Healthcare Cyber-Physical Systems (H-CPS) - Demystified

Keynote - International Conference on Innovative Computing and Applications (ICICA 2022)

Nagpur, India, 25-26 Nov 2022

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Outline

- Healthcare → Smart Healthcare
- Smart Healthcare - Characteristics
- Smart Healthcare - Components
- Smart Healthcare - Examples
- Smart Healthcare – Challenges
- Smart Healthcare – Solutions of Challenges
- Smart Healthcare – Pharmaceutical Supply Chain
- Conclusions and Future Directions

Healthcare
to
Smart Healthcare

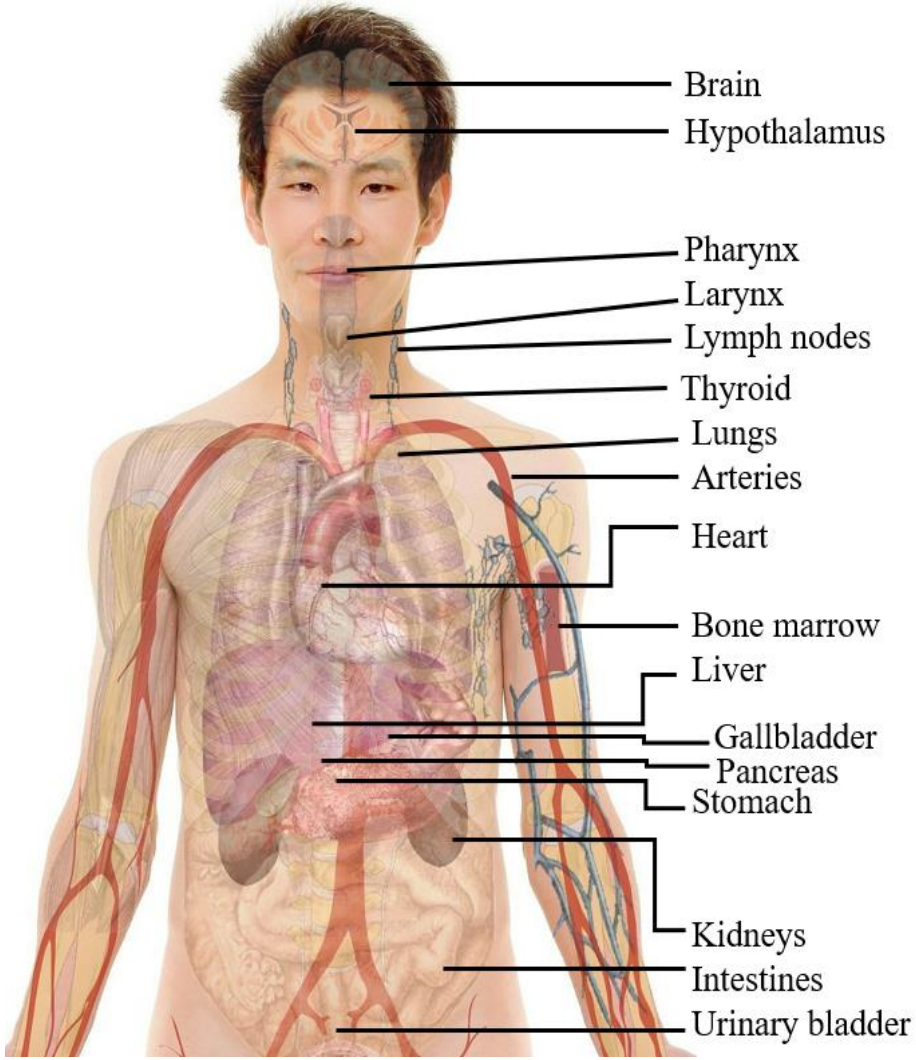
Human Body and Health

Human Body

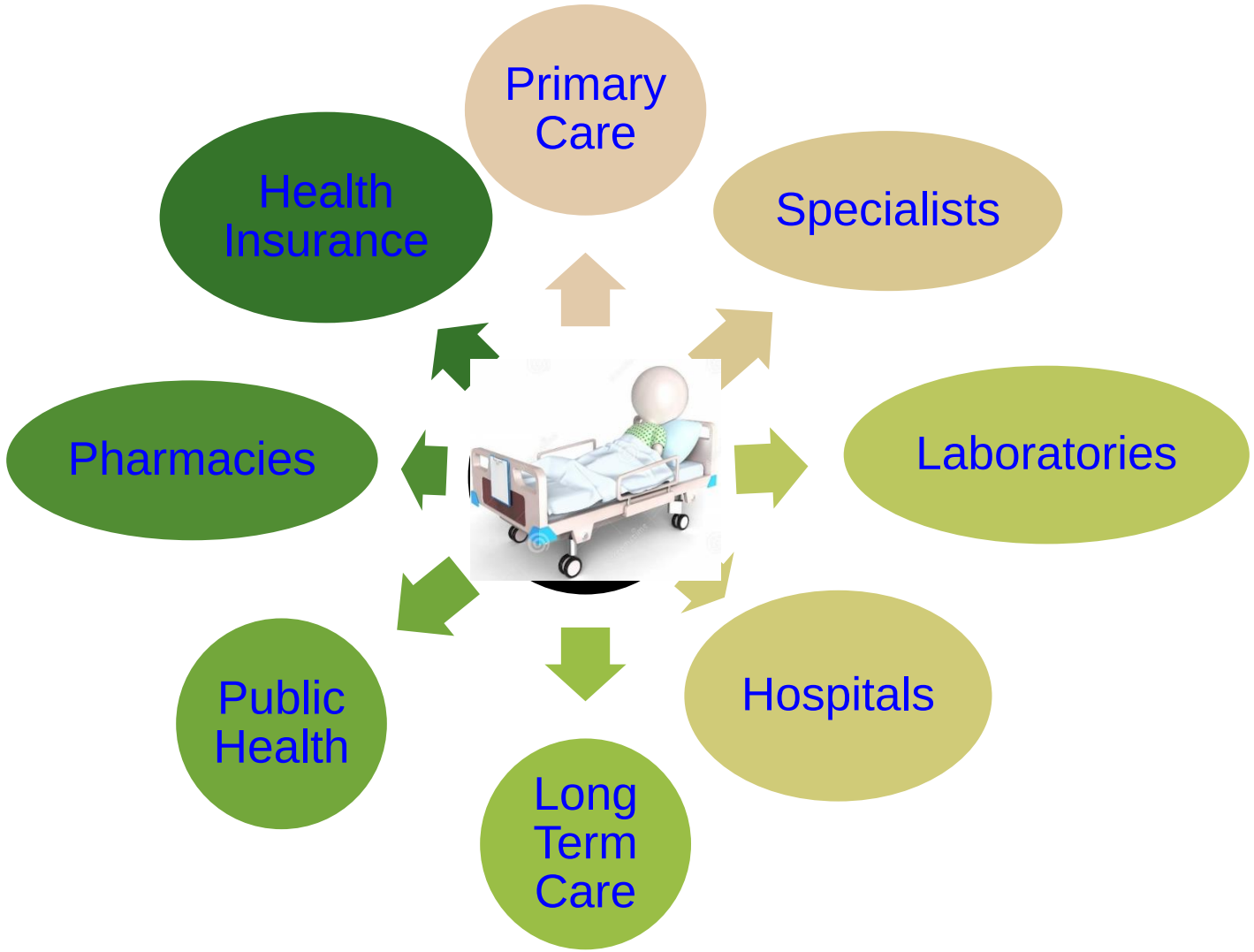
- From an engineering perspective - Human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical …).

Health

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



Traditional Healthcare

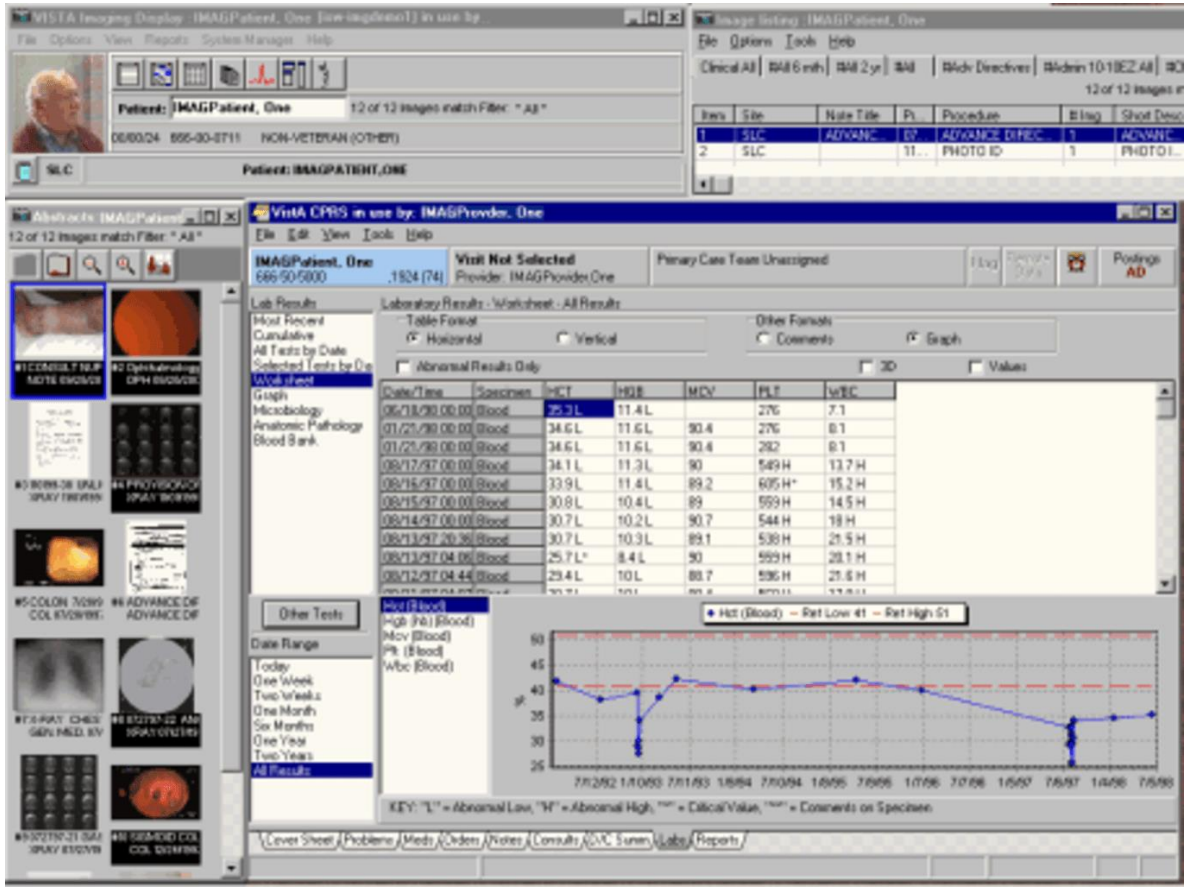


- Physical presence needed
- Deals with many stakeholders
- Stakeholders may not interact
- May not be personalized
- Not much active feedback
- Less effective follow-up from physicians

Telemedicine

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

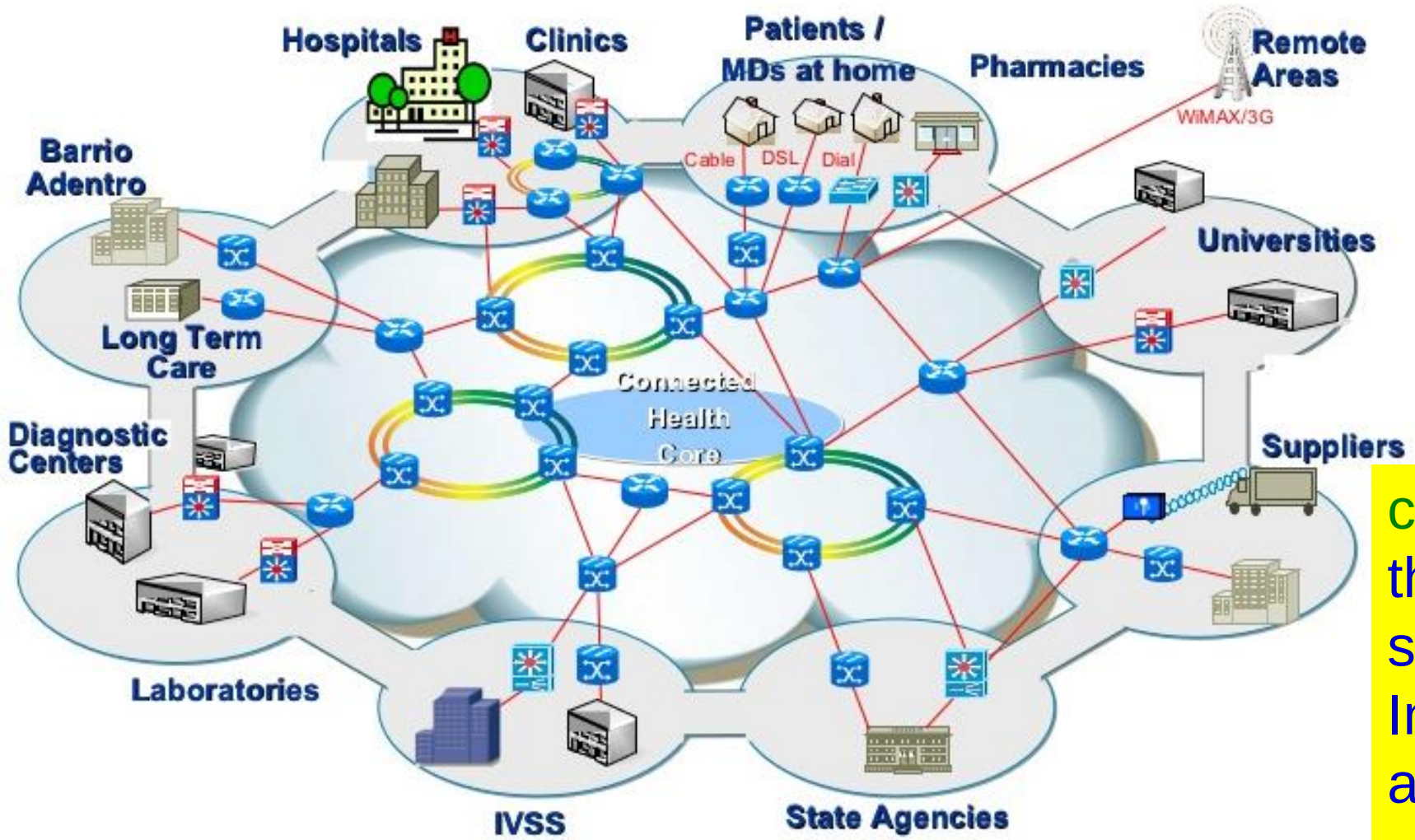
Electronic Health (eHealth)



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 technology to improve healthcare services.

Connected Health (cHealth)



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

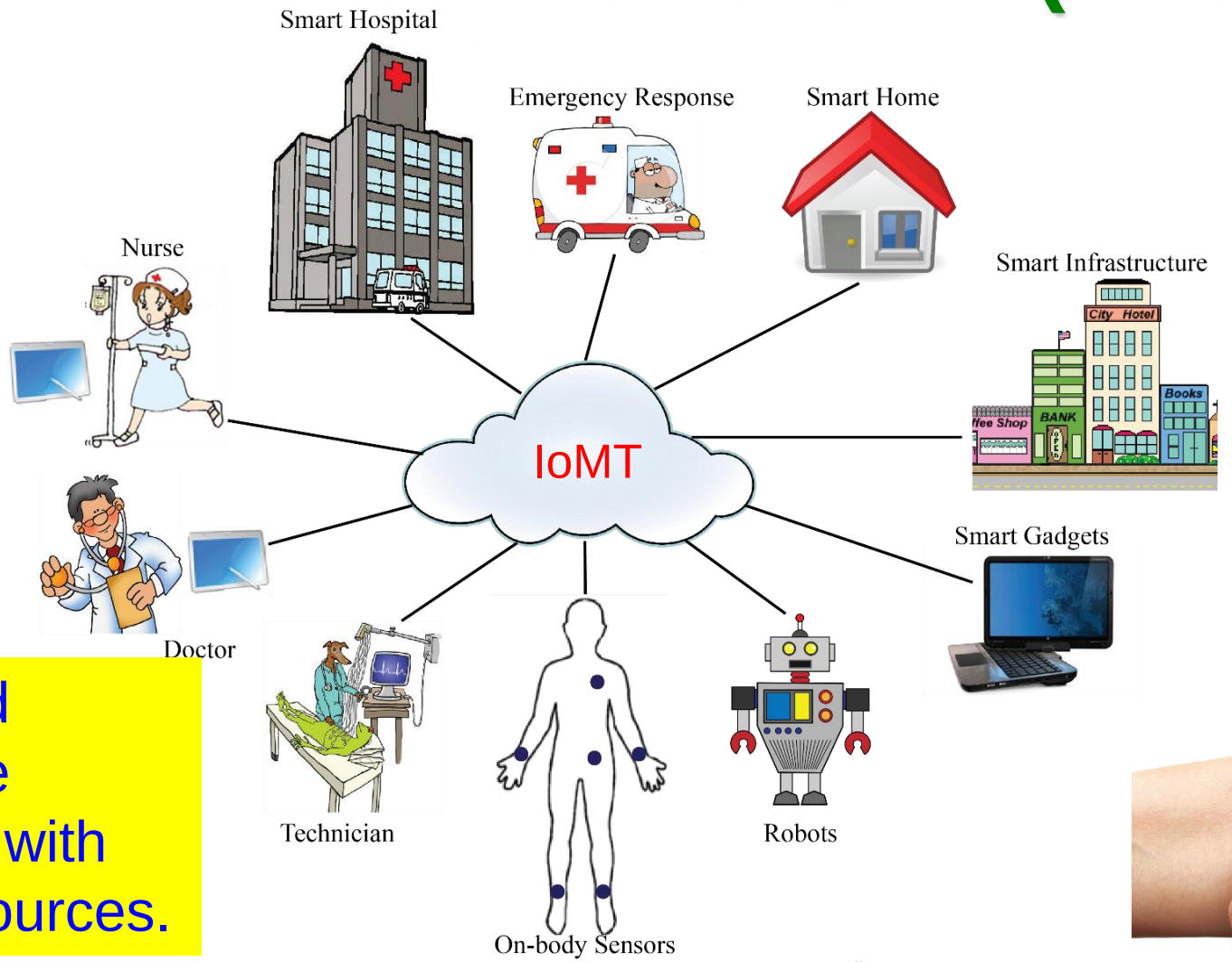
cHealth: Connections of the various healthcare stake holders through Internet to share appropriate data to better serve the patients.

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.

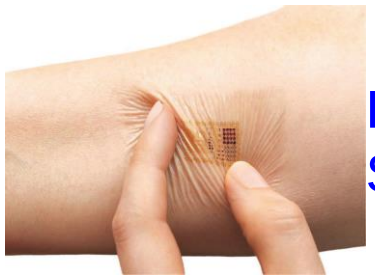
Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Smart Healthcare (sHealth)



Fitness Trackers

Headband with Embedded Neurosensors



Embedded Skin Patches

Quality and sustainable healthcare with limited resources.

