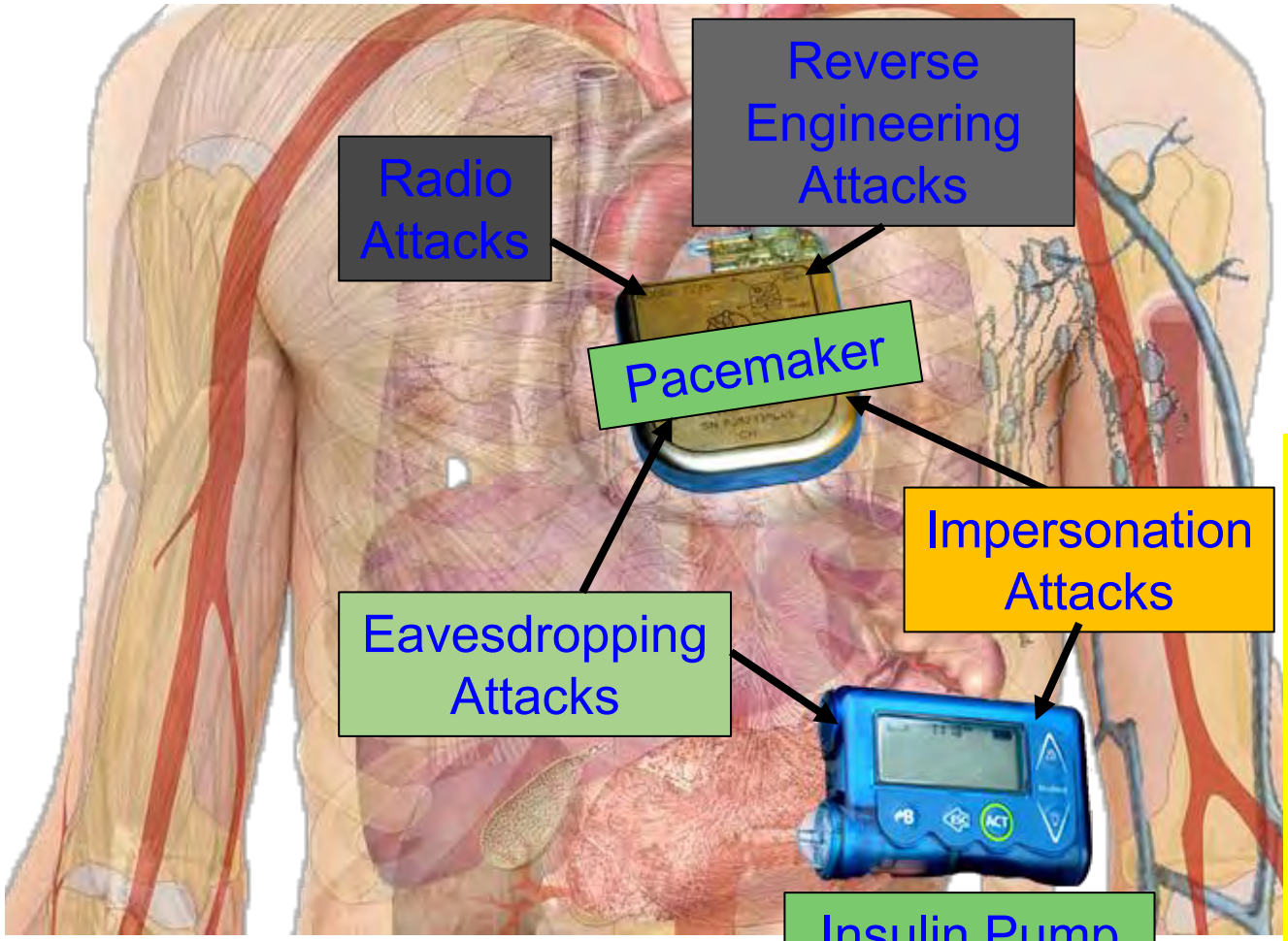
IoMT Security – Selected Attacks





Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

IoMT Security Measures is Hard



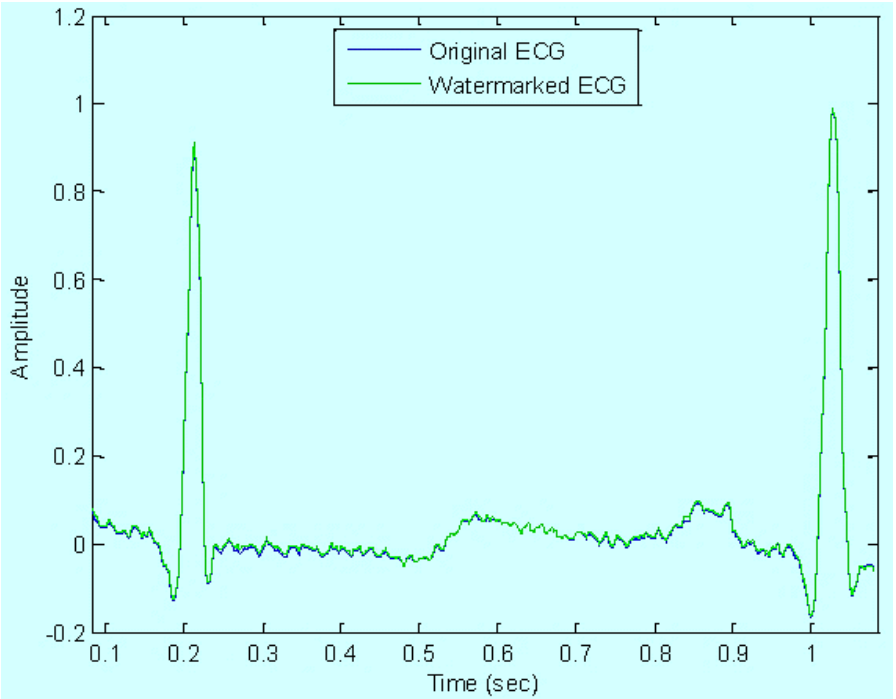
Collectively (WMD+IMD): Implantable and Wearable Medical Devices (IWMDs)

Implantable and Wearable Medical Devices (IWMDs) -- Battery Characteristics:
→ Longer life
→ Safer
→ Smaller size
→ Smaller weight

Pacemaker Battery Life - 10 years

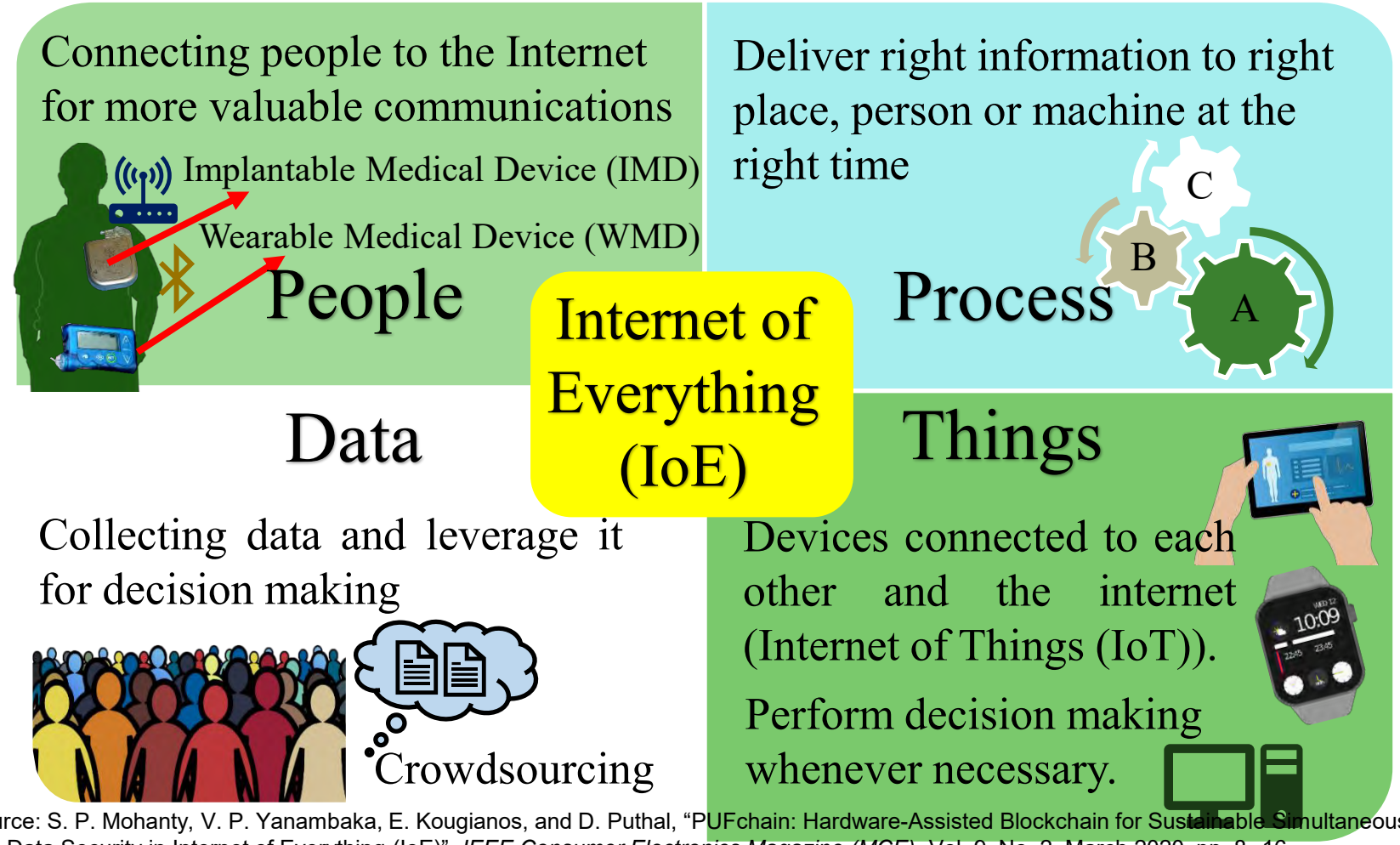
Smart Healthcare Security – Medical Signal Authentication

- Physiological signals like the electrocardiogram (EKG) are obtained from patients, transmitted to the cloud, and can also stored in a cloud repository.
- With increasing adoption of electronic medical records and cloud-based software-as-service (SaaS), advanced security measures are necessary.
- Protection from unauthorized access to Protected Health Information (PHI) also protects from identity theft schemes.
- From an economic stand-point, it is important to safeguard the healthcare and insurance system from fraudulent claims.