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.

Smart Healthcare - Applications

Healthy Living

- Fitness Tracking
- Disease Prevention
- Food monitoring

Home Care

- Mobile health
- Telemedicine
- Self-management
- Assisted Living

Acute Care

- Hospital
- Specialty clinic
- Nursing Home
- Community Hospital

Frost and Sullivan predicts smart healthcare market value to reach US$348.5 billion by 2025.

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.

Smart Healthcare - Characteristics

What is Smart Healthcare?

Smart Healthcare

←

Conventional Healthcare

+ Body sensors

+ Information & Communication Technology (ICT)

+ Artificial Intelligence (AI)/ Machine Learning (ML)

+ Smart Technology (BCI, VR, etc.)

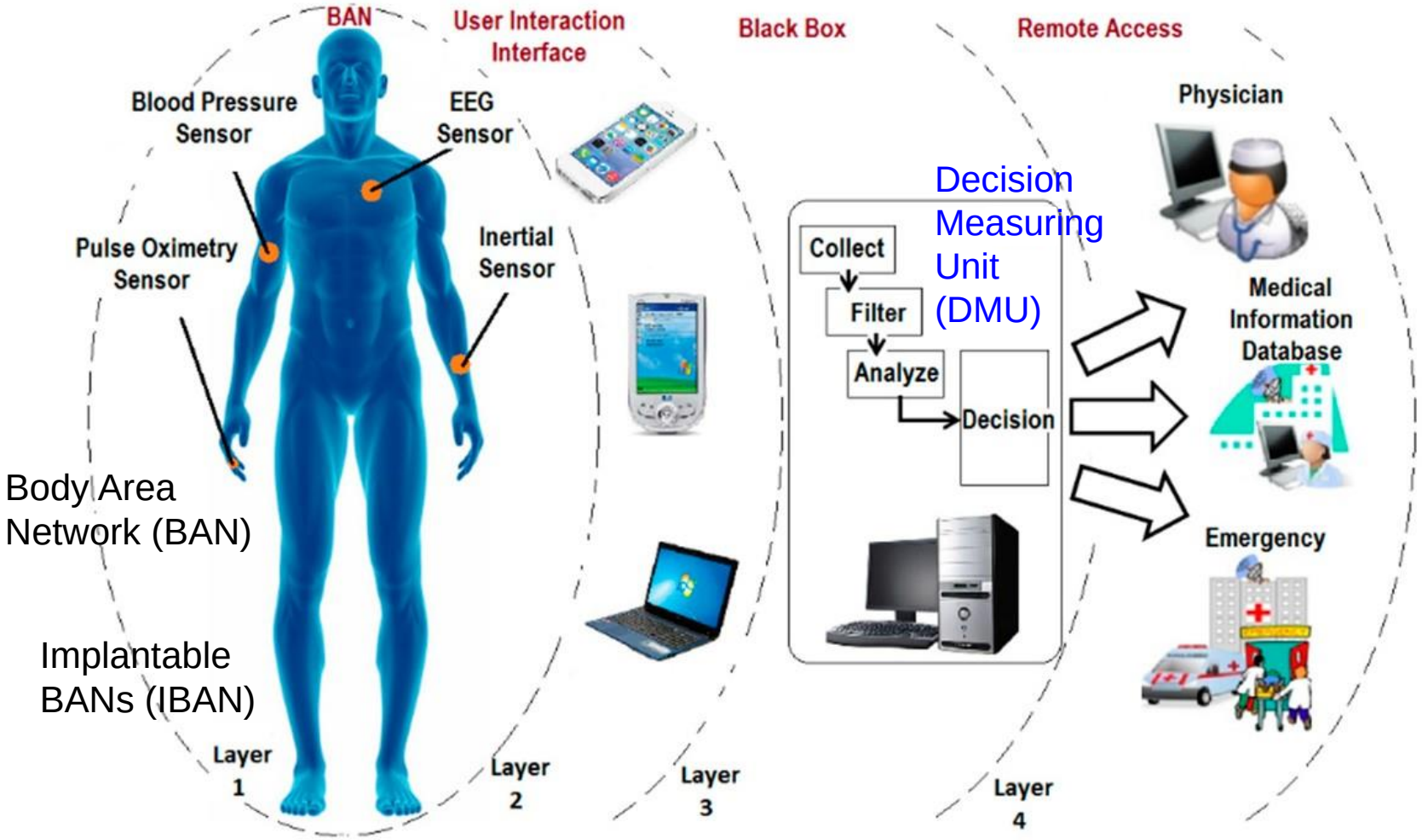
Internet of Medical Things (IoMT)

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



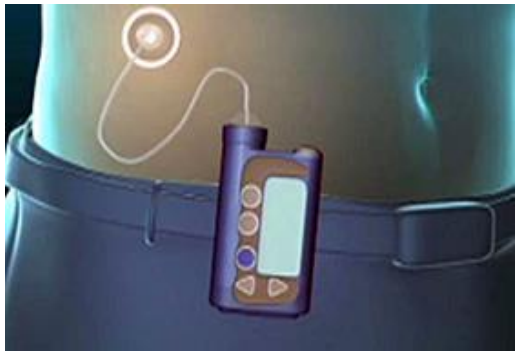
Healthcare Cyber-Physical Systems (H-CPS)

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.

Wearable Medical Devices (WMDs)

Fitness Trackers

Headband with Embedded Neurosensors

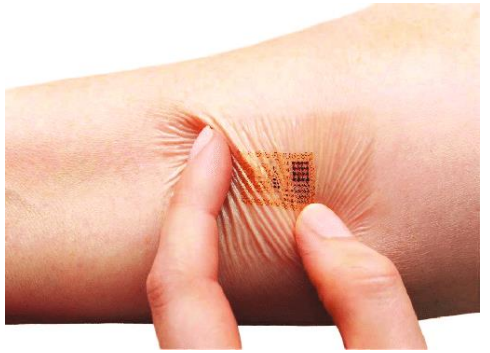


Insulin Pump

Source: https://www.webmd.com

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

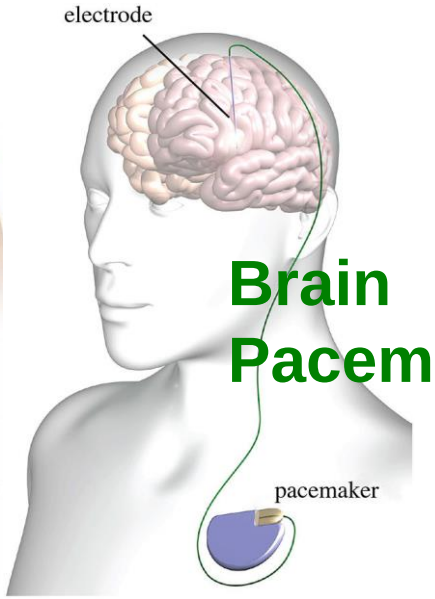
Medical grade smart watch to detect seizure



Embedded Skin Patches

Implantable Medical Devices (IMDs)

Pill Camera



Brain Pacemaker

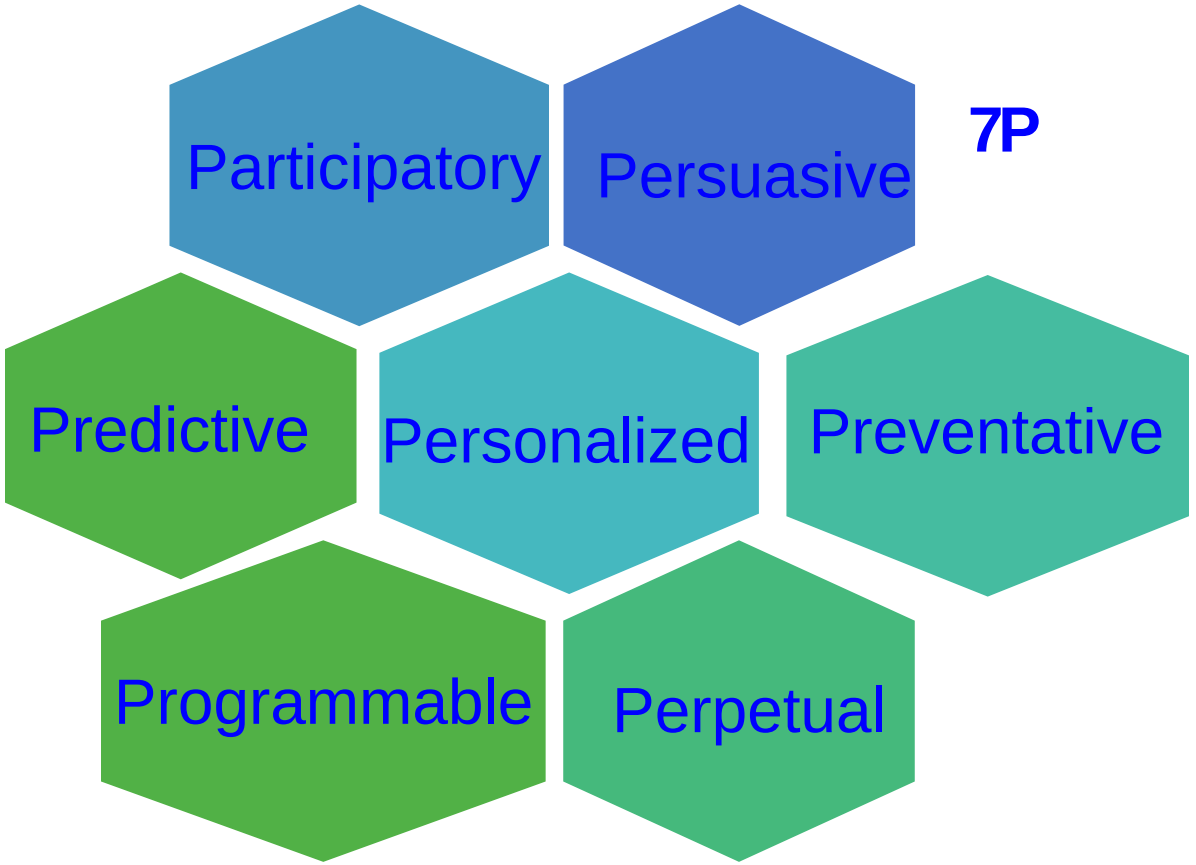
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "*Everything You Wanted to Know about Smart Health Care*", IEEE Consumer Electronics Magazine (MCE), Volume 7, Issue 1, January 2018, pp. 18-28.

Collectively:
Implantable and Wearable Medical Devices (IWMDs)

Implantable MEMS Device

Source: http://web.mit.edu/cprl/www/research.shtml

Smart Healthcare – 7Ps



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Smart Healthcare - 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

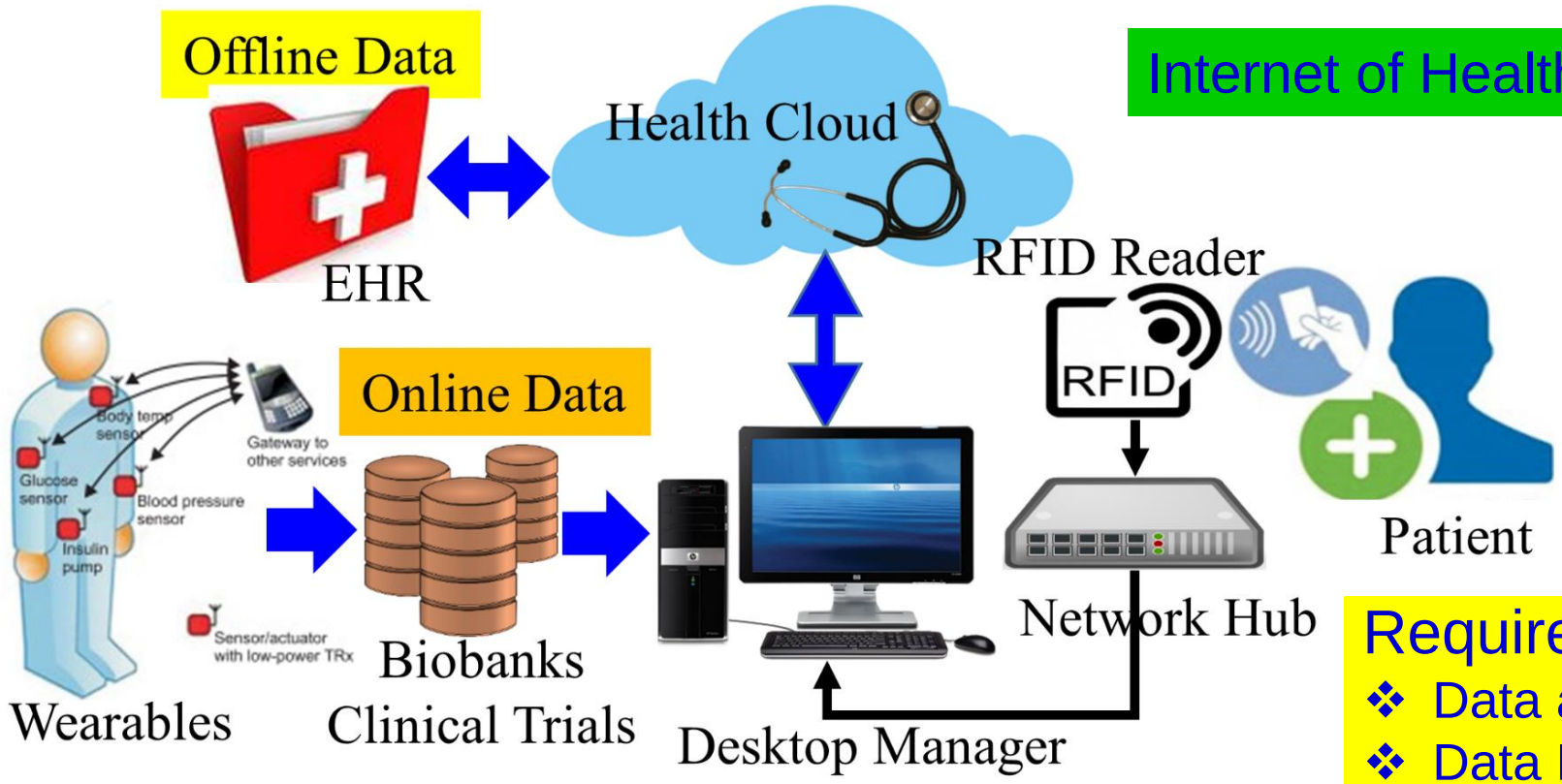
Market Challenges

- 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)



Internet of Health Things (IoHT)

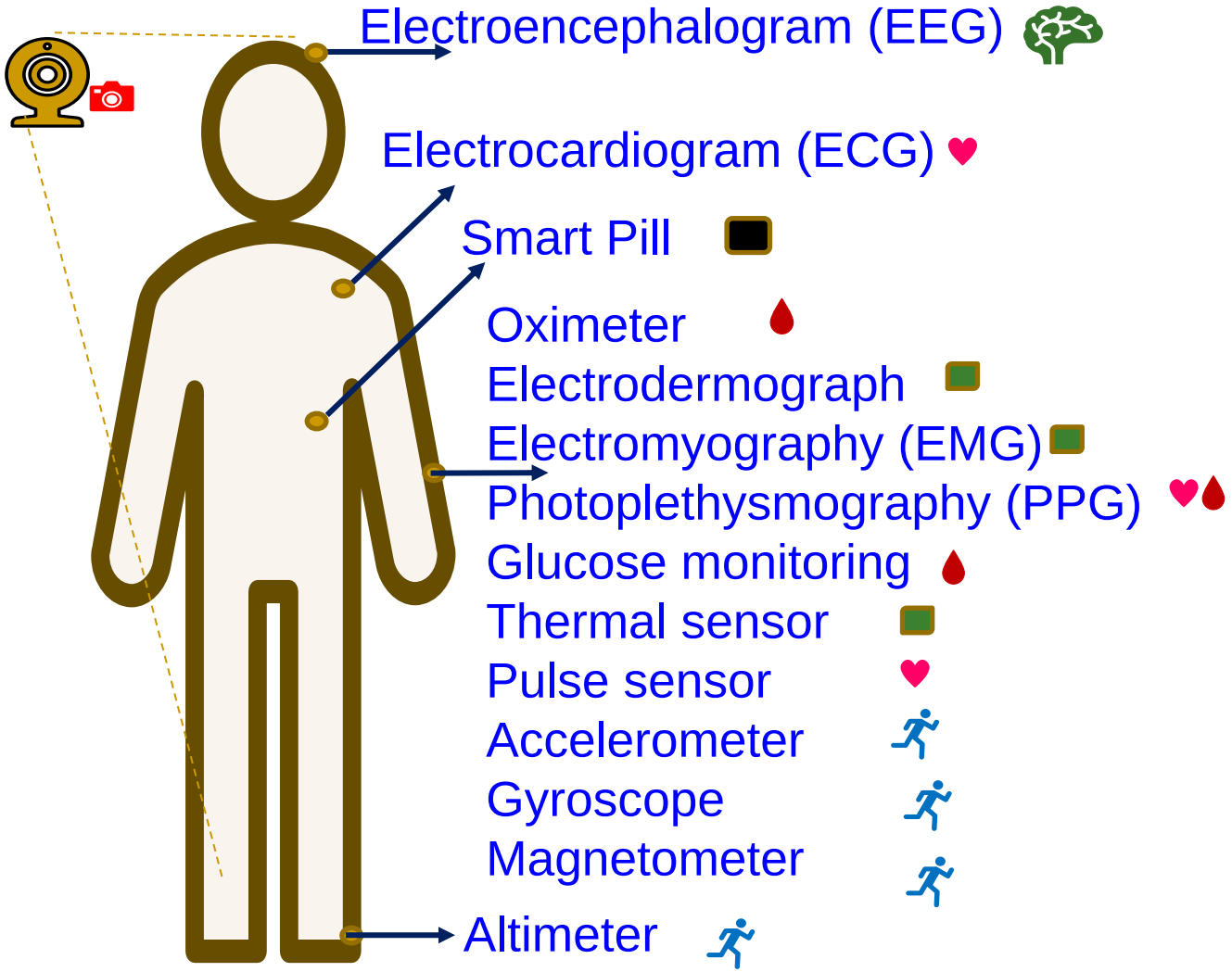
Requires:

- Data and Device Security
- Data Privacy

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 Sensors



Types of Sensors

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

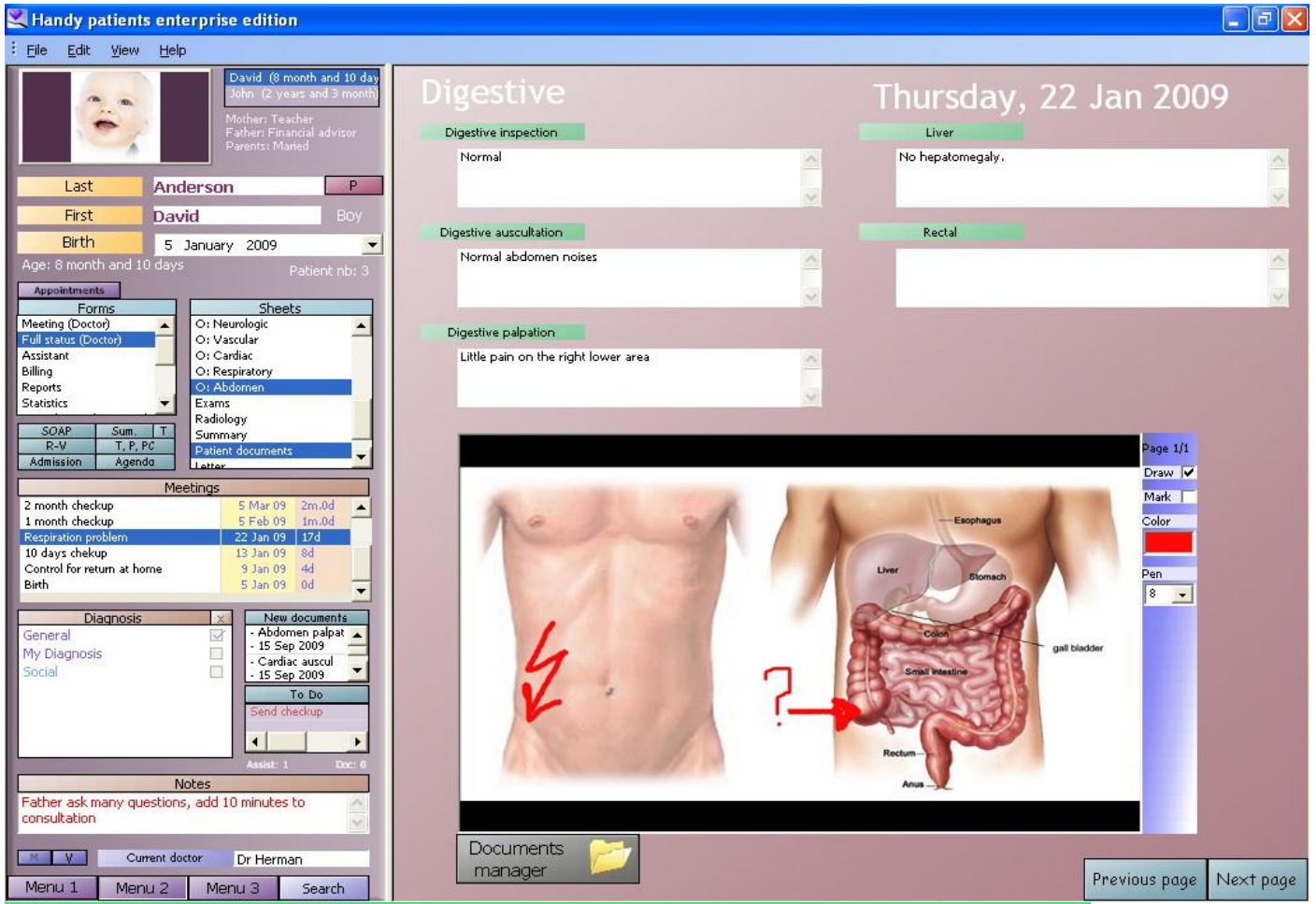
Smart Healthcare Communication

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.

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)

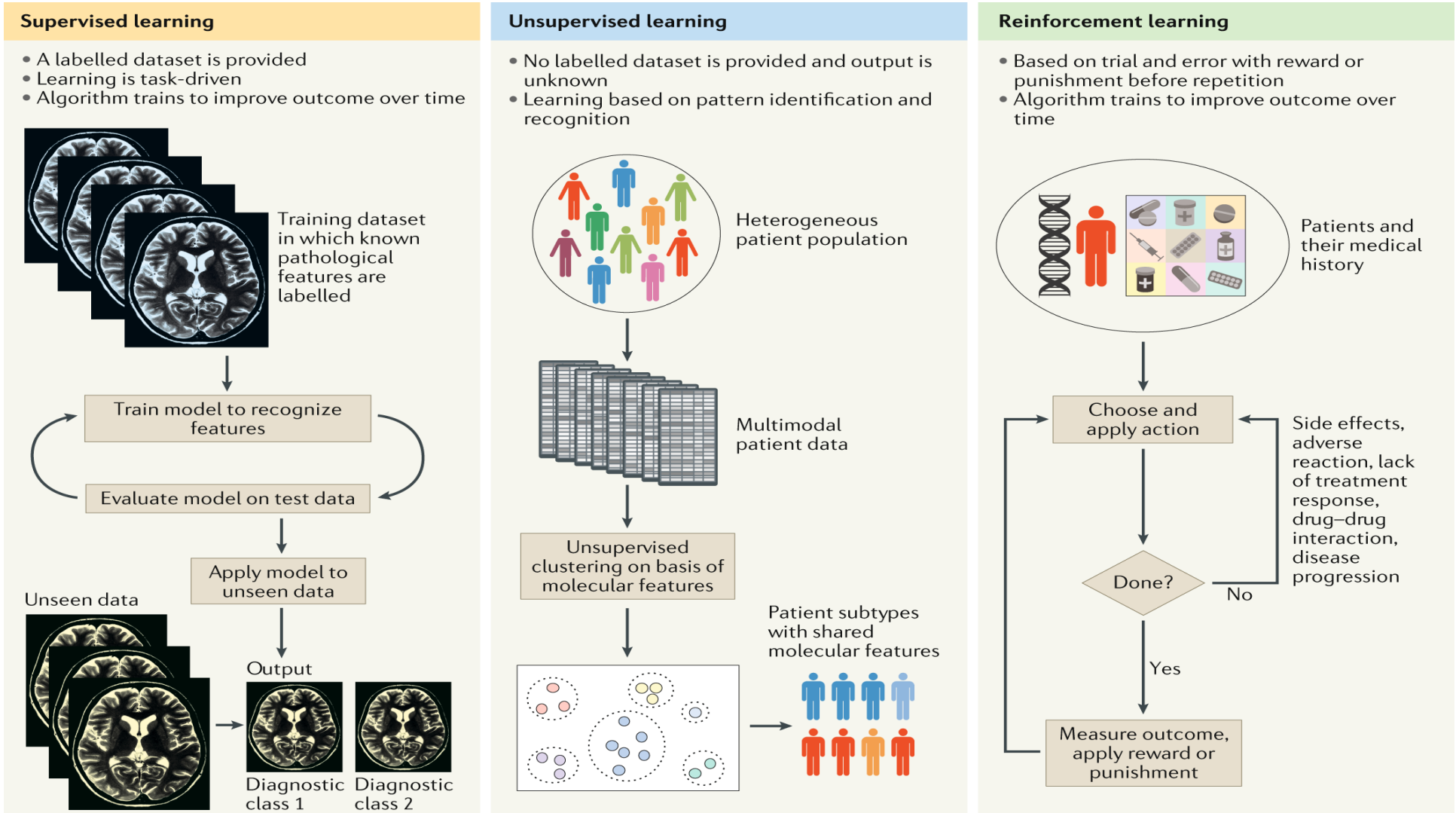
Smart Healthcare – AI/ML is Key

AI Role Includes:

- Automatic diagnosis
- Disease predication
- Diet prediction
- Pandemic projection
- Automatic prescription

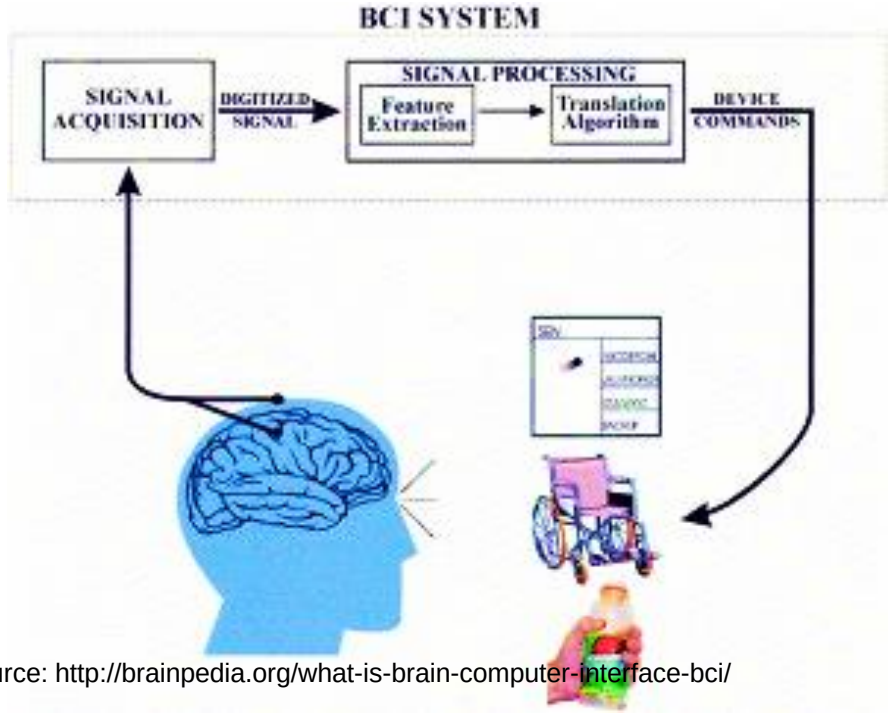
Source: Robert Pearl, "Artificial Intelligence In Healthcare: Separating Reality From Hype", 13 Mar 2018, *https://www.forbes.com/sites/robertpearl/2018/03/13/artificial-intelligence-in-healthcare/?sh=598aa64d1d75*

Smart Healthcare – ML …



Source: Myszczynska, M.A., Ojamies, P.N., Lacoste, A.M.B. *et al.* Applications of machine learning to diagnosis and treatment of neurodegenerative diseases. *Nat Rev Neurol* **16,** 440–456 (2020). https://doi.org/10.1038/s41582-020-0377-8

Brain Computer Interface (BCI)

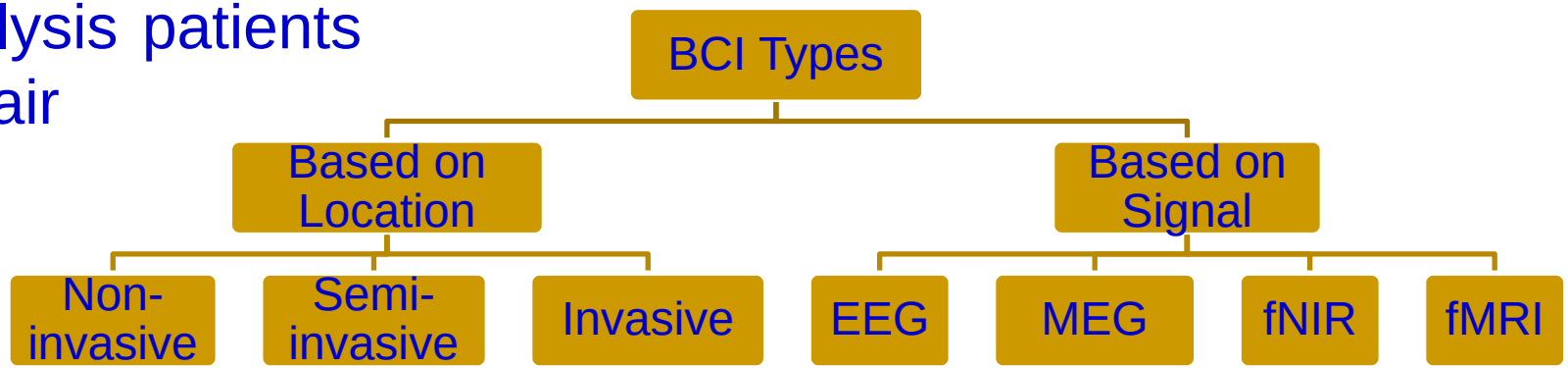


Source: http://brainpedia.org/what-is-brain-computer-interface-bci/

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/

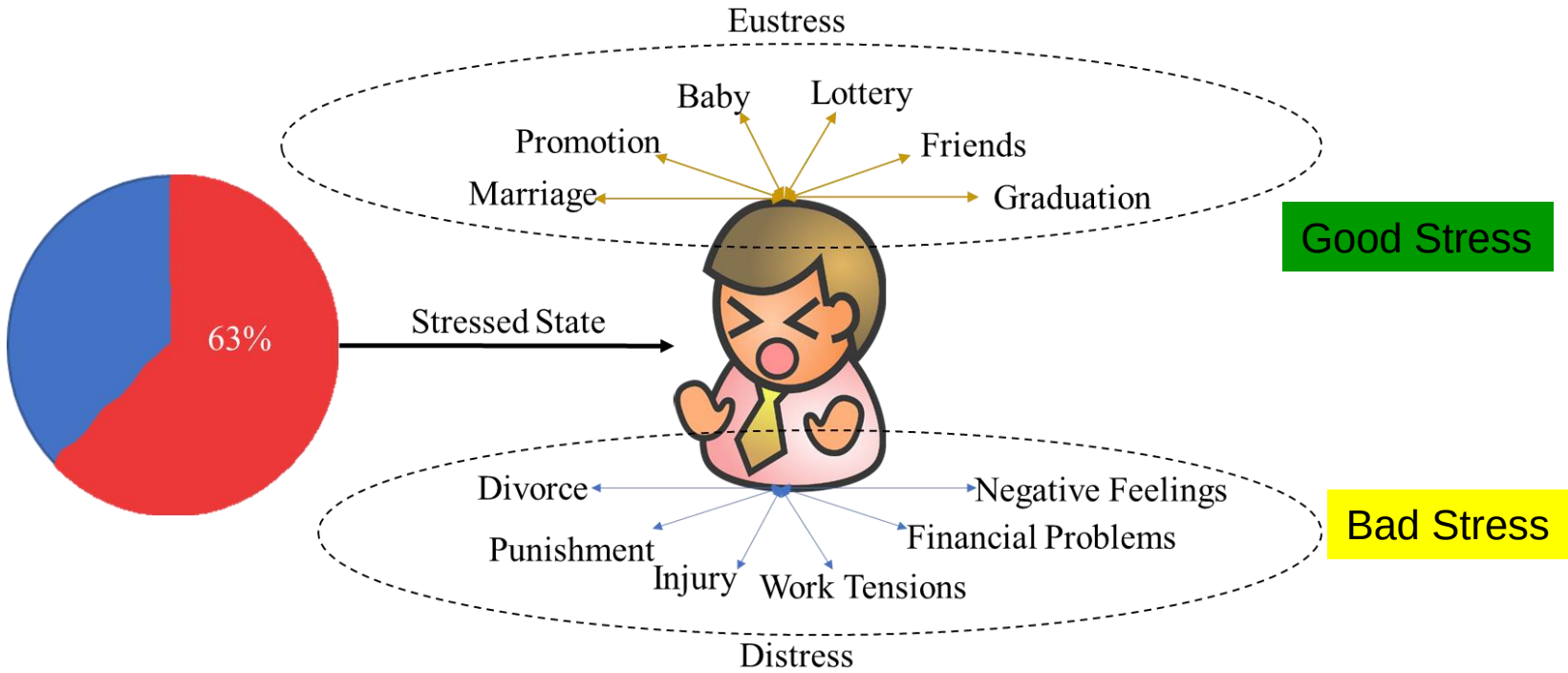
In Surgery

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

For Therapy

Smart Healthcare – Specific Examples

What is Stress?



- Stress is the relationship between a person and a situation, which adversely impacts the happiness and health of the sufferer or physiological reactions.
- Stress can be divided into two parts: stressor and reaction.
- Stressor is the activity or effect that triggers a change in the physiological parameter values of the human body.
- Reaction is the deviation of these parameter values from their normal levels.

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/

Stress Monitoring and Control is Needed

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

Distress

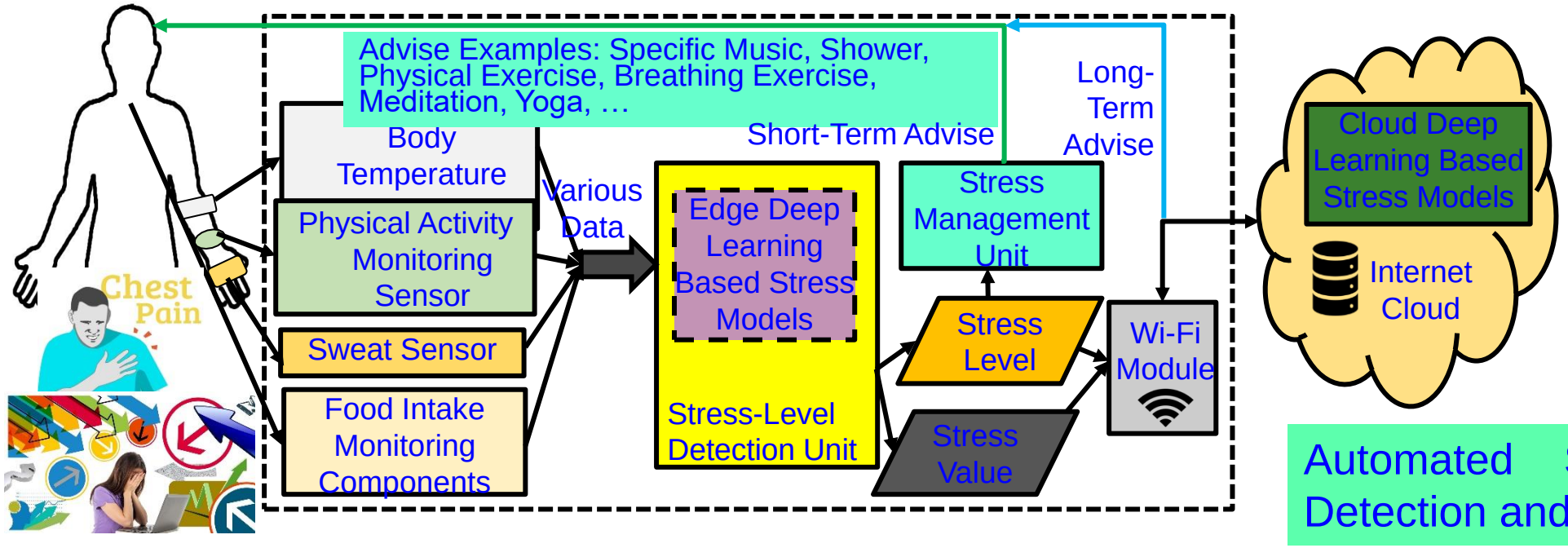
Sudden encounter with **stress**

→Brain floods **body** with chemicals and hormones (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

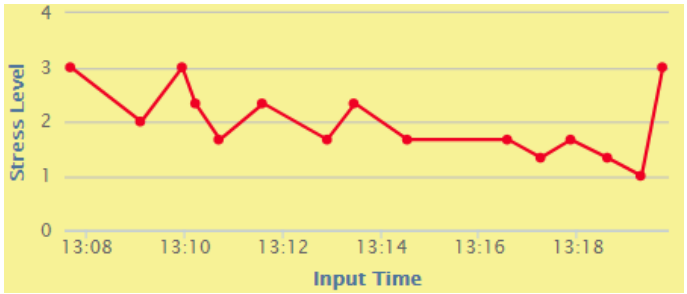
Eustress

Stress Monitoring & Control – Our Vision



Automated Stress Level Detection and Management

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.

Consumer Electronics Devices – Can Provide Data for Stress Detection

Brand	Device	Signals	RTI	Ambulant
Empatica	E4 wristband	PPG, GSR, HR, ACC, ST	Yes	Yes
Garmin	Vivosmart	HR, HRV, ACC	Yes	Yes
Zephyr	BioHarness 3.0	HR, HRV, GSR, ACC, ST	Yes	Yes
iMotions	Shimmer 3+ GSR	GSR, PPG	Yes	No
BIOPAC	Mobita Wearable	ECG, EEG, EGG EMG, and EOG	Yes	No

GSR = Galvanic Skin Response, HR = Heart Rate, ACC = Acceleration, ST = Skin Temperature, HRV = Heart Rate Variability, PPG = Photoplethysmograph, RTI = Real Time Implementation

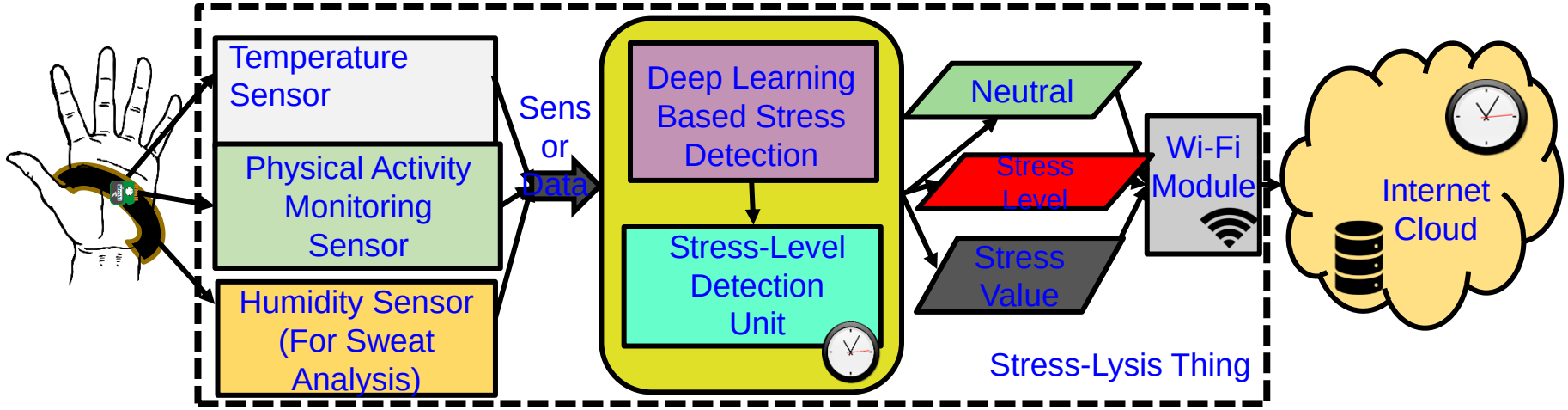
Source: R. K. Nath, H. Thapliyal, A. Caban-Holt, and S. P. Mohanty, "Machine Learning Based Solutions for Real-Time Stress Monitoring", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 9, No. 5, September 2020, pp. 34--41.

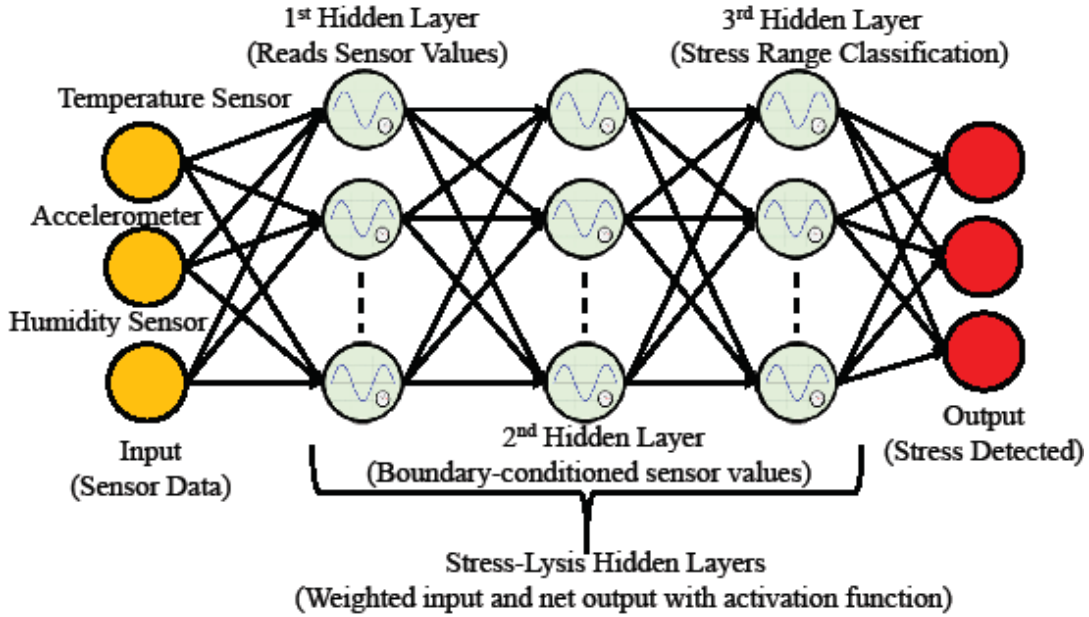
Consumer Electronics Sleep Trackers

Consumer Products	Approach	Features	Drawbacks
Fitbit [34]	Wearable	Heart rate monitor, sleep stages monitor. Has techniques to improve the sleep score.	Relationship between stress and sleep is not discussed.
SleepScore Max [36]	Non-wearable	Invisible radio wave sleep tracking	Does not manage stress with sleep.
Nokia Sleep [38]	Non-wearable	Uses Ballistocardiography sensor	Does not explain the relationship with stress with sleep.
Xiaomi Mi Band 3 [31]	Wearable	Pulse Monitor	No information on importance of quality sleep.
Eversleep [32]	wearable	Snoring and breathing interruptions	No explanation on the relationship between stress and sleep.
Beddit [35]	Non-wearable	Monitors snoring	Doesn't consider other possible features.
Eight [37]	Non-Wearable	Humidity, temperature, heartbeat, breathing rate	No data on how it is important to have a good sleep.
Dreem [33]	Wearable	Simulates slow brain waves	It doesn't consider other features; Does not manage stress with sleep.
Muse [26]	Wearable	Simulates brain waves	No understanding of the importance of quality sleep.

Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: A Blockchain-Enabled, Privacy-Assured Framework for Stress Detection, Prediction and Control Considering Sleeping Habits in the IoMT", *arXiv Computer Science*, arXiv:2007.07377, July 2020, 38-pages.

Stress-Lysis: From Physiological Signals

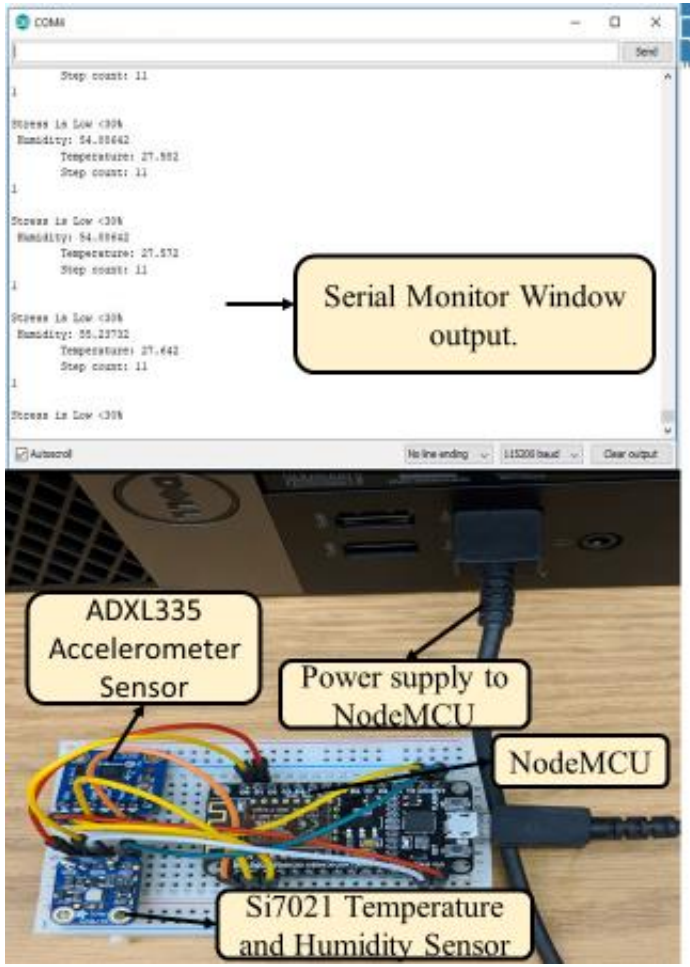




Stress-Lysis - DNN has been trained with a total of 26,000 samples per dataset and has accuracy upto 99.7%.

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



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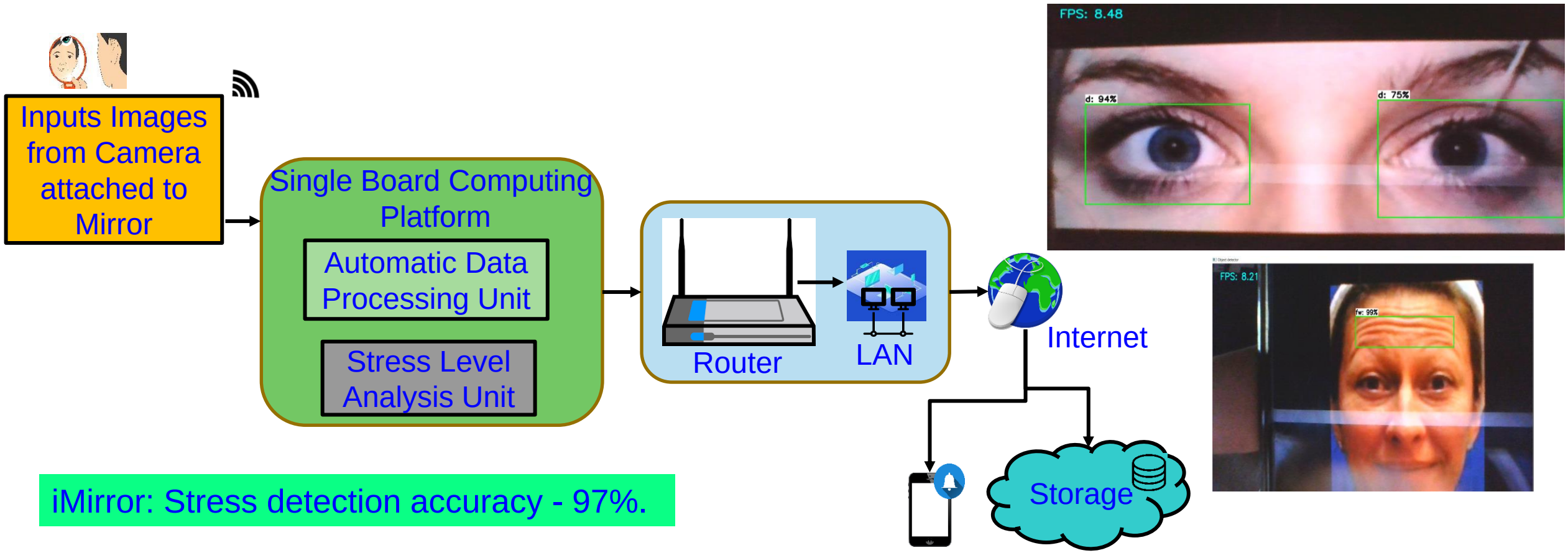
iMirror: Our Smart Mirror for Stress Detection from Facial Features



iMirror: Stress detection accuracy - 97%.

Source: L. Rachakonda, P. Rajkumar, **S. P. Mohanty**, and E. Kougianos, "iMirror: A Smart Mirror for Stress Detection in the IoMT Framework for Advancements in Smart Cities", *Proceedings of the 6th IEEE Smart Cities Conference (ISC2)*, 2020.

Smart-Yoga Pillow (SaYoPillow) - Sleeping Pattern

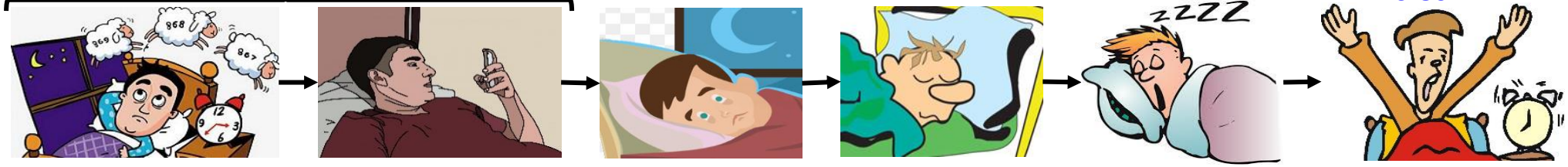
Person On Pillow:
Physiological Sensor Data Monitoring Starts