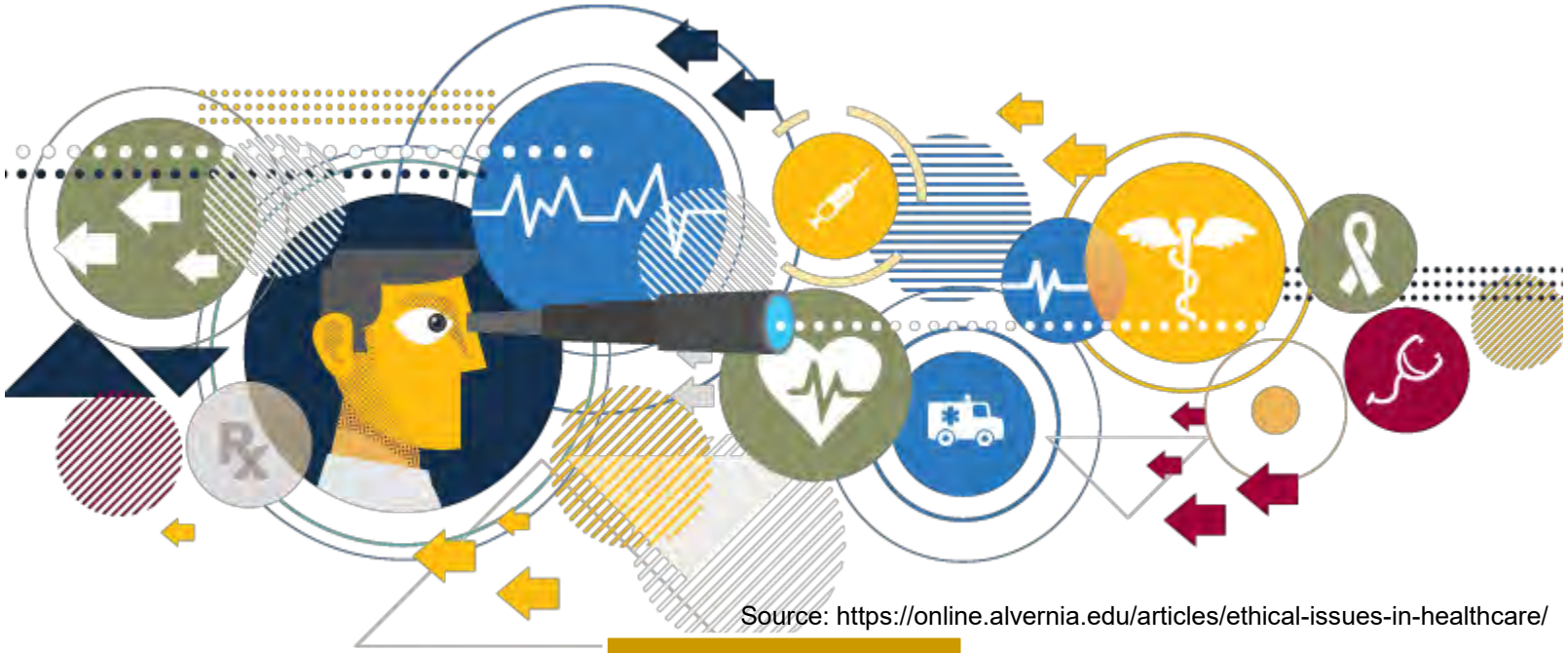
Source: Tseng 2014, Tseng Sensors Feb 2014

Users are Integral Part: For Them and By Them

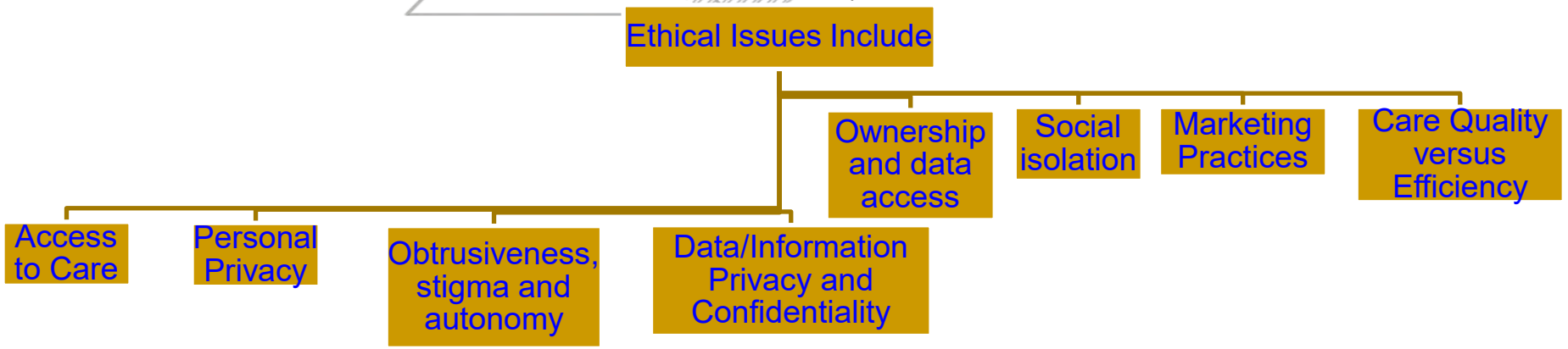


Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in Internet of Everything (IoE)", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 2, March 2020, pp. 8--16.