Person Off Pillow:
Physiological Sensor Data Monitoring Ends

Period 1. Lying on bed but not Sleeping

Period 3: Drift from Wakefulness to Sleep

Period 5: Awake Person



Period 2: Trying to Sleep

Period 4: Deep Sleep

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

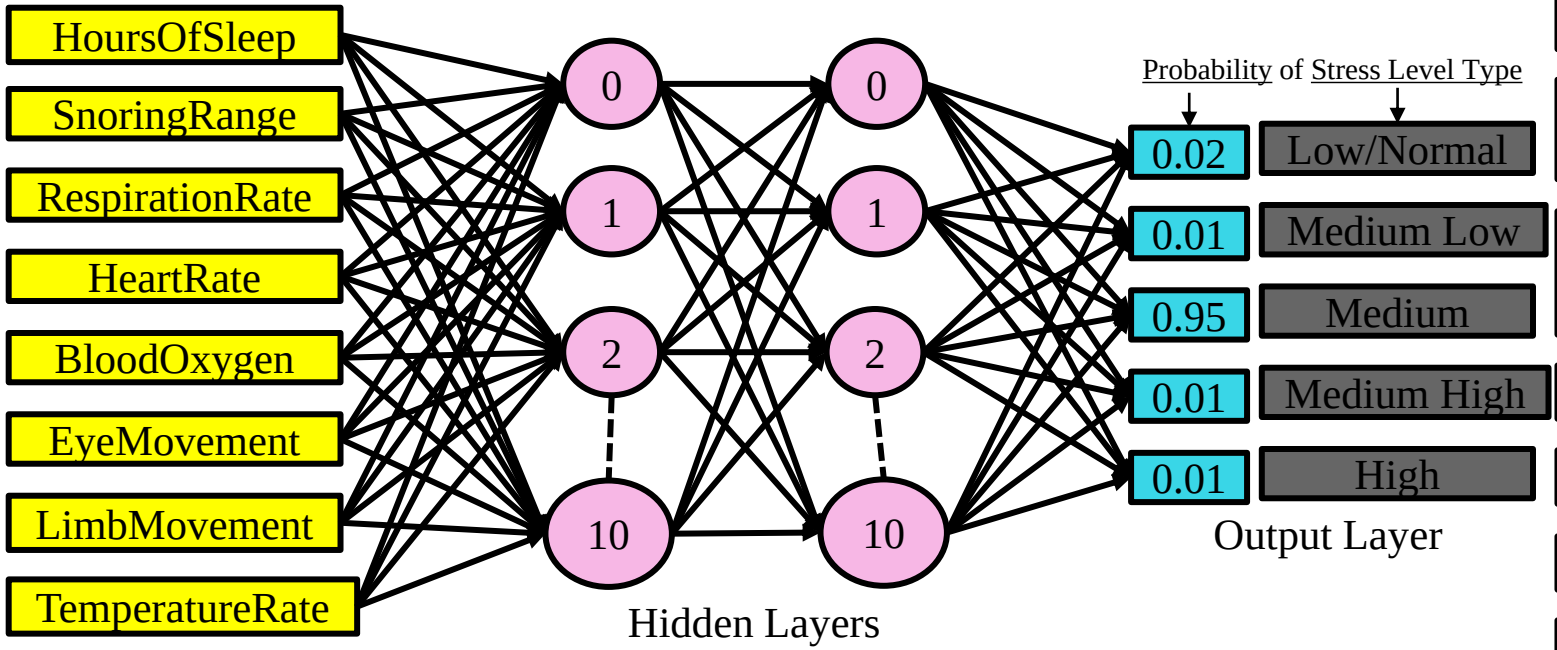
Secure Data Storage

Secure Data Access

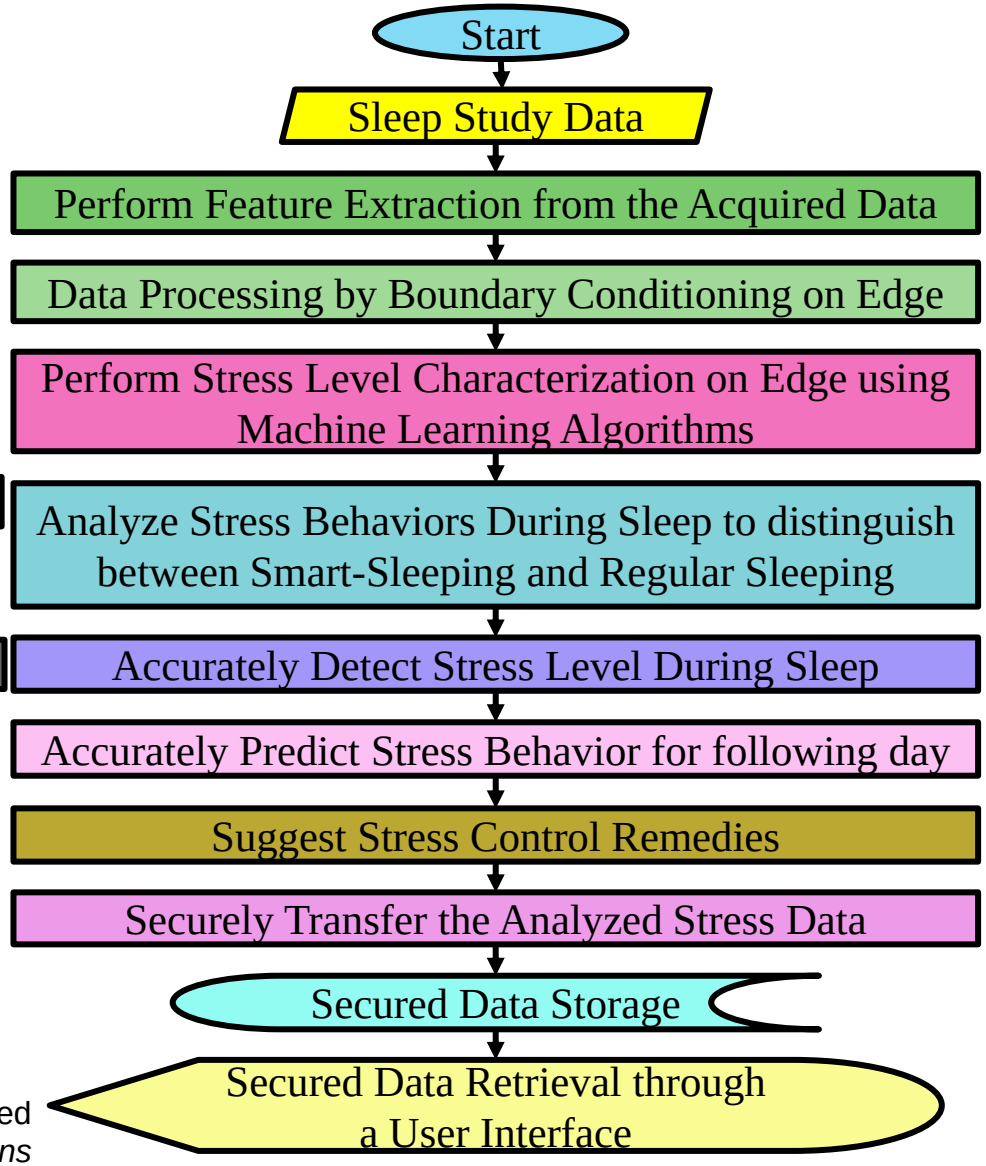
User Applications

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

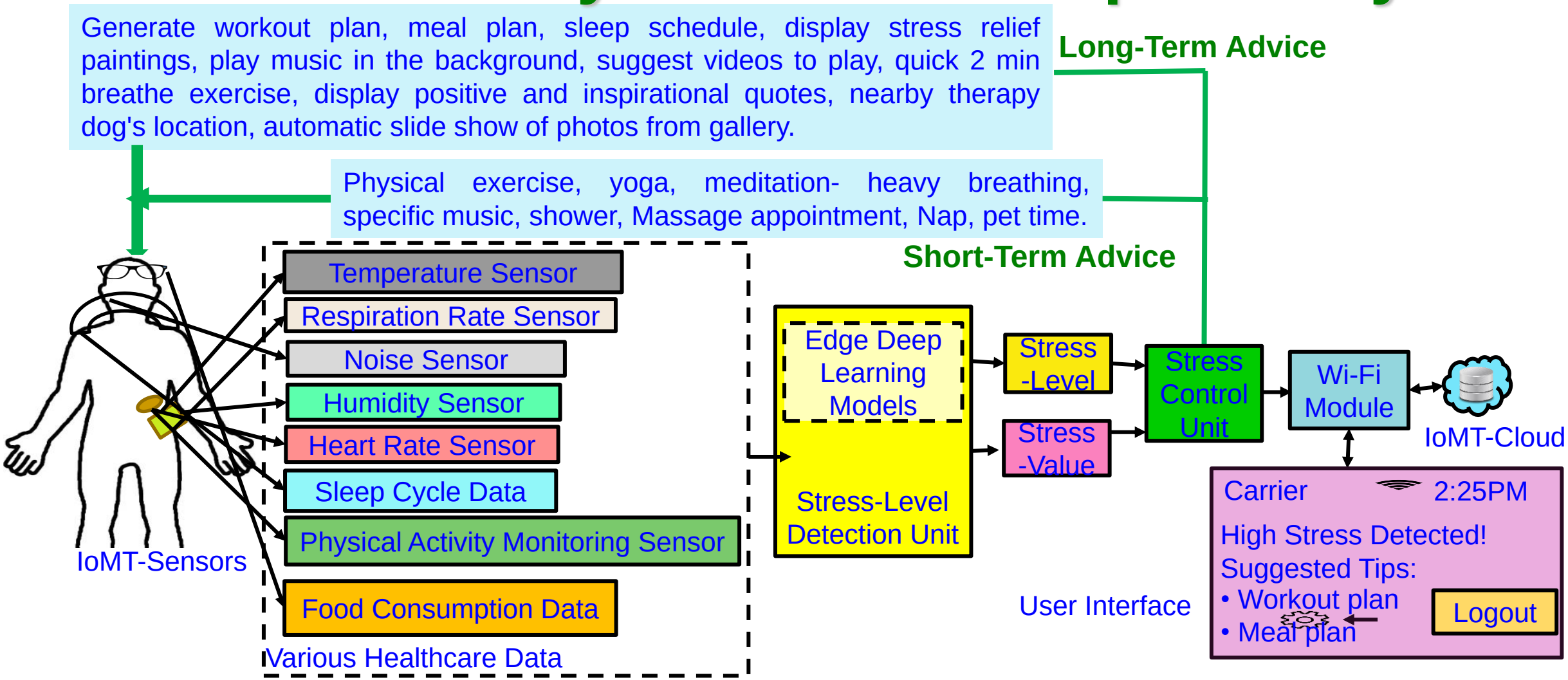


SaYoPillow – Uses deep learning for 96% accuracy with blockchain based security features



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.

Stress Control by iFeliz: Our 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: Stress Control Approaches

Smart Devices

Classified Stress Level Data

Live Approach

Day-End Approach

Weekly Approach

Monthly Approach

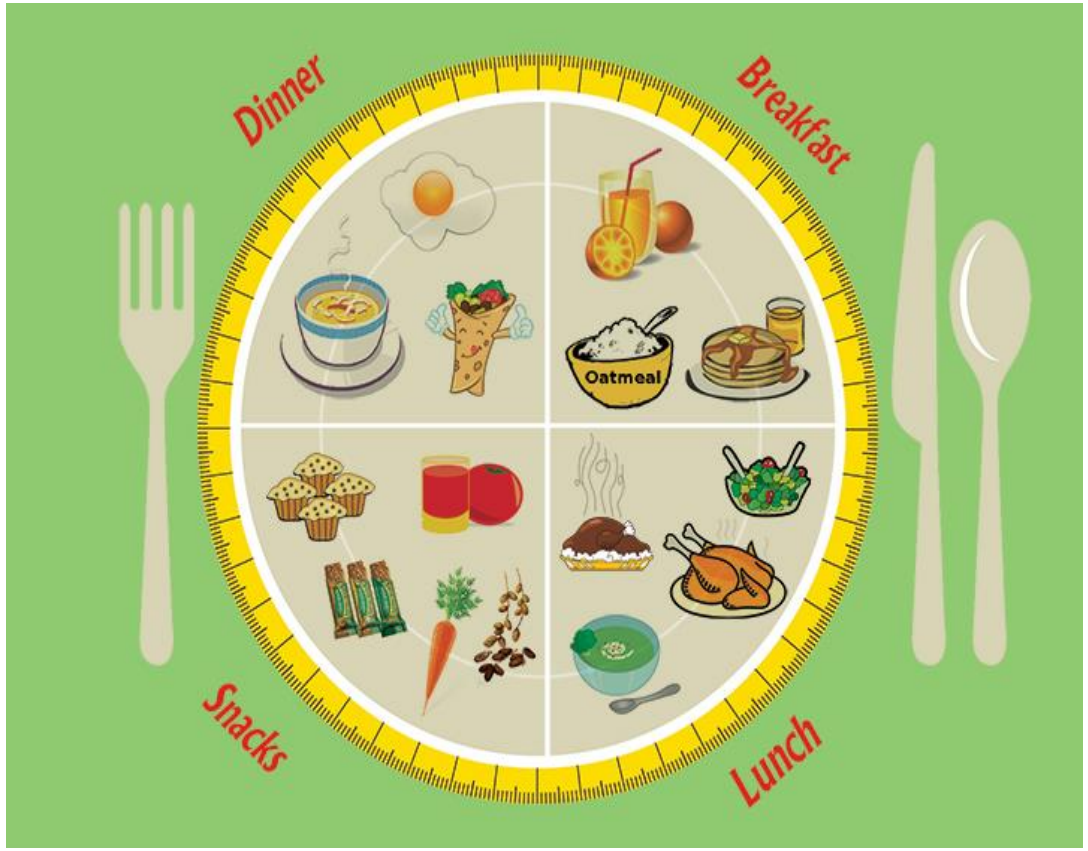
Short-Term Remedies

Long-Term Remedies

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.

Automatic Food Intake Monitoring and Diet Management is Important

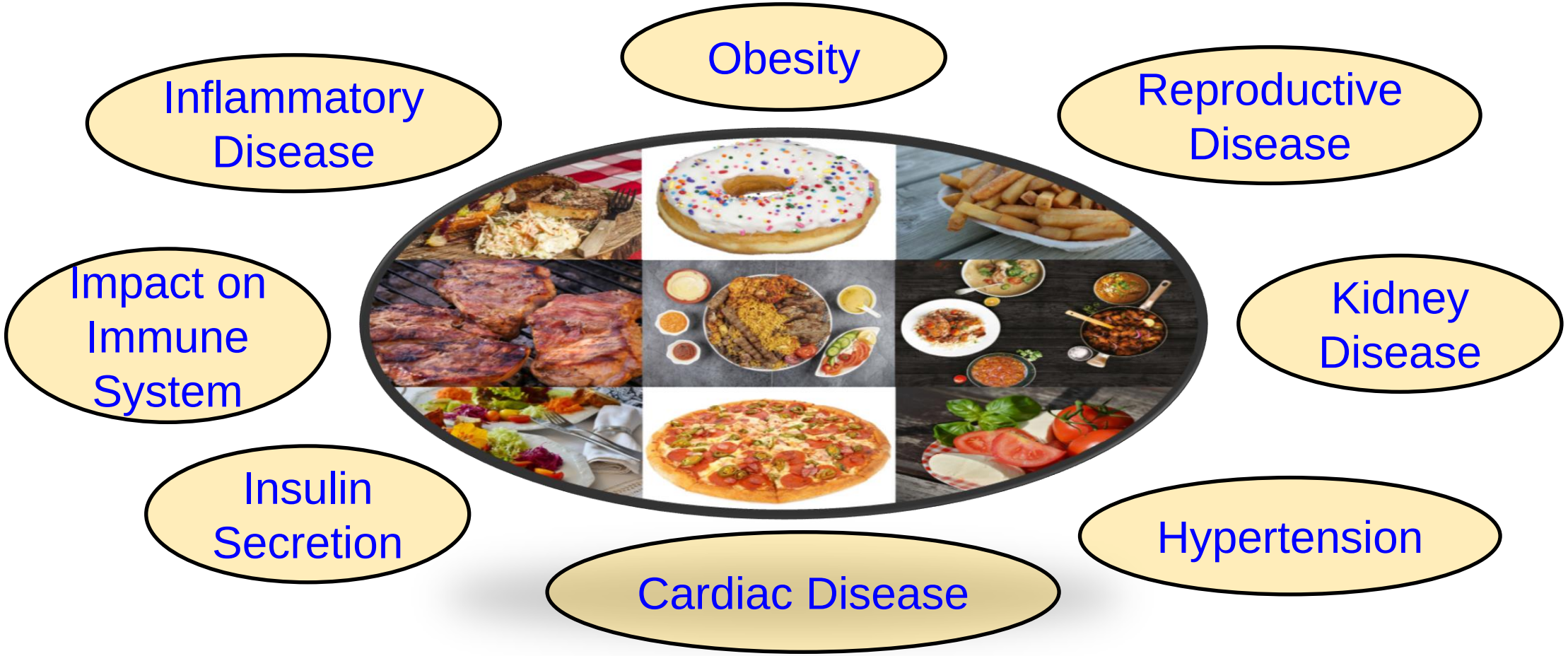


Imbalance Diet is a Global Issue

- 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:

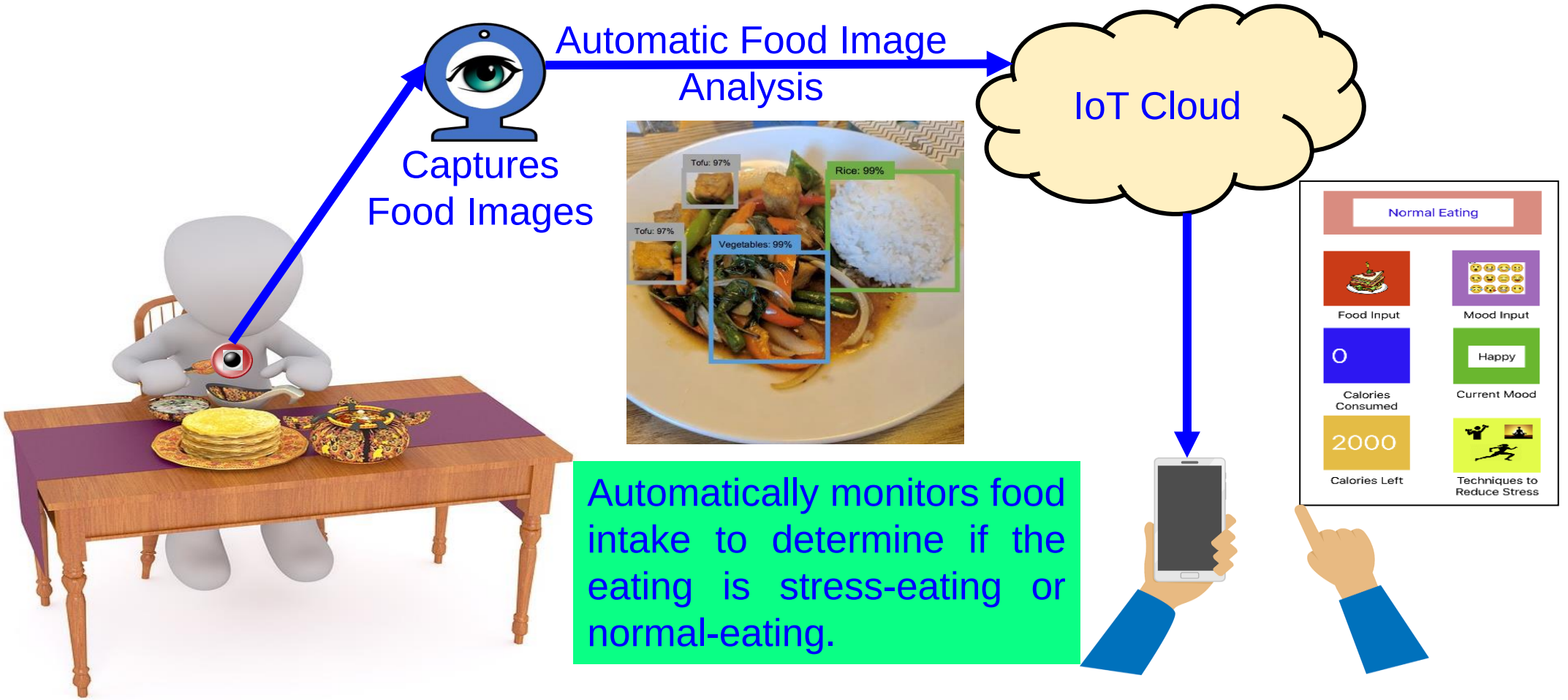
Source: https://obesity-diet.nutritionalconference.com/events-list/imbalanced-diet-effects-and-causes
https://www.thelancet.com/article/S0140-6736(19)30041-8/fulltext

Imbalance Diet – Impact on Hunan Body



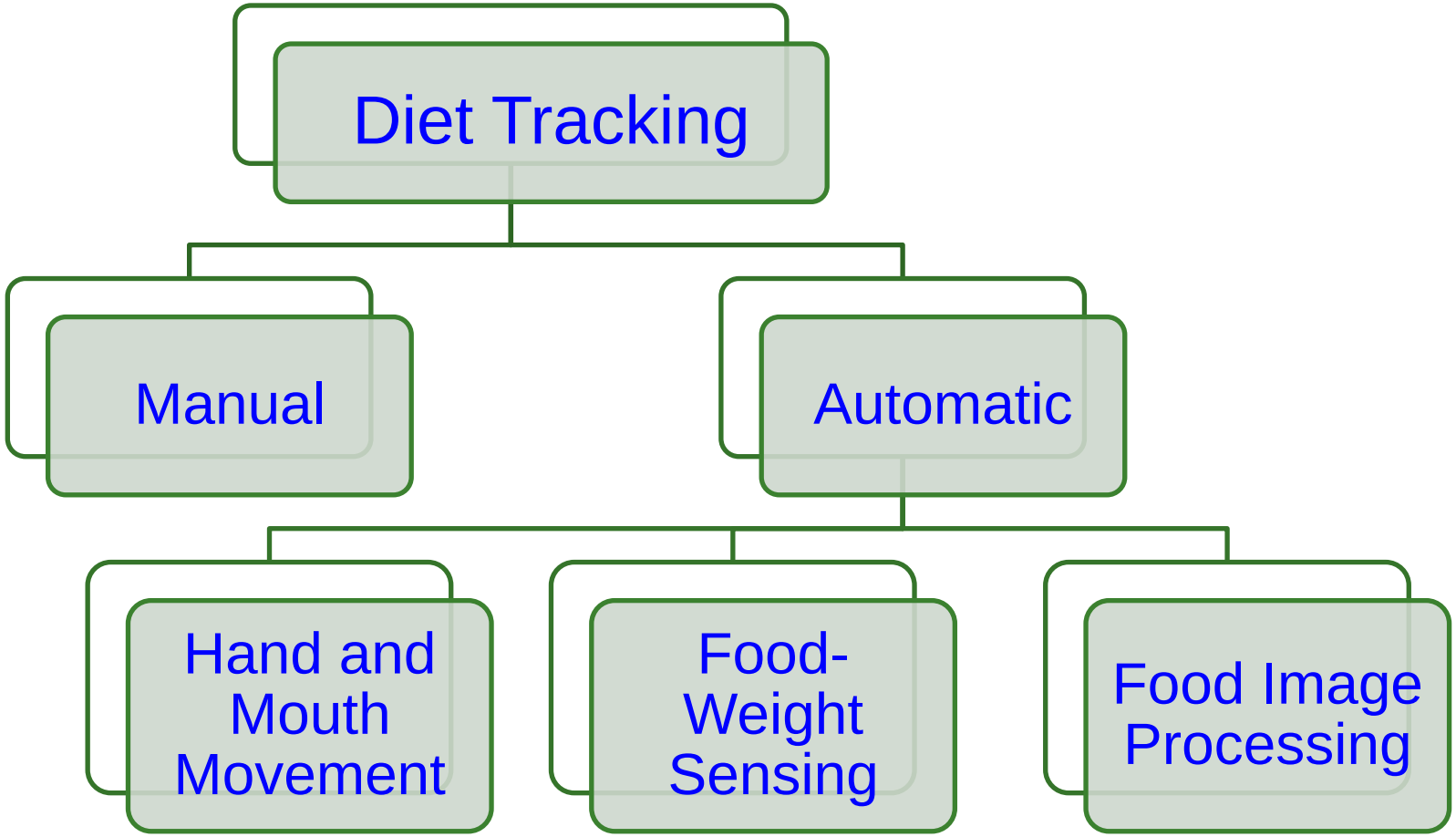
Source: A. Mitra, S. Goel, **S. P. Mohanty**, E. Kougianos, and L. Rachakonda, "iLog 2.0: A Novel Method for Food Nutritional Value Automatic Quantification in Smart Healthcare", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Automatic Diet Monitoring & Control - Our Vision



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.