Smart Healthcare - Ethics

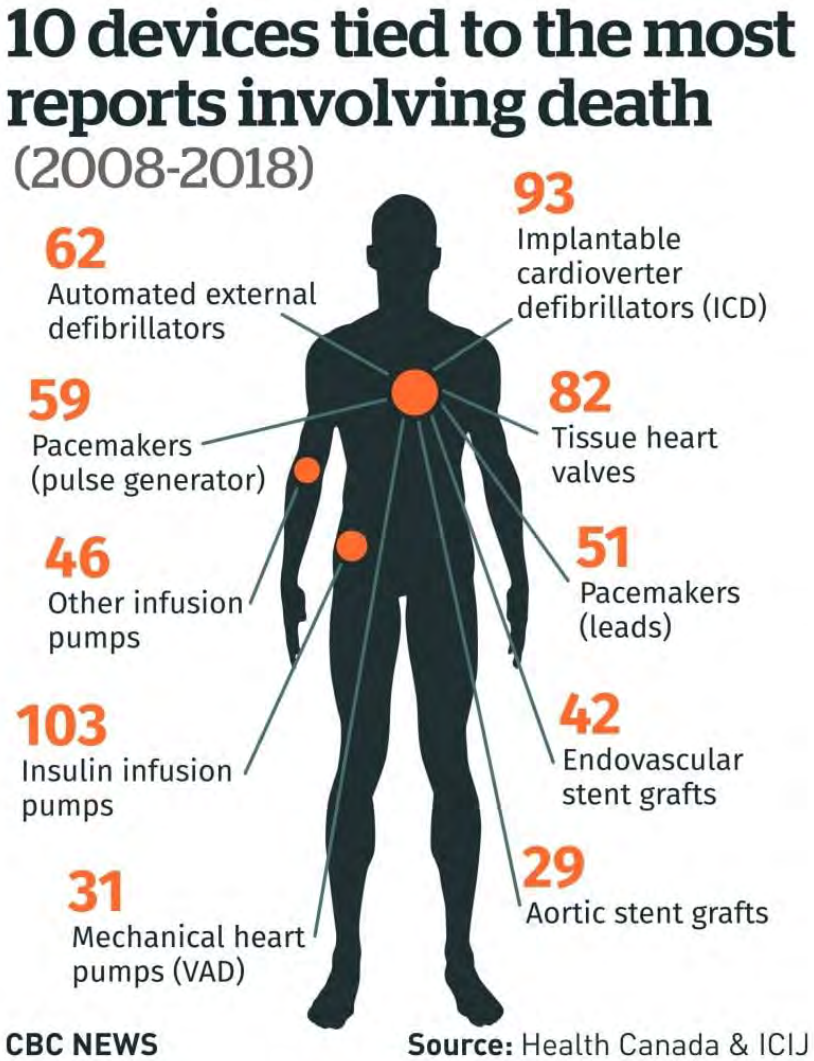


Source: https://online.alvernia.edu/articles/ethical-issues-in-healthcare/

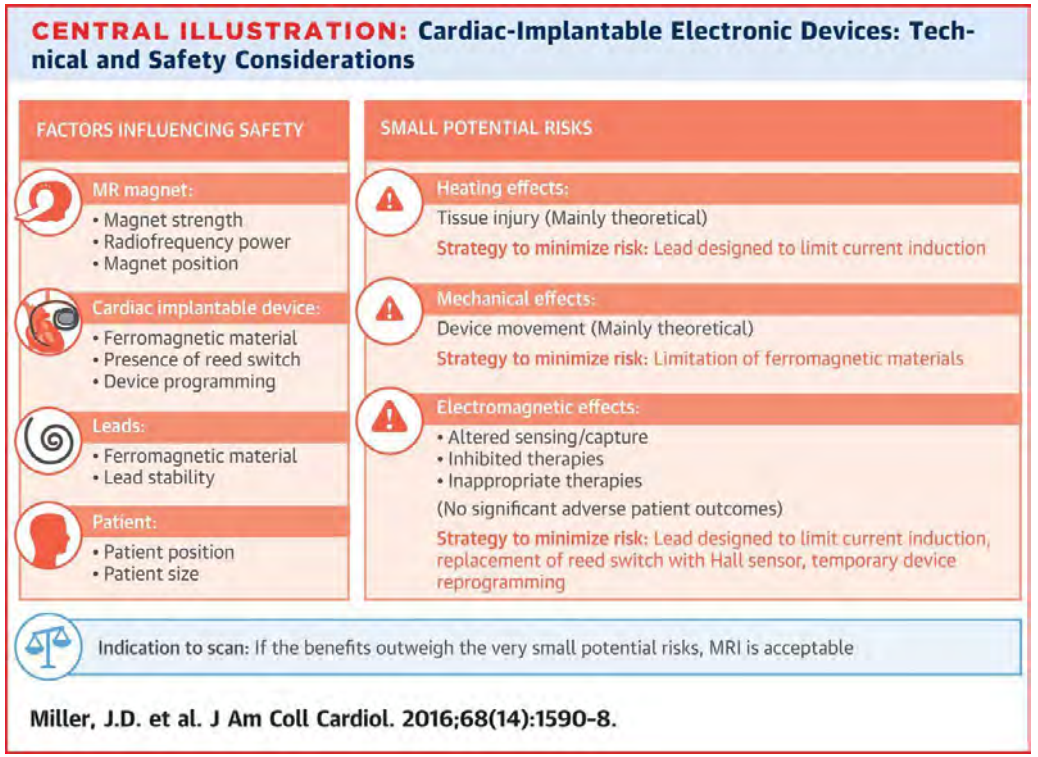


Source: B. Mittelstadt, "Ethics of the health-related internet of things: a narrative review", *Ethics Inf Technol* **19,** 157–175 (2017), DOI: https://doi.org/10.1007/s10676-017-9426-4.

Smart Healthcare - Safety



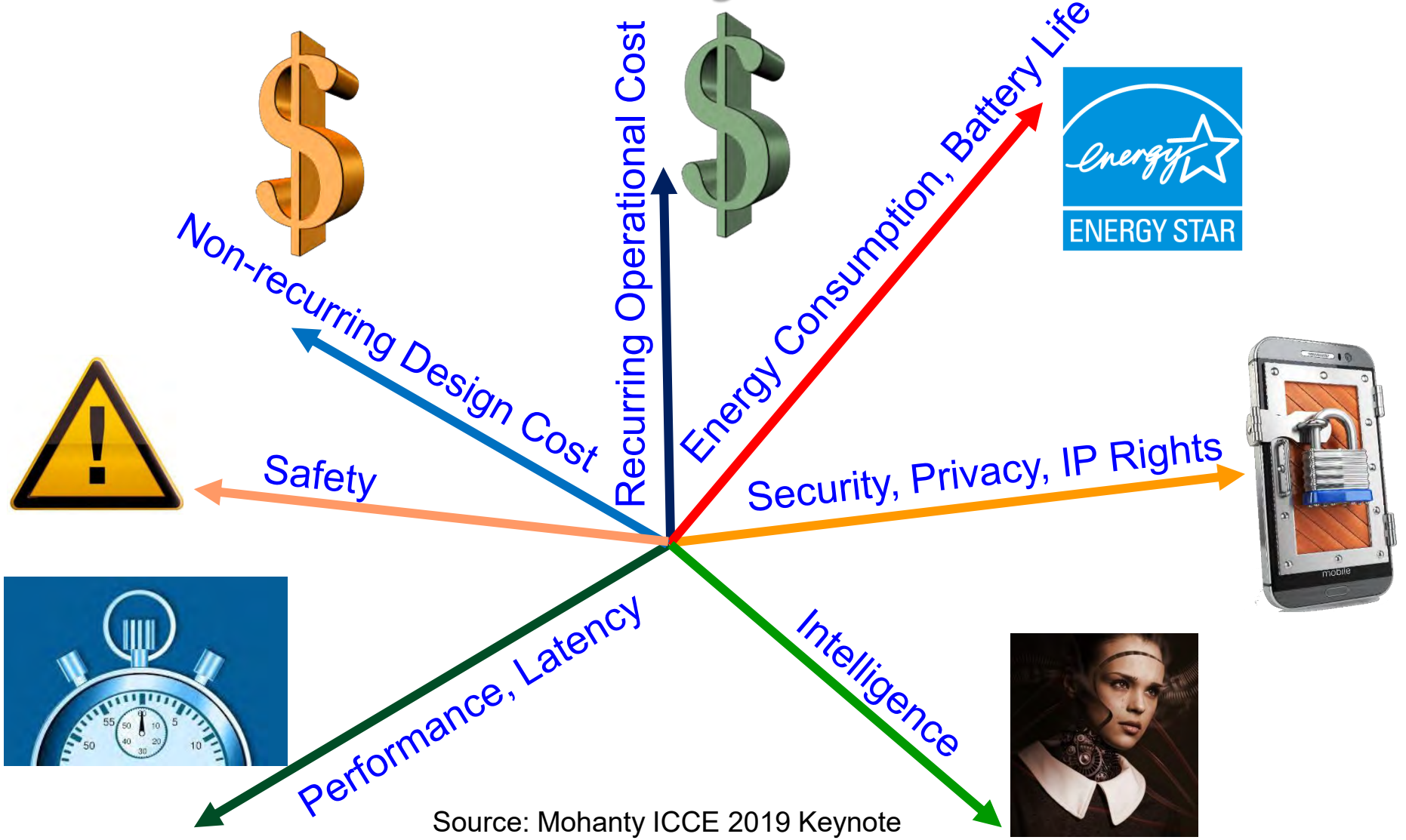
Source https://planet-report.com/canadian-advocates-call-for-all-medical-implants-to-be-registered-cbc-news/



Source: J. D. Miller, S. Nazarian, H. R. Halperin, "Implantable Electronic Cardiac Devices and Compatibility With Magnetic Resonance Imaging", J Am Coll Cardiol. 2016 Oct, 68 (14), pp. 1590-1598.

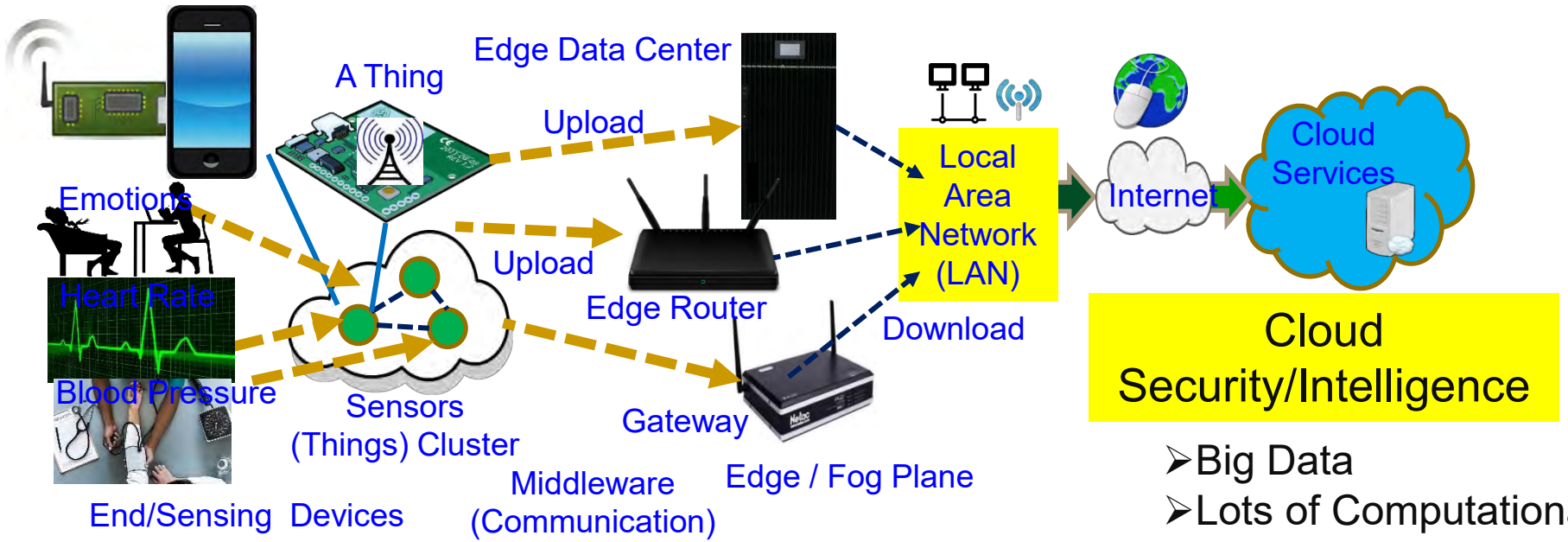
Smart Healthcare – Some Solutions

H-CPS - Multi-Objective Tradeoffs



Source: Mohanty ICCE 2019 Keynote

Smart Healthcare – Edge Vs Cloud



Cloud Security/Intelligence

- Big Data
- Lots of Computational Resource
- Accurate Data Analytics
- Latency in Network
- Energy overhead in Communications