Diet Tracking Approaches



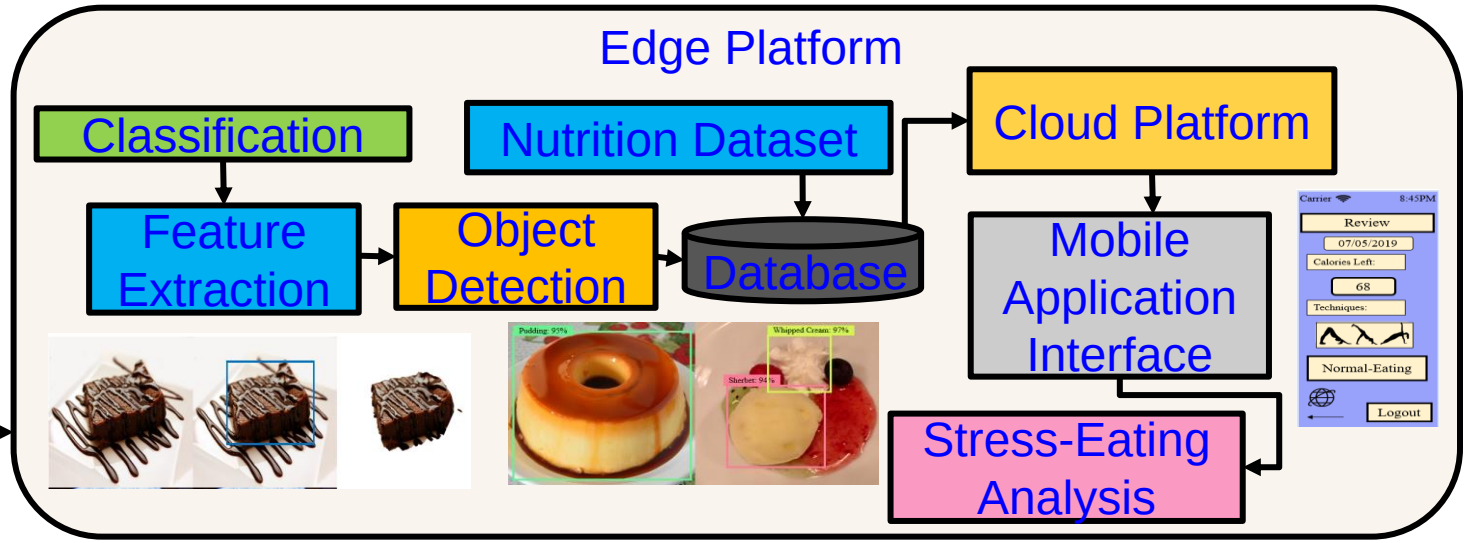
Food Tracking Apps

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	

Smart Healthcare – Diet Monitoring - iLog

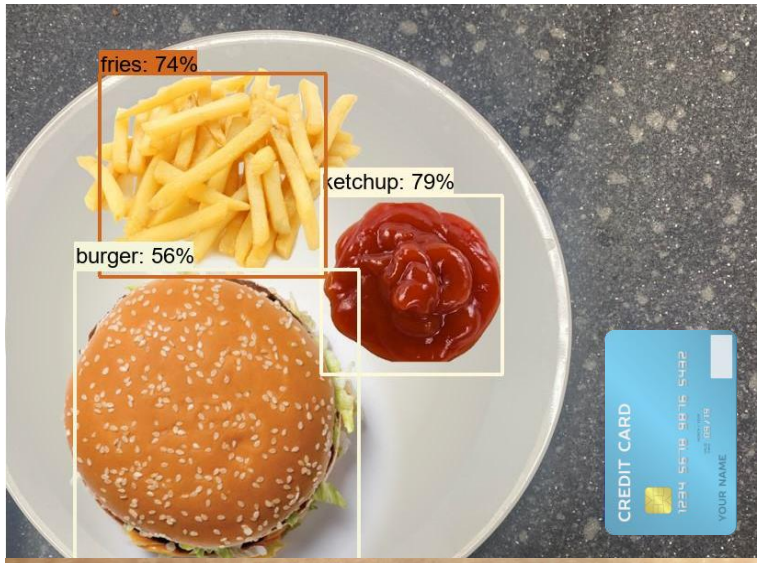
Reference Image



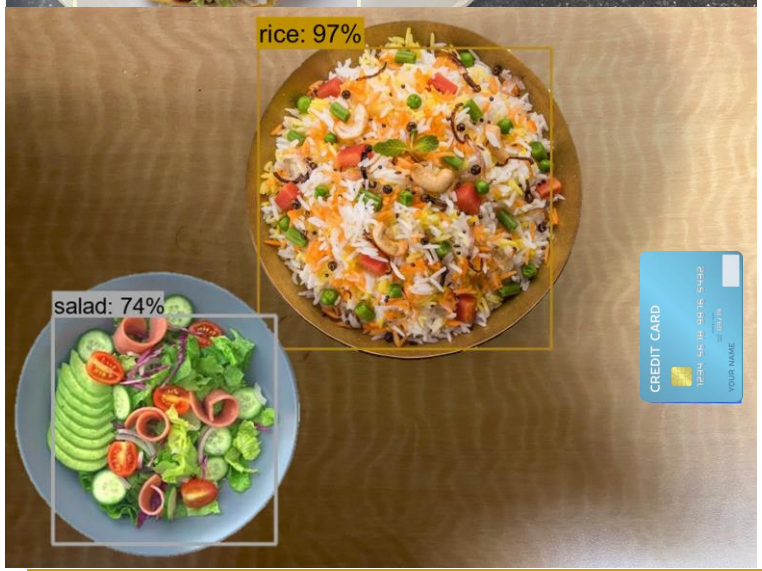
iLog- Fully Automated Detection System with 98% accuracy.

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 - Diet Monitoring - iLog 2.0



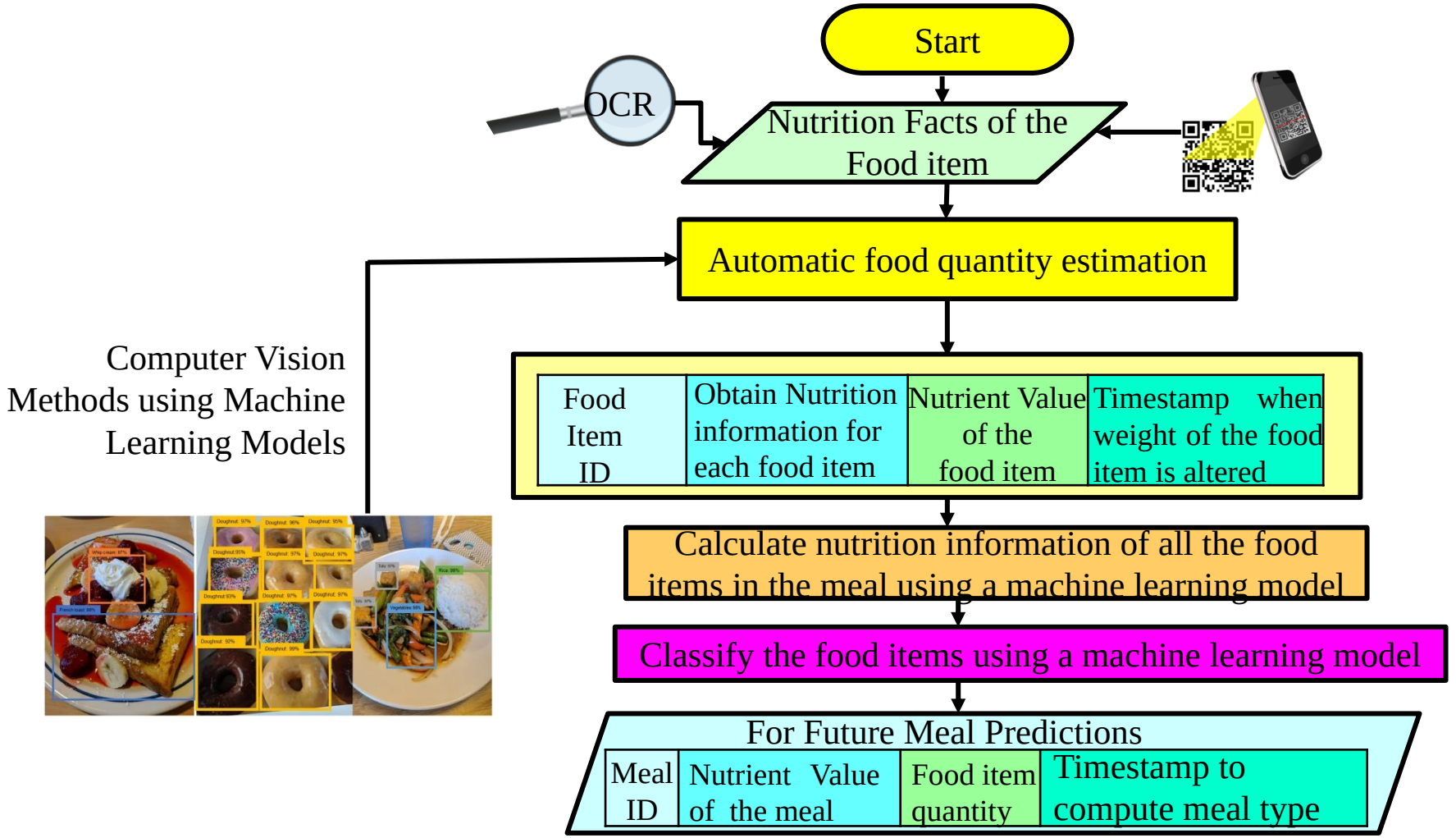
Food Item	Saturated Fat (g)	Sugar (g)	Sodium (mg)	Protein (g)	Carbohydrates (g)
Fries	6.44	1.56	244	4.03	34.84
Burger	6.87	4.67	481	17.29	48.14
Ketchup	0	3.2	136	0.2	4.13
Total	13.31	9.43	861	21.52	87.11



Food Item	Saturated Fat (g)	Sugar (g)	Sodium (mg)	Protein (g)	Carbohydrates (g)
Rice	0.3	0.3	6	12.9	135
Salad	0.8	3.9	264	1.1	7
Total	1.1	4.2	270	14	142

Source: A. Mitra, S. Goel, **S. P. Mohanty**, E. Kougianos, and L. Rachakonda, "iLog 2.0: A Novel Method for Food Nutritional Value Automatic Quantification in Smart Healthcare", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

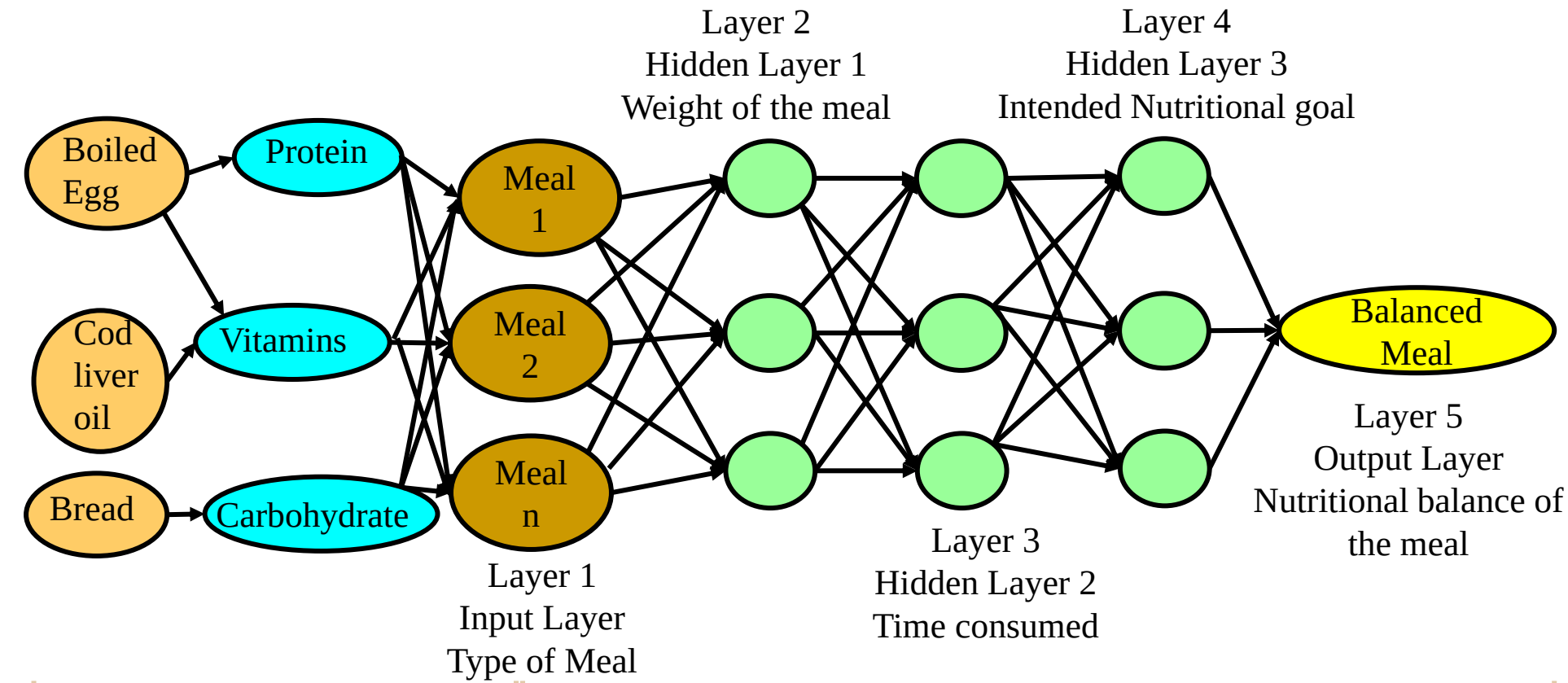
Smart Healthcare – Diet Prediction – Smart-Log



Smart-Log Prediction Accuracy - 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)*, 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.

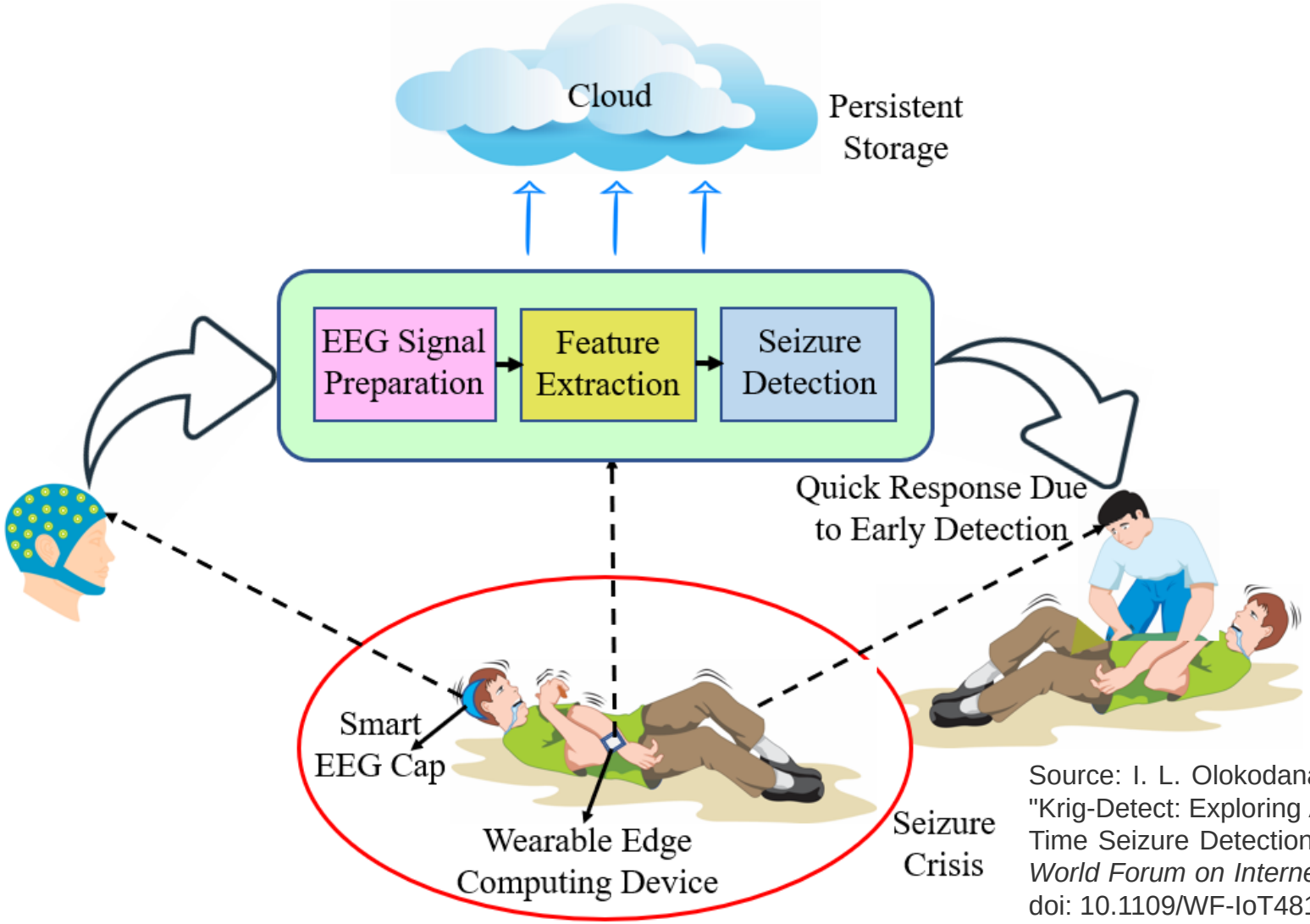
Epileptic Seizure Has Global Impact

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

- 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).