Edge Security/Intelligence

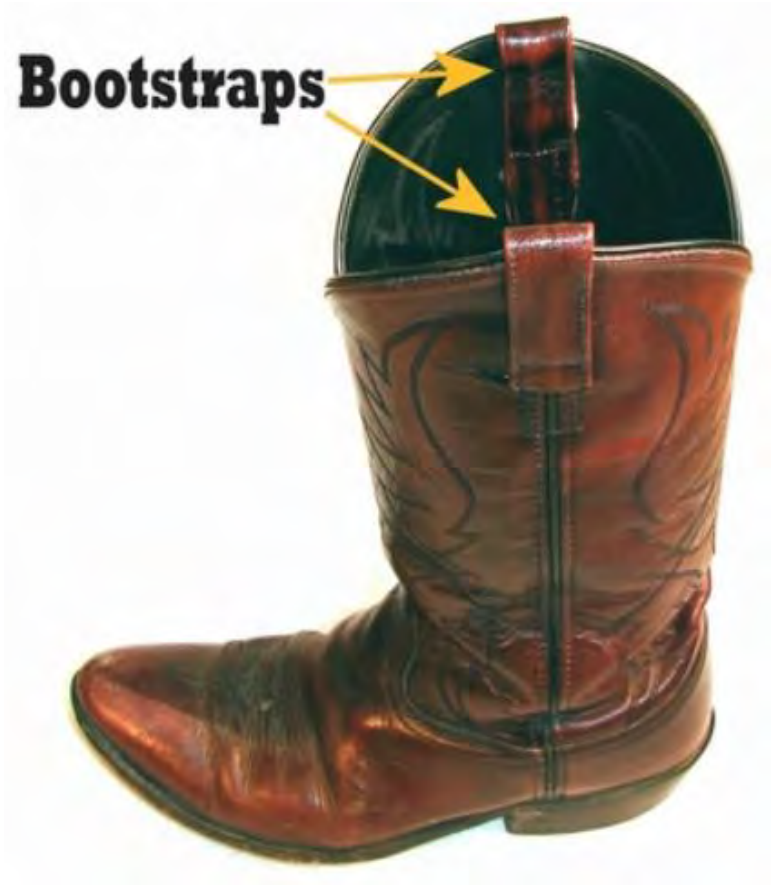
- Less Data
- Less Computational Resource
- Less Accurate Data Analytics
- Rapid Response

End Security/Intelligence

- Minimal Data
- Minimal Computational Resource
- Least Accurate Data Analytics
- Very Rapid Response

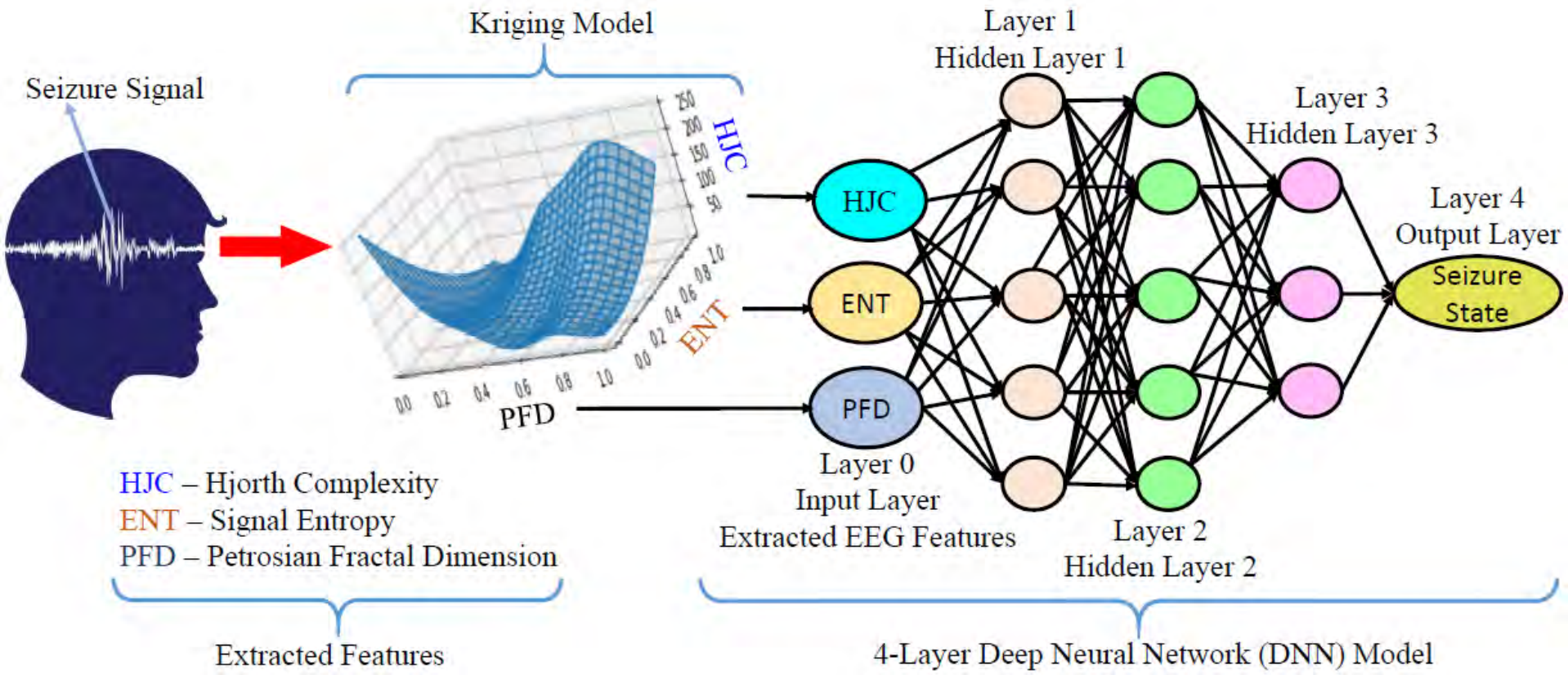
Hierarchical ML to Reduce Training Time - Bootstrapping

- A Bootstrap helps in pulling on a boot.
- It means solving a problem without external resources



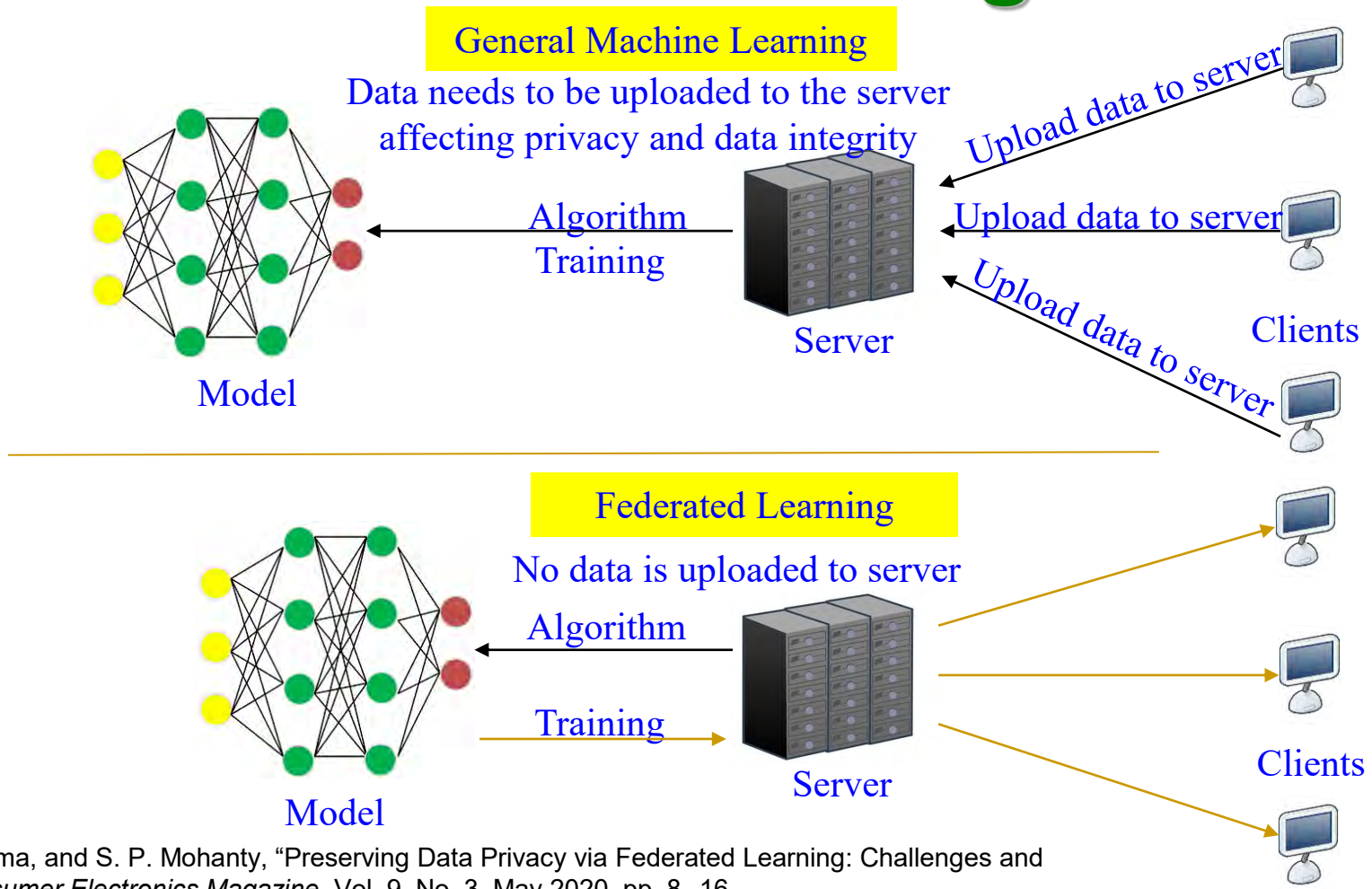
Source: http://www.lemen.com/dictionary-b.html#bootstrap