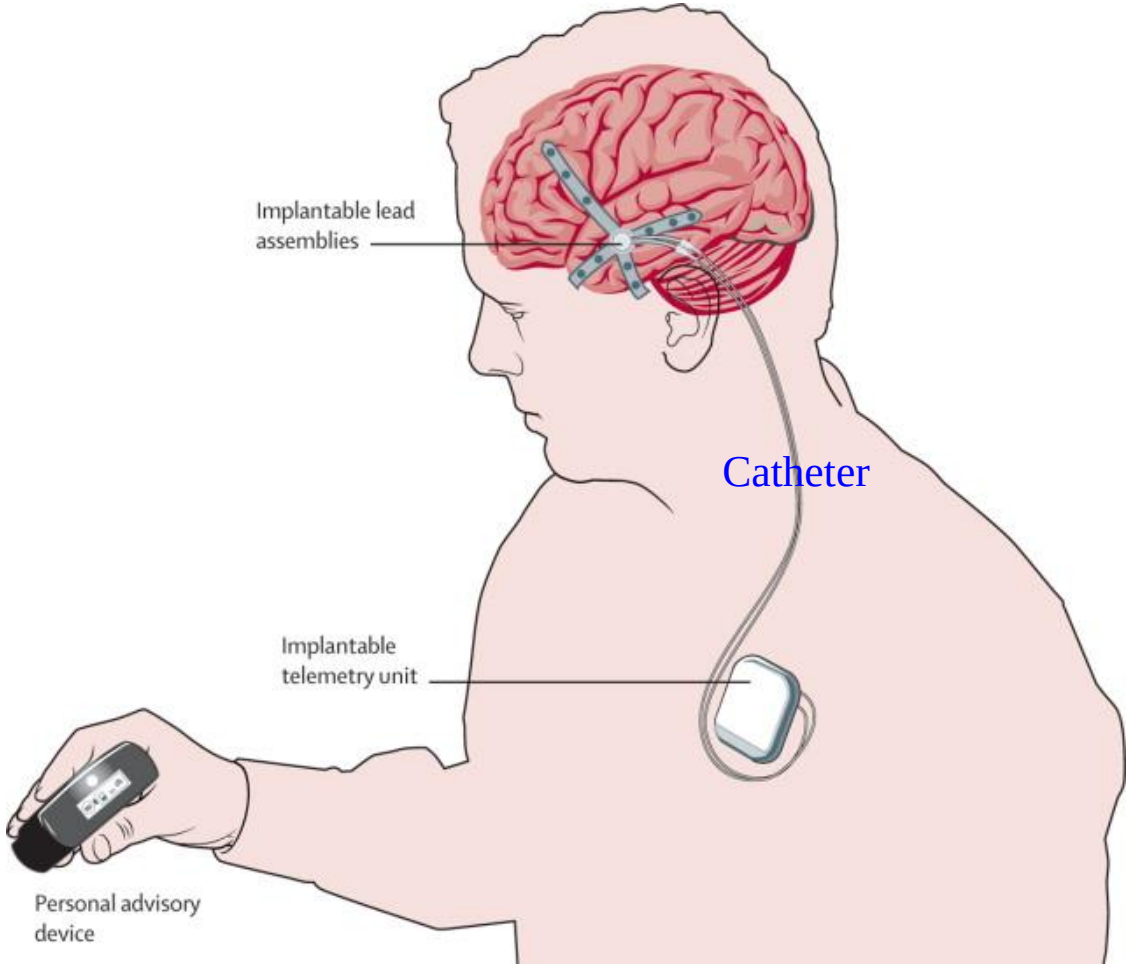
Source: https://www.epilepsy.com/learn/about-epilepsy-basics/epilepsy-statistics

Epileptic Seizure - Our Vision



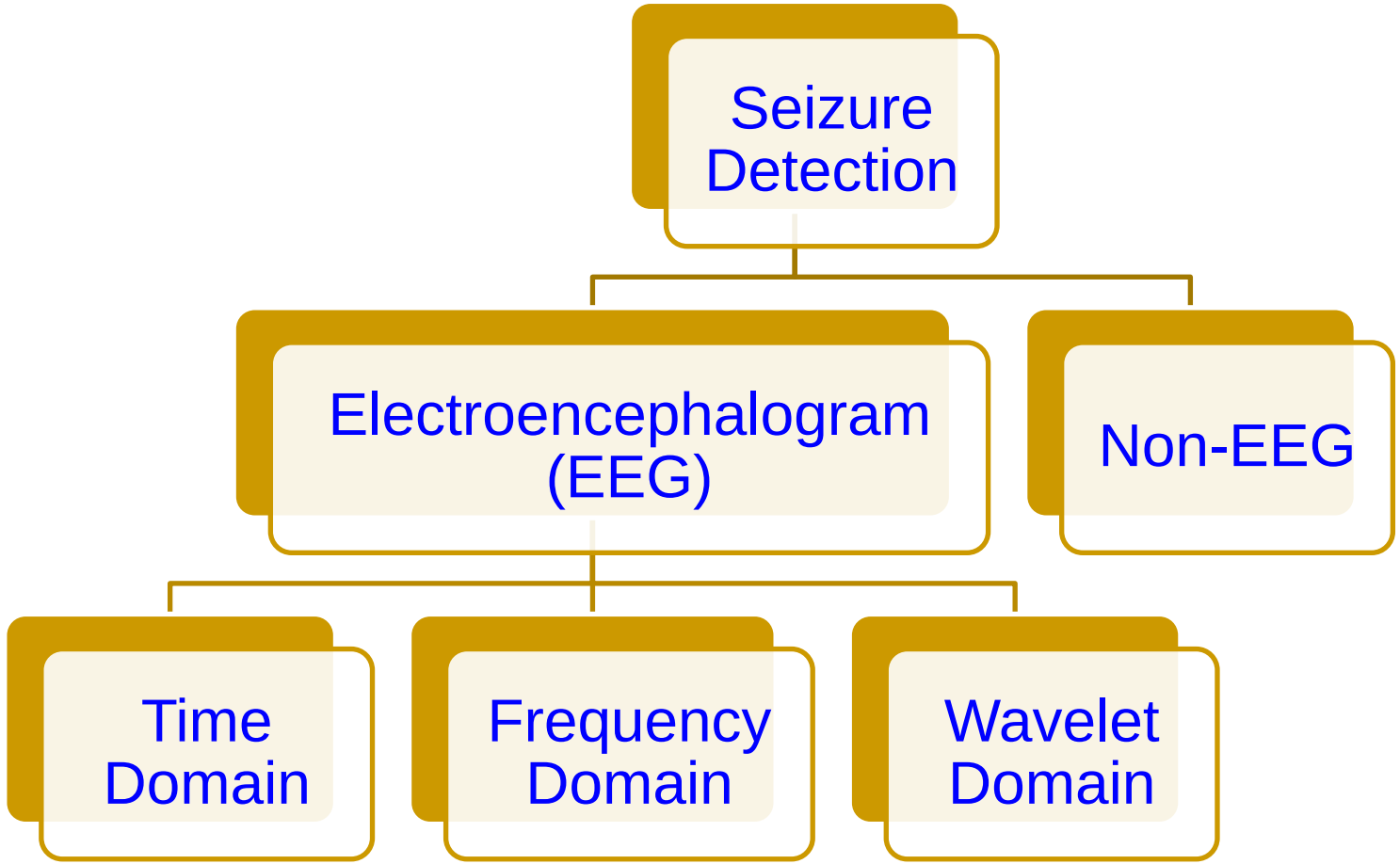
Source: I. L. Olokodana, S. P. Mohanty and E. Kougianos, "Krig-Detect: Exploring Alternative Kriging Methods for Real-Time Seizure Detection from EEG Signals," *2020 IEEE 6th World Forum on Internet of Things (WF-IoT)*, 2020, pp. 1-6, doi: 10.1109/WF-IoT48130.2020.9221260.

Implantable for Seizure Detection and Control



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

Seizure Detection Methods



Consumer Electronics for Seizure Detection

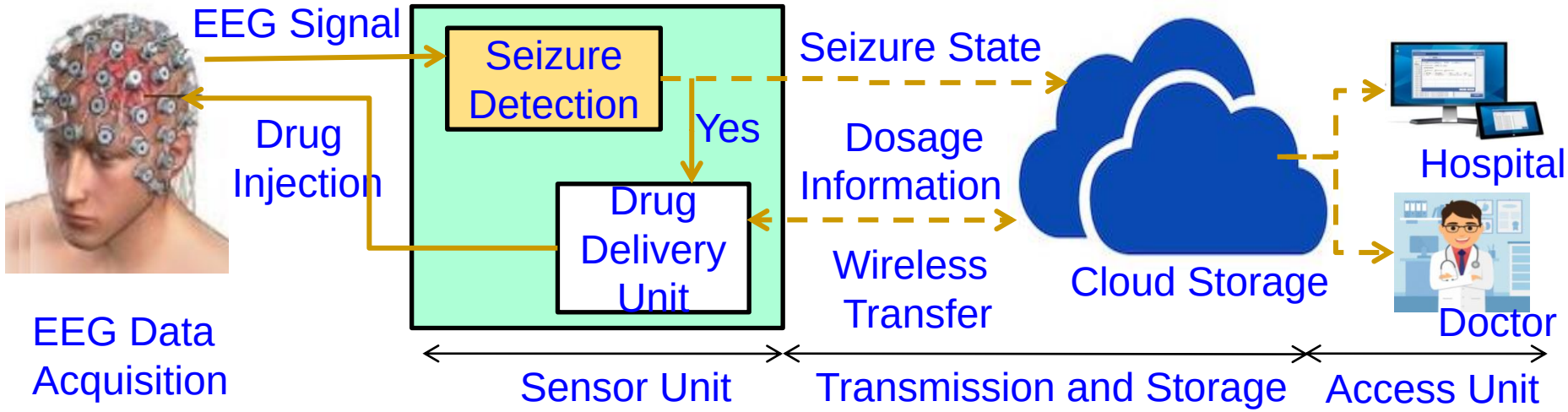
Source: https://spectrum.ieee.org/the-human-os/biomedical/diagnostics/this-seizuredetecting-smartwatch-could-save-your-life

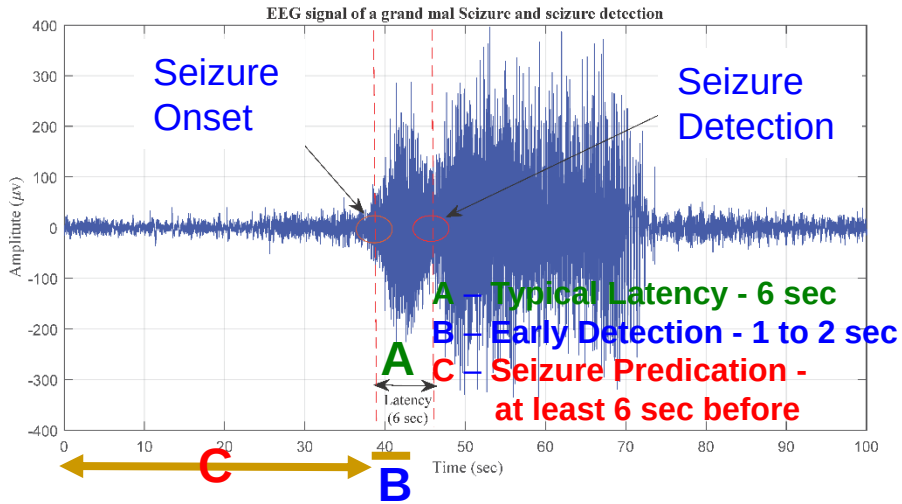
- Embrace2: Smart-band which uses machine learning to detect convulsive Seizures and notifies caregivers.

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

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

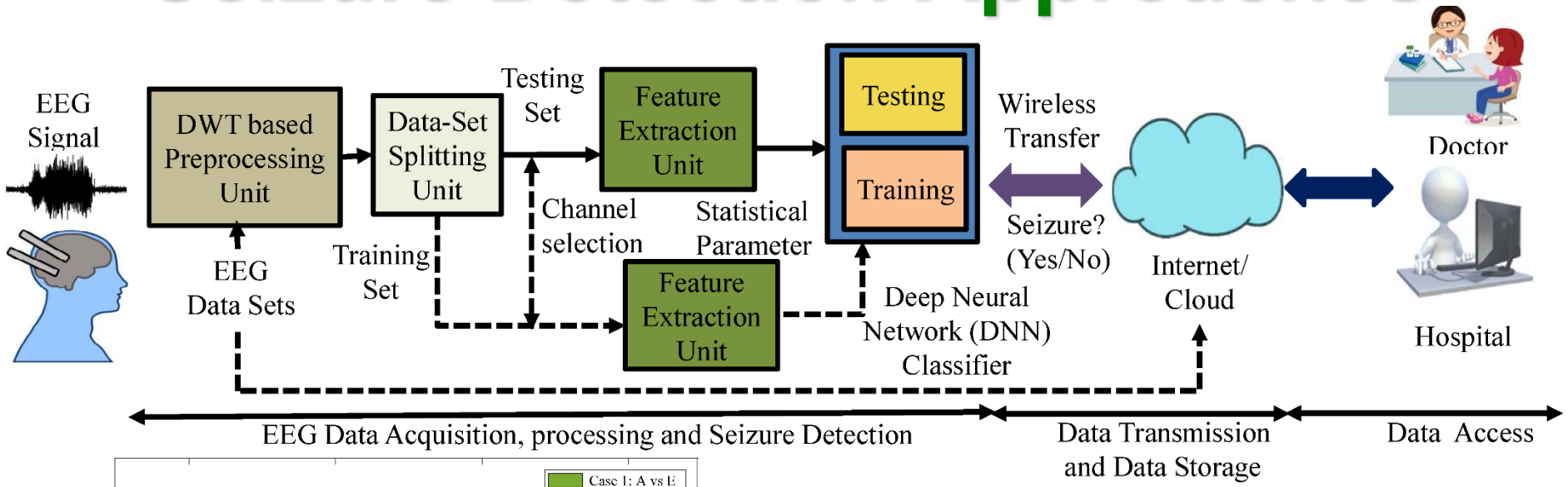
Smart Healthcare - Seizure Detection & Control

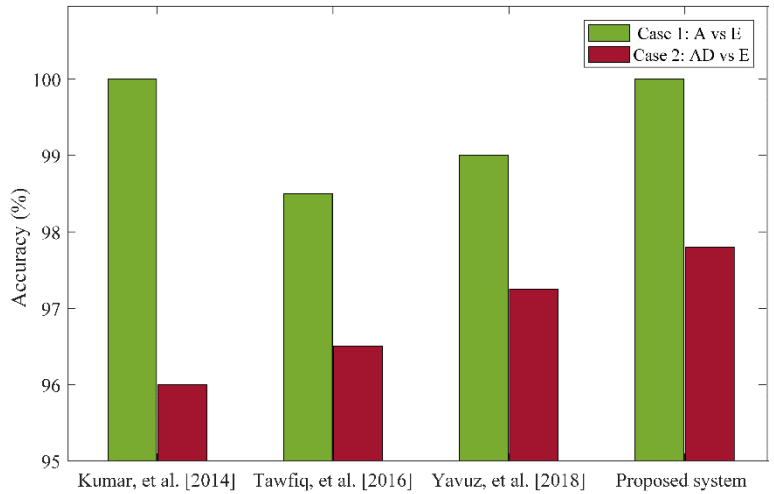




Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "eSeiz: An Edge-Device for Accurate Seizure Detection for Smart Healthcare", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 379--387.

Seizure Detection Approaches



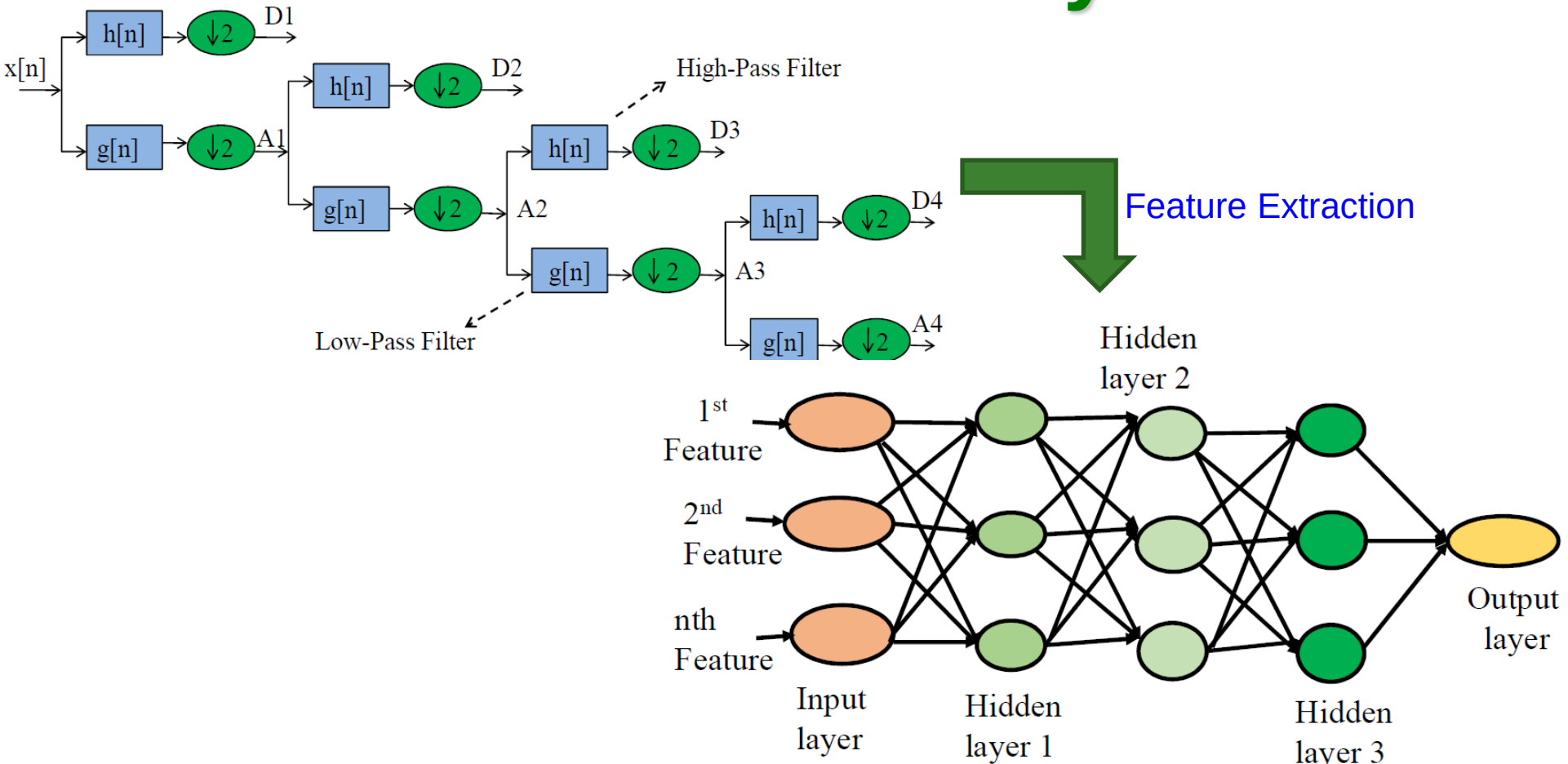


Cloud Vs Edge Computing

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

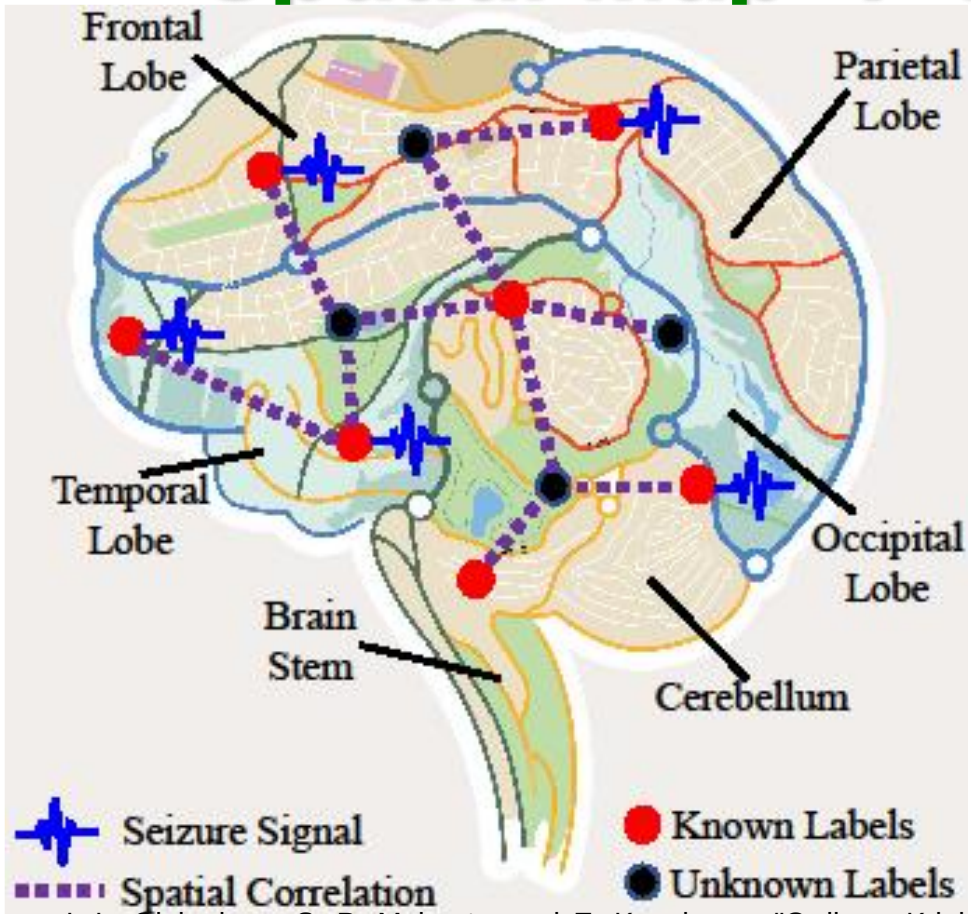
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 3, Aug 2019, pp. 359--368.