Our Kriging-Bootstrapped DNN Model



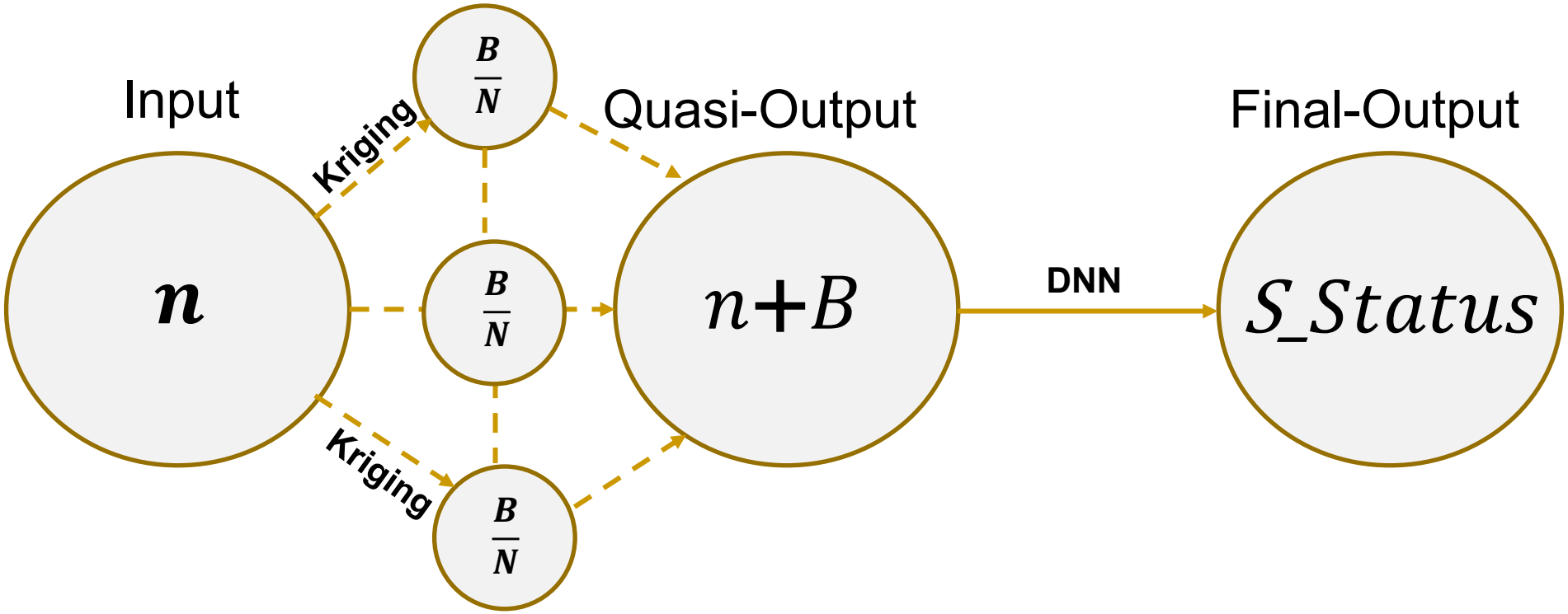
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Kriging-Bootstrapped DNN Hierarchical Model for Real-Time Seizure Detection from EEG Signals", in *Proceedings of the 6th IEEE World Forum on Internet of Things (WF-IoT)*, 2020

Distributed Machine Learning to Reduce Training Time



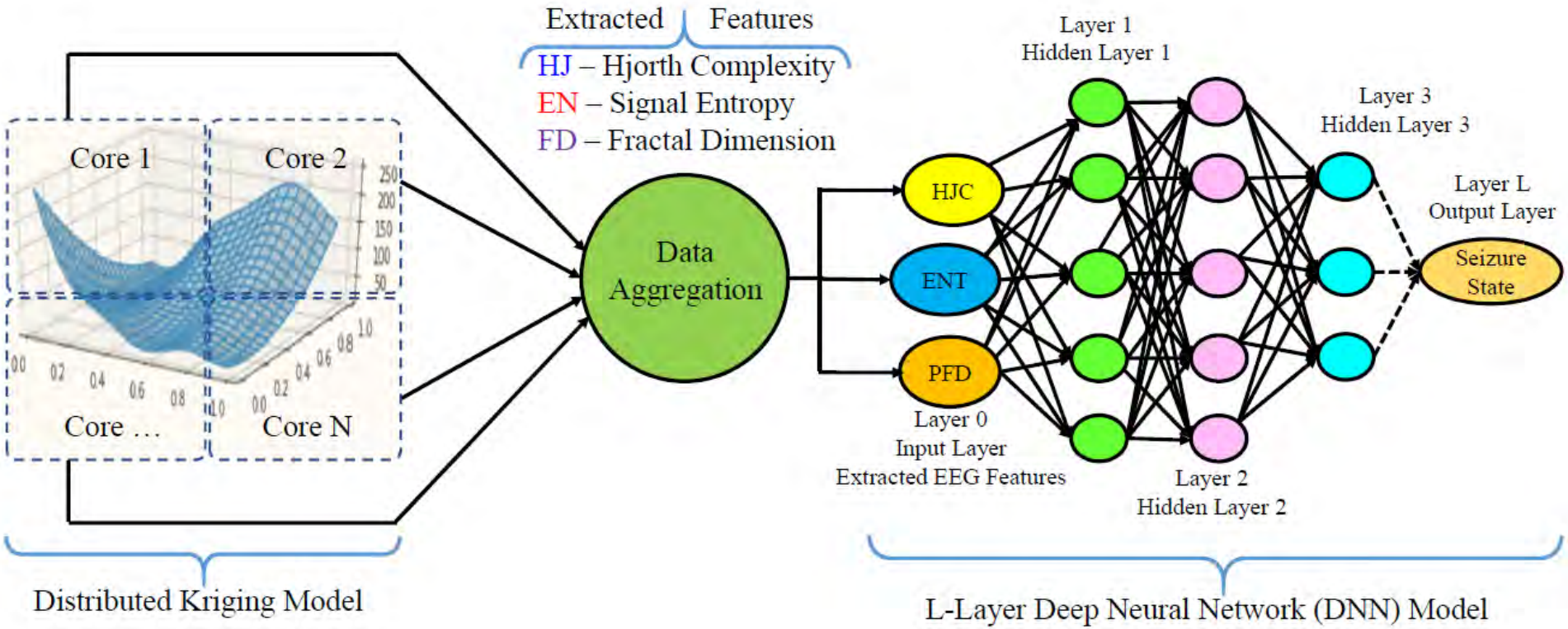
Source: Z. Li, V. Sharma, and S. P. Mohanty, "Preserving Data Privacy via Federated Learning: Challenges and Solutions", *IEEE Consumer Electronics Magazine*, Vol. 9, No. 3, May 2020, pp. 8--16.

Model Training or Learning Process



Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

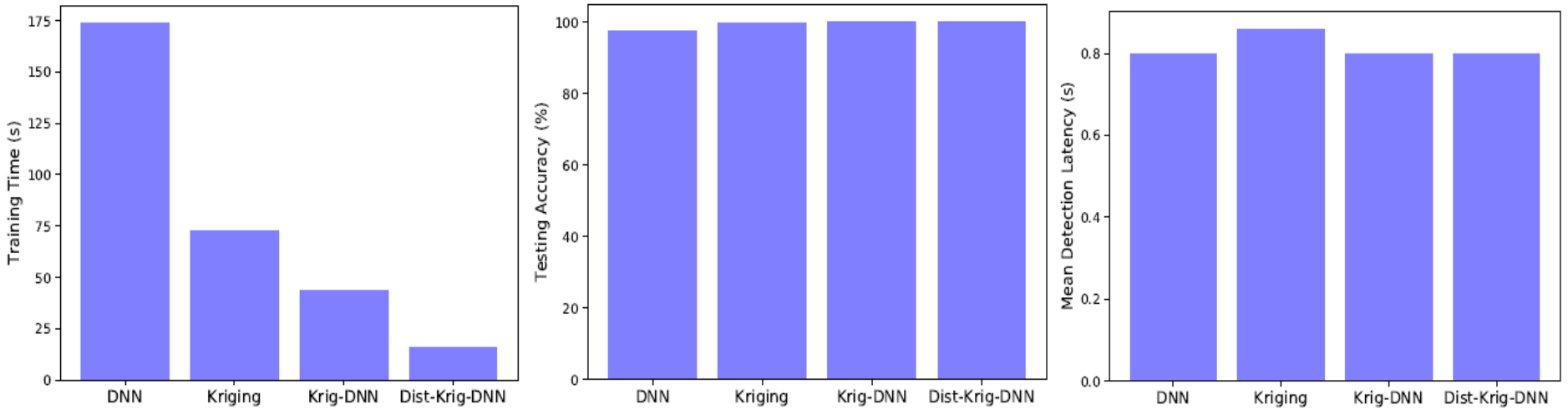
Our Distributed Kriging-Bootstrapped DNN Model



Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

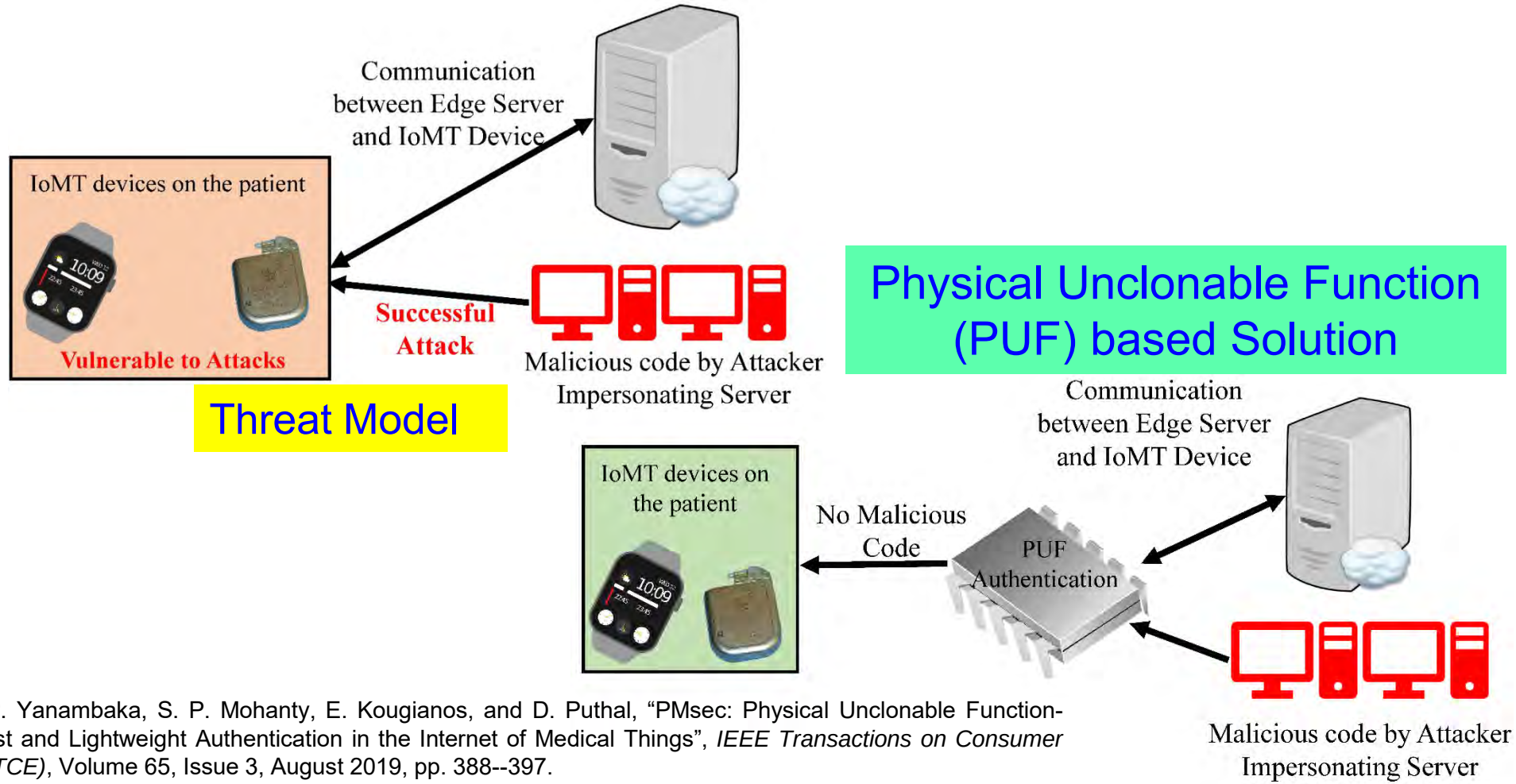
Experimental Results: Dataset A

Models	Detection Latency
DNN	0.80s
Ordinary Kriging	0.86s
Krig-DNN	0.80s
Dist-Krig-DNN	0.80s



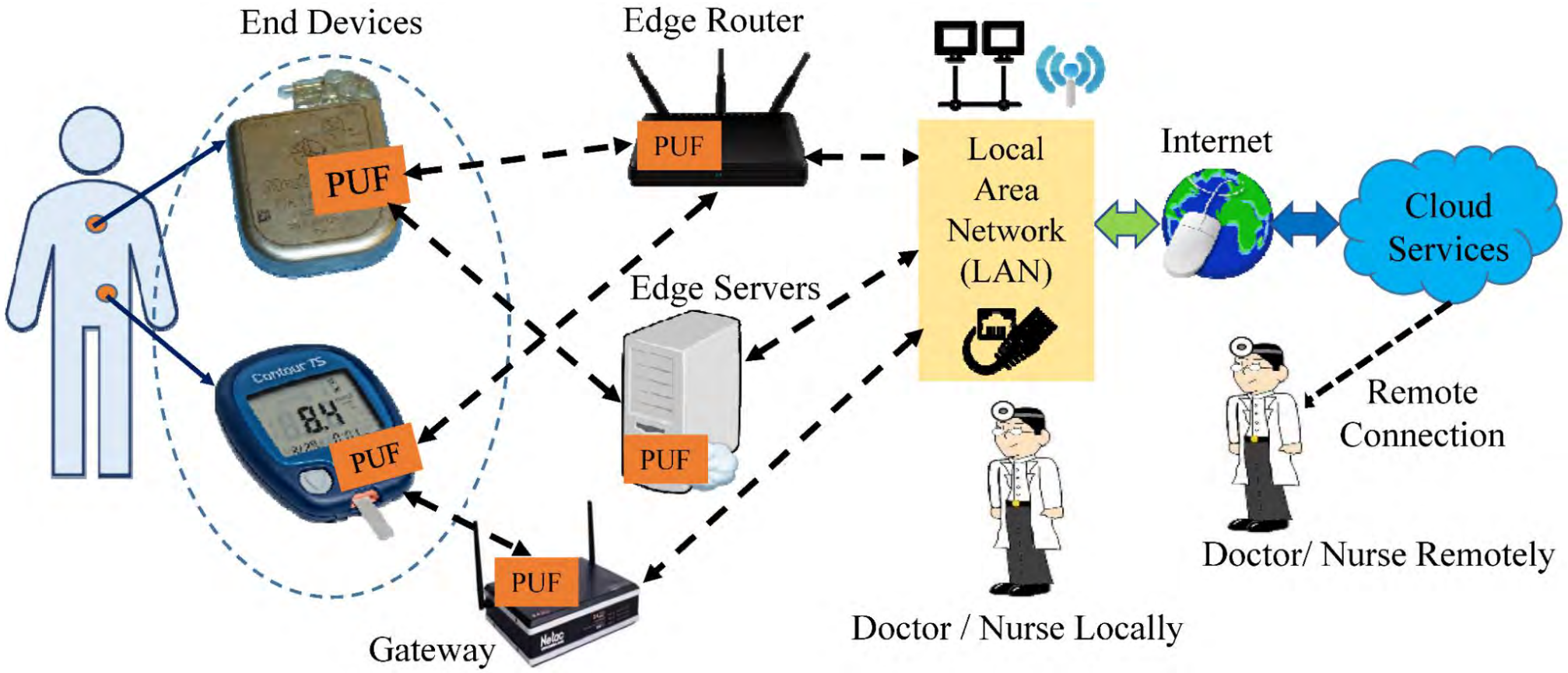
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

Our Secure by Design Approach for Robust Security in Healthcare CPS



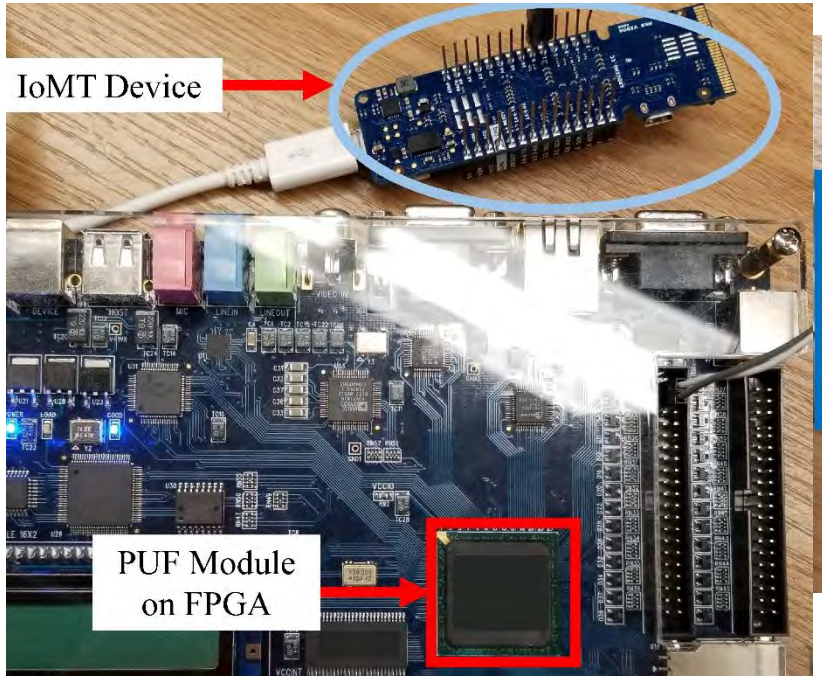
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

Our Secure by Design Approach for Robust Security in Healthcare CPS



Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

IoMT Security – Our Proposed PMsec

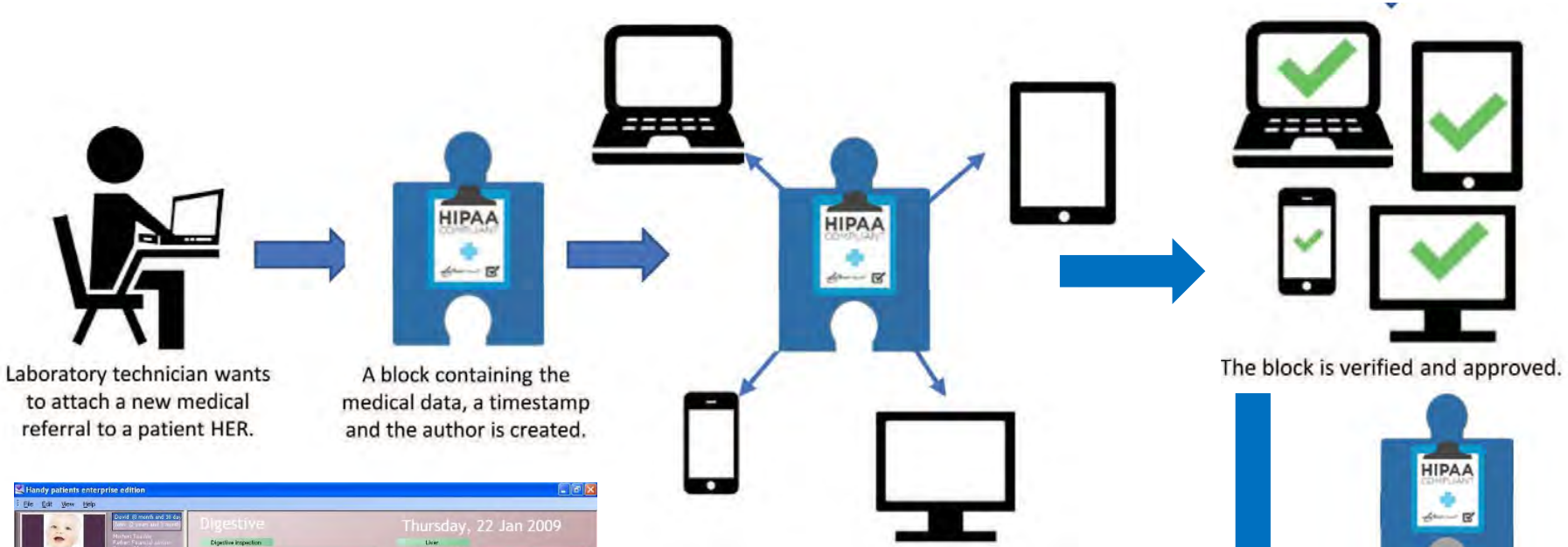


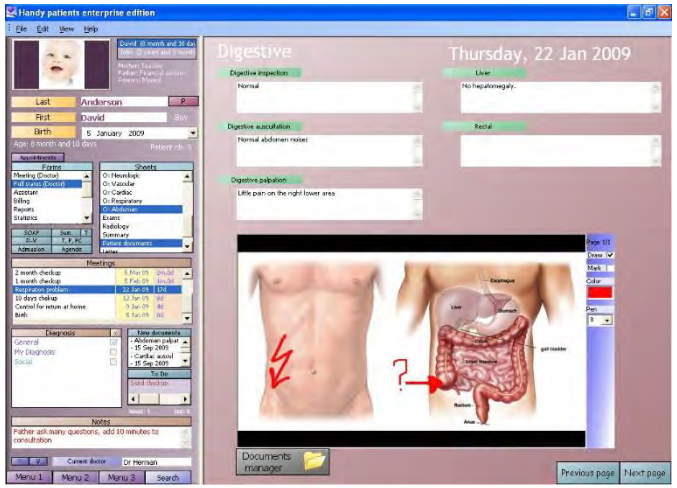
Average Power Overhead – ~ 200 μW

Proposed Approach Characteristics	Value (in a FPGA / Raspberry Pi Platform)
Time to Generate the Key at Server	800 ms
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

Blockchain in Smart Healthcare





Can it preserve privacy?

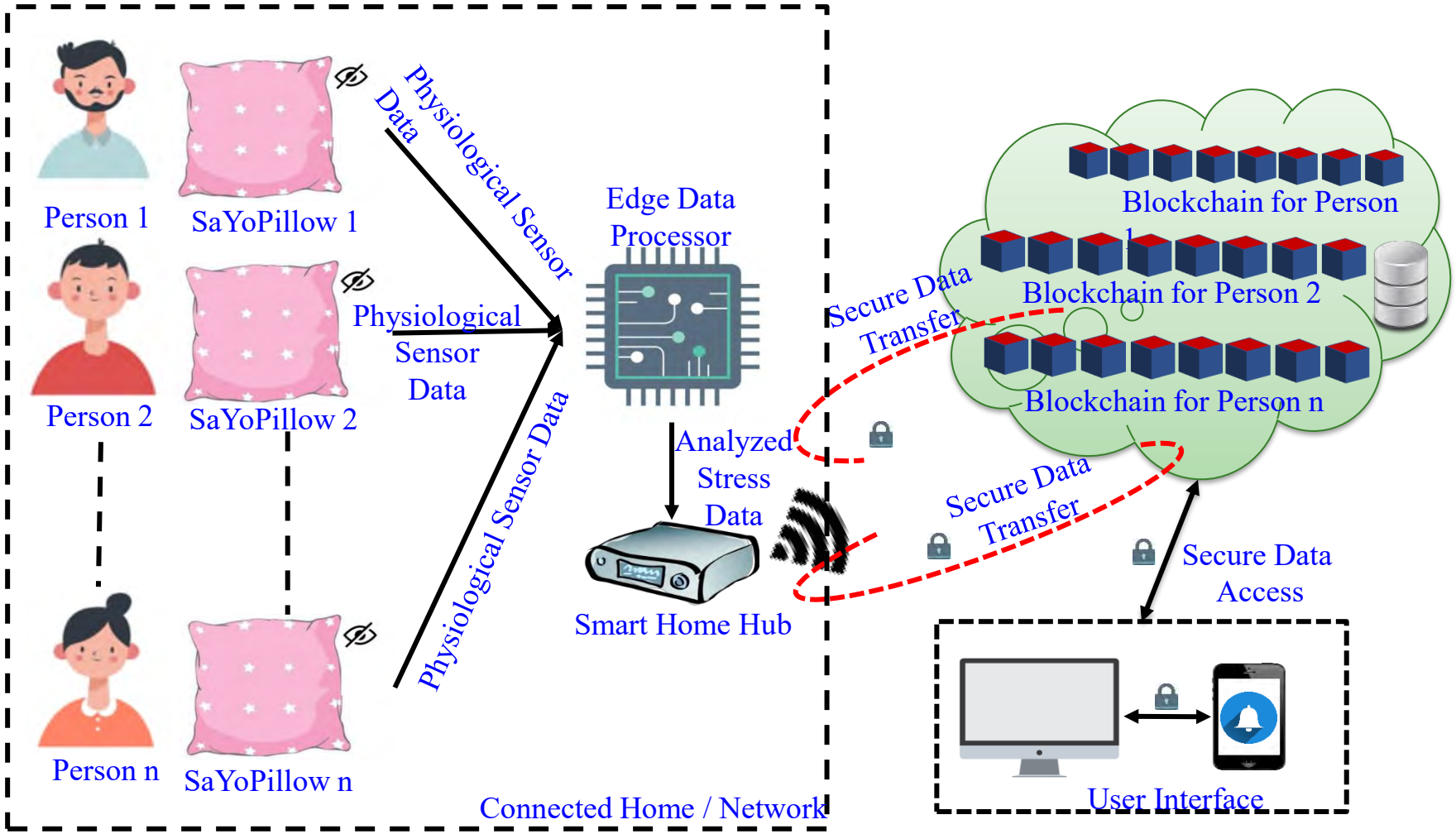
Source: C. Esposito, A. De Santis, G. Tortora, H. Chang and K. R. Choo, "Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?," IEEE Cloud Computing, vol. 5, no. 1, pp. 31-37, Jan./Feb. 2018.

Traditional Versus Blockchain EHR

Health Information Exchange (HIE) Pain Points	Blockchain Opportunities
Establishing a Trust Network depends on the HIE as an intermediary to establish point-to-point sharing and "book-keeping" of what data was exchanged.	**Disintermediation of Trust** likely would not require an HIE operator because all participants would have access to the distributed ledger to maintain a secure exchange without complex brokered trust.
Cost Per Transaction, given low transaction volumes, reduces the business case for central systems or new edge networks for participating groups.	**Reduced Transaction Costs** due to disintermediation, as well as near-real time processing, would make the system more efficient.
Master Patient Index (MPI) challenges arise from the need to synchronize multiple patient identifiers between systems while securing patient privacy.	**Distributed framework for patient digital identities,** which uses private and public identifiers secured through cryptography, creates a singular, more secure method of protecting patient identity.
Varying Data Standards reduce interoperability because records are not compatible between systems.	**Shared data** enables near real-time updates across the network to all parties.
Limited Access to Population Health Data, as HIE is one of the few sources of integrated records.	**Distributed, secure access** to patient longitudinal health data across the distributed ledger.
Inconsistent Rules and Permissions inhibit the right health organization from accessing the right patient data at the right time.	**Smart Contracts** create a consistent, rule-based method for accessing patient data that can be permissioned to selected health organizations.

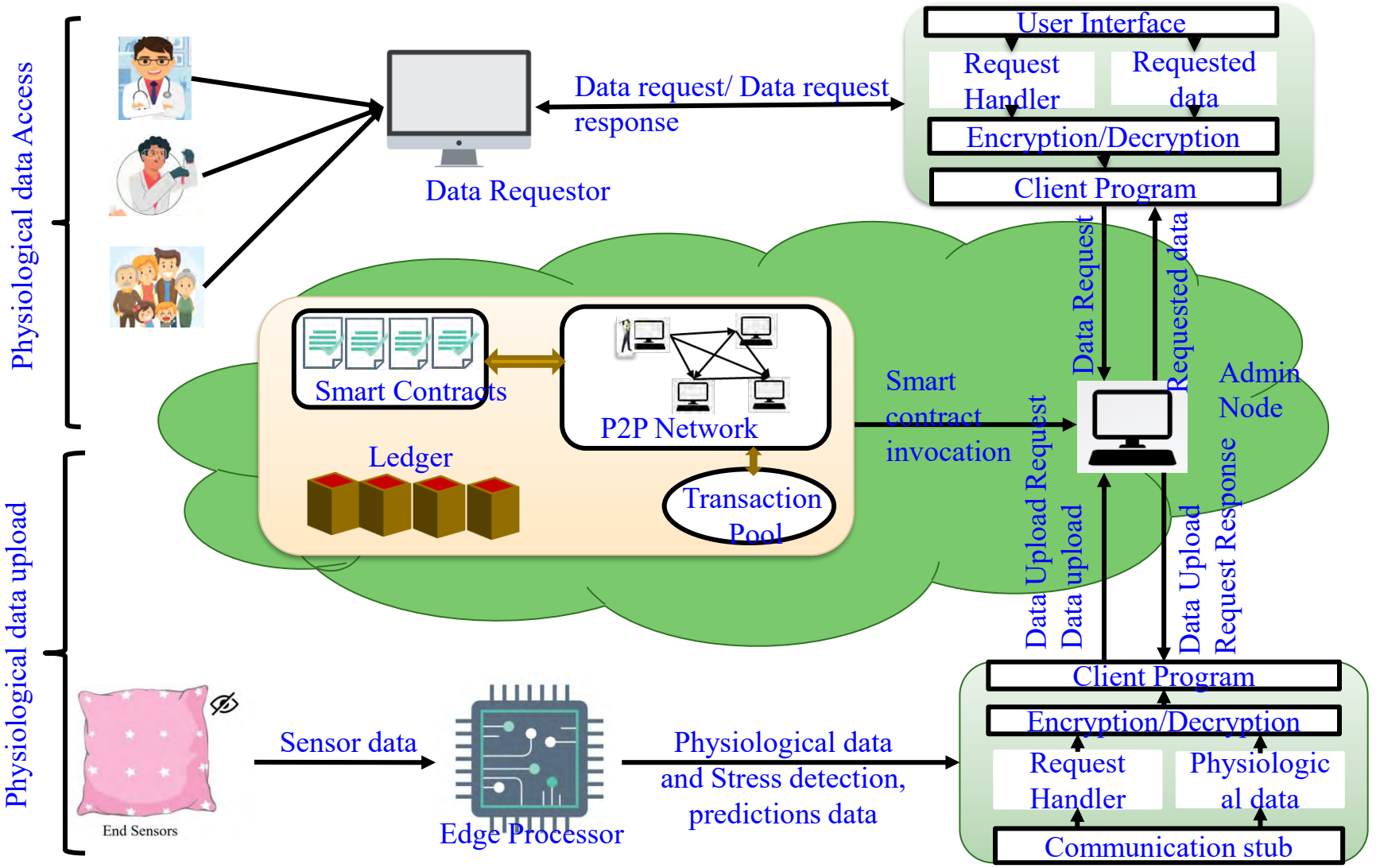
Source: Exploring the Use of Blockchain for EHRs, Healthcare Big Data, https://healthitanalytics.com/features/exploring-the-use-of-blockchain-for-ehrs-healthcare-big-data

Our Smart-Yoga Pillow (SaYoPillow)



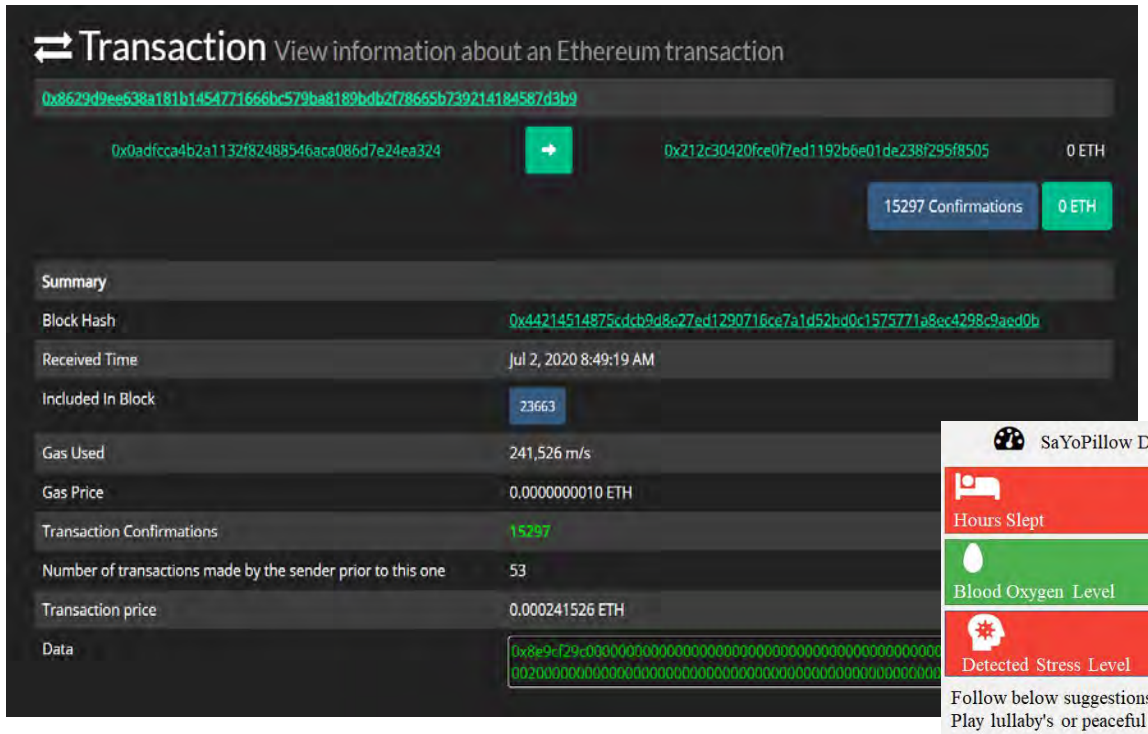
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

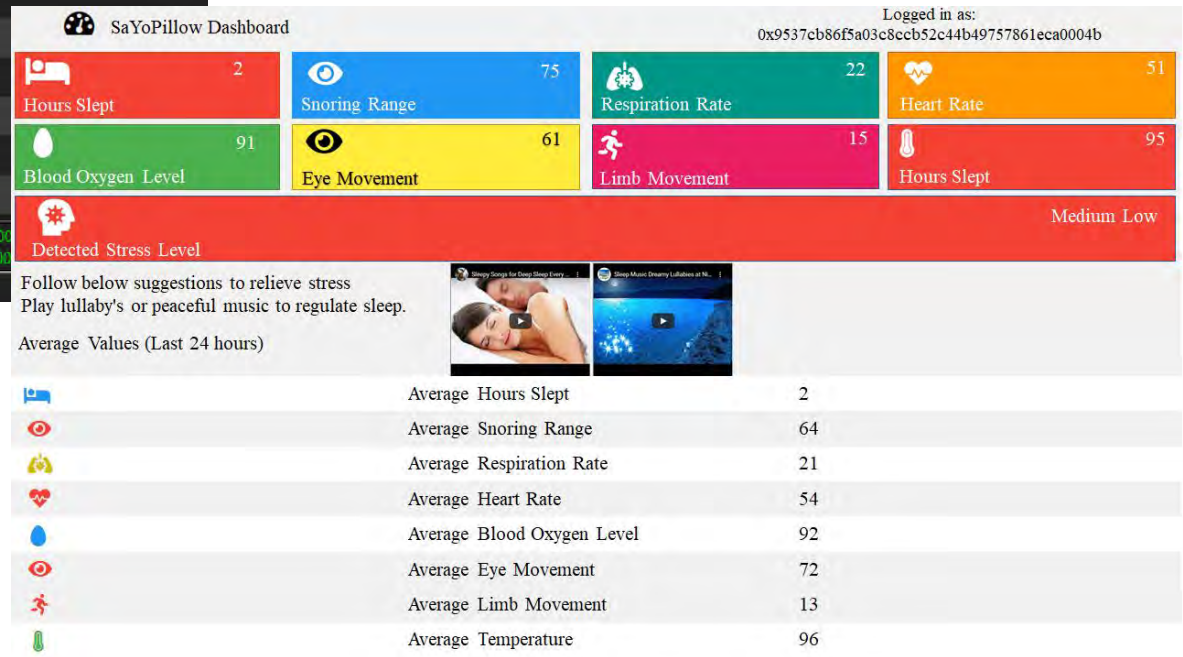
SaYoPillow: Blockchain Details



Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

SaYoPillow: Prototyping





Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

Conclusions and Future Research

Conclusions

- Healthcare has been evolving to Healthcare-Cyber-Physical-System (H-CPS) i.e. smart healthcare.
- Internet of Medical Things (IoMT) plays a key role smart healthcare.
- Smart healthcare can reduce cost of healthcare and give more personalized experience to the individual.
- IoMT provides advantages but also has limitations in terms of security, and privacy.
- Smart Healthcare can be effective during stay-at-home scenario during pandemic.

Future Research

- Machine learning (ML) models for smart healthcare needs research.
- Internet-of-Everything (IoE) with Human as active part as crowdsourcing need research.
- IoE will need robust data, device, and H-CPS security need more research.
- Security of IWMDs needs to have extremely minimal energy overhead to be useful and hence needs research.
- Integration of blockchain for smart healthcare need research due to energy and computational overheads associated with it.

Key References

- P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", IEEE Consumer Electronics Magazine (CEM), Volume 7, Issue 1, January 2018, pp. 18-28.
- L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", IEEE Transactions on Consumer Electronics (TCE), Vol. 67, No. 1, Feb 2021, pp. 20-29.
- L. Rachakonda, S. P. Mohanty, and E. Kougianos, "iLog: An Intelligent Device for Automatic Food Intake Monitoring and Stress Detection in the IoMT", IEEE Transactions on Consumer Electronics (TCE), Vol. 66, No. 2, May 2020, pp. 115--124.