Our Neuro-Detect : A ML Based Seizure Detection System

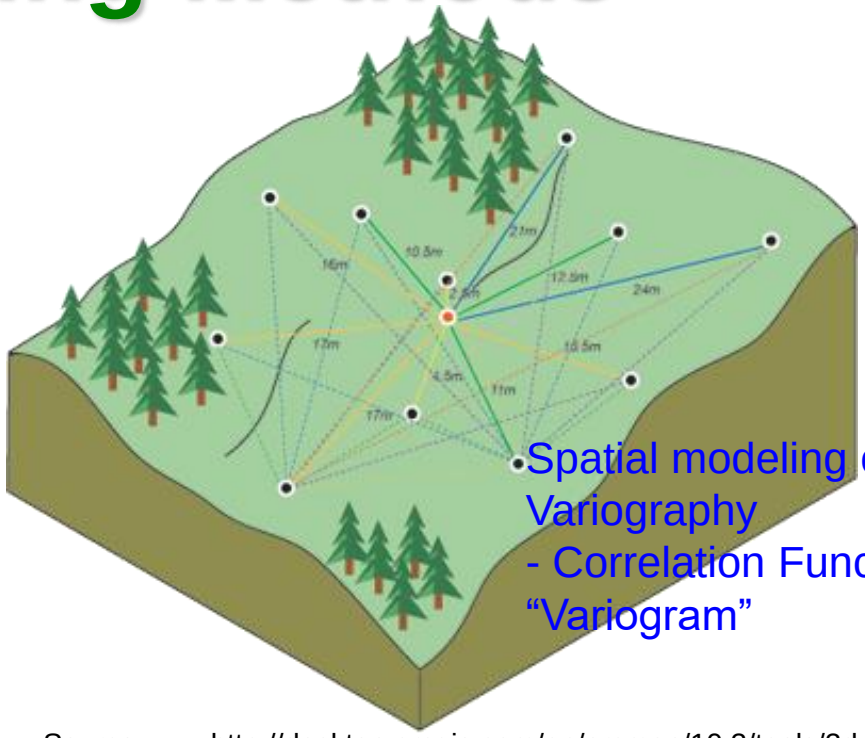


Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri , "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, Issue 3, Aug 2019, pp. 359-368.

Smart Healthcare – Brain as a Spatial Map → Kriging Methods



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.

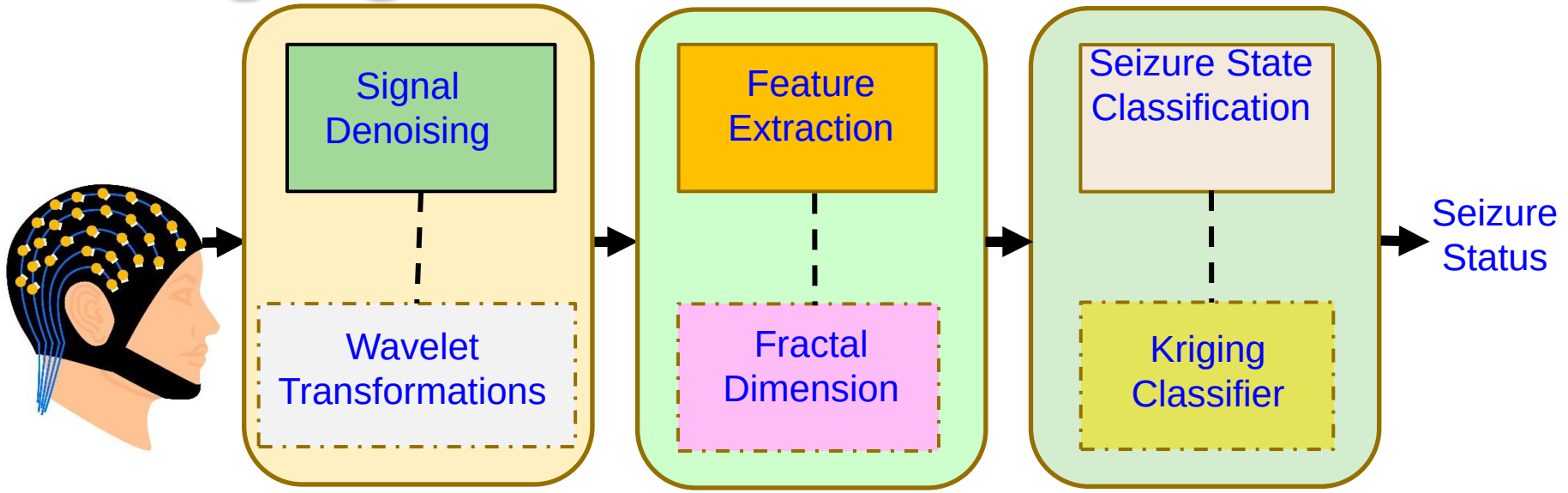


Spatial modeling or Variography
- Correlation Function is "Variogram"

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

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

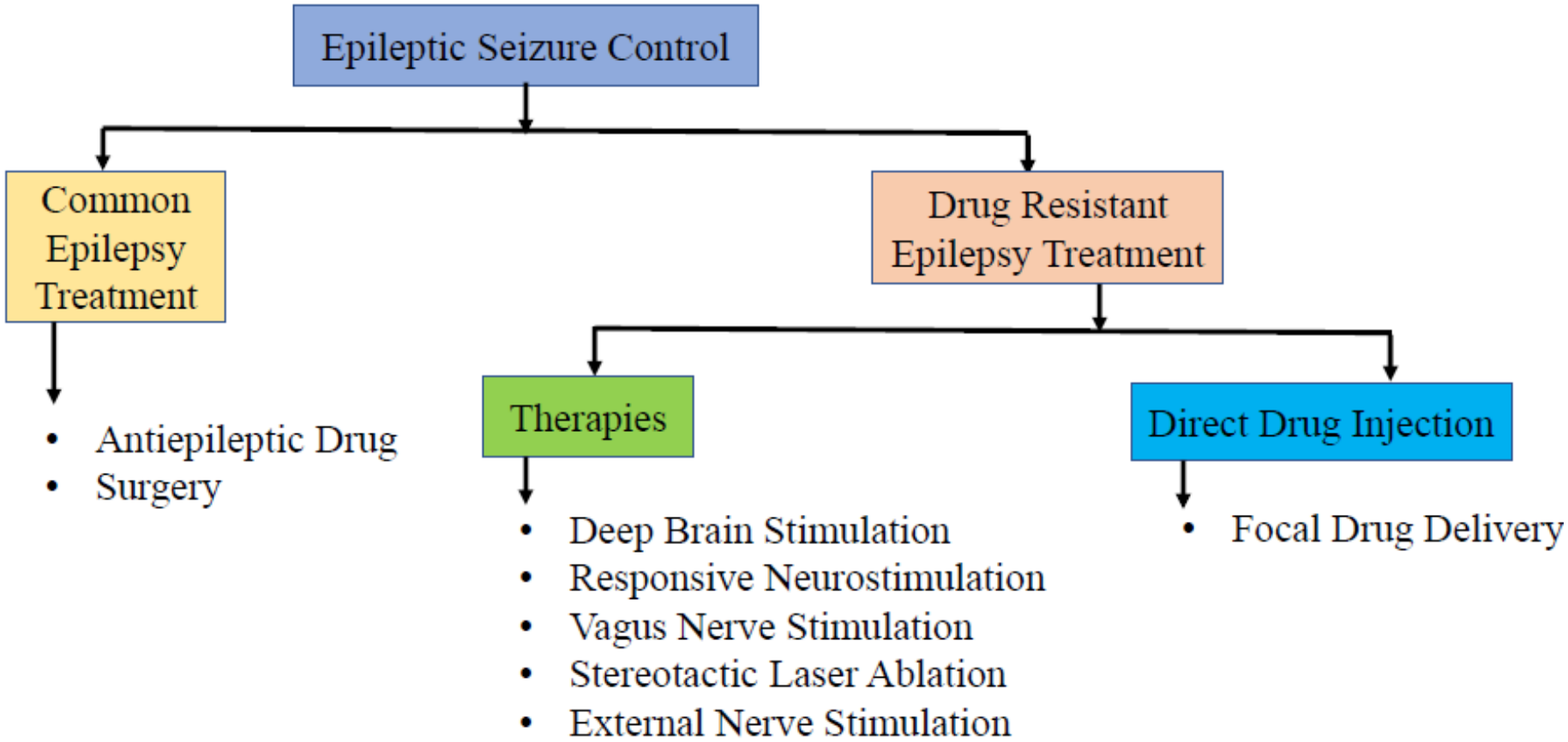
Kriging based Seizure Detection



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

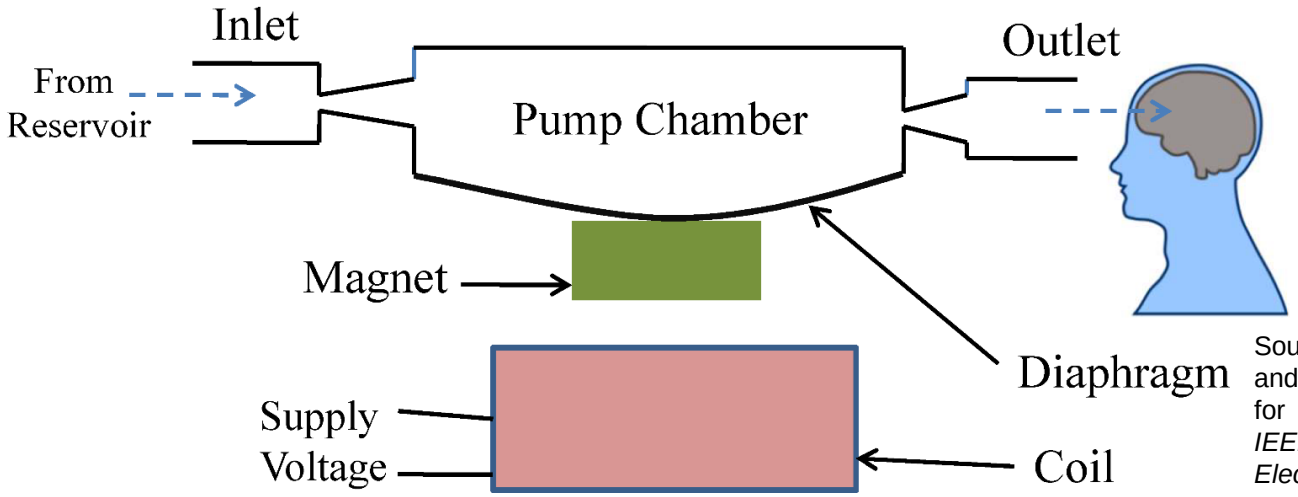
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Ordinary-Kriging Based Real-Time Seizure Detection in an Edge Computing Paradigm", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

Seizure Control Methods



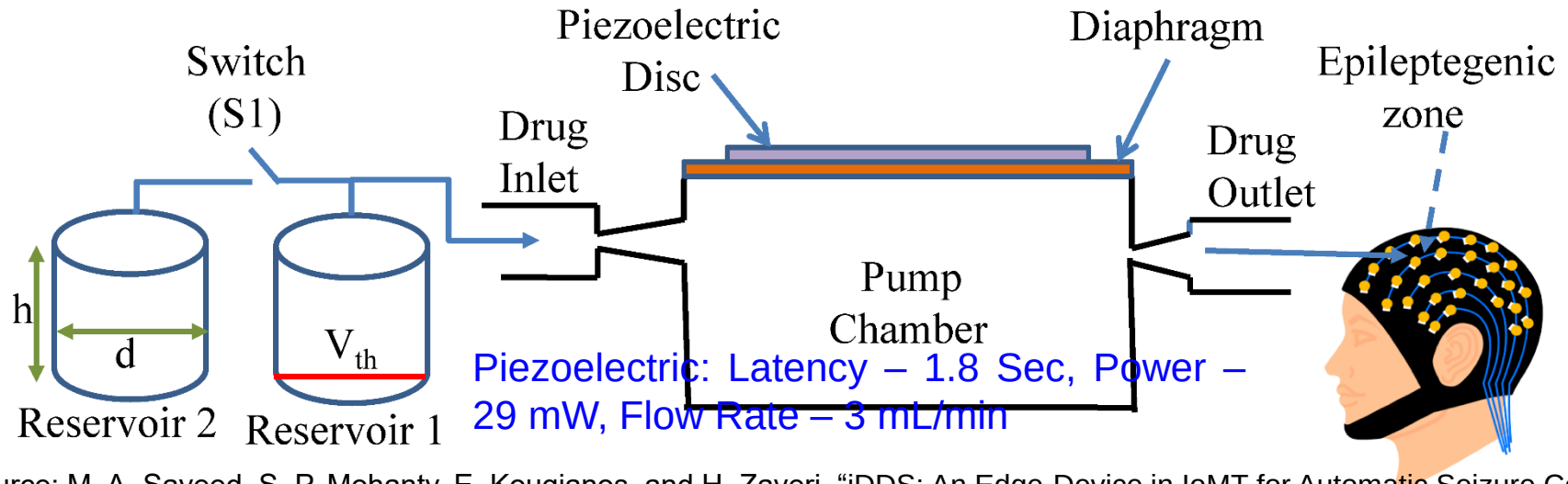
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

Seizure Control Methods



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

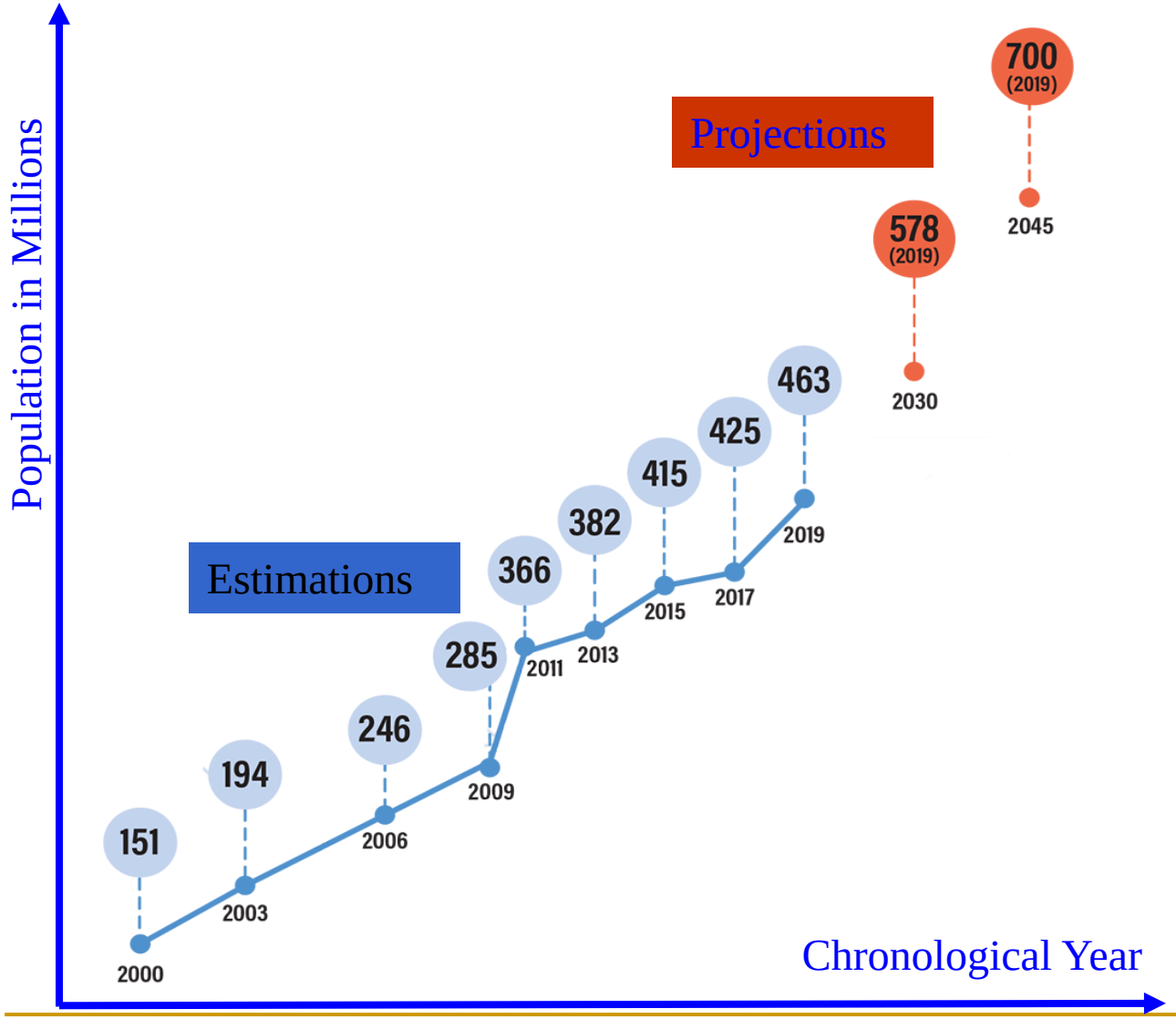
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "An IoT-based Drug Delivery System for Refractory Epilepsy", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.



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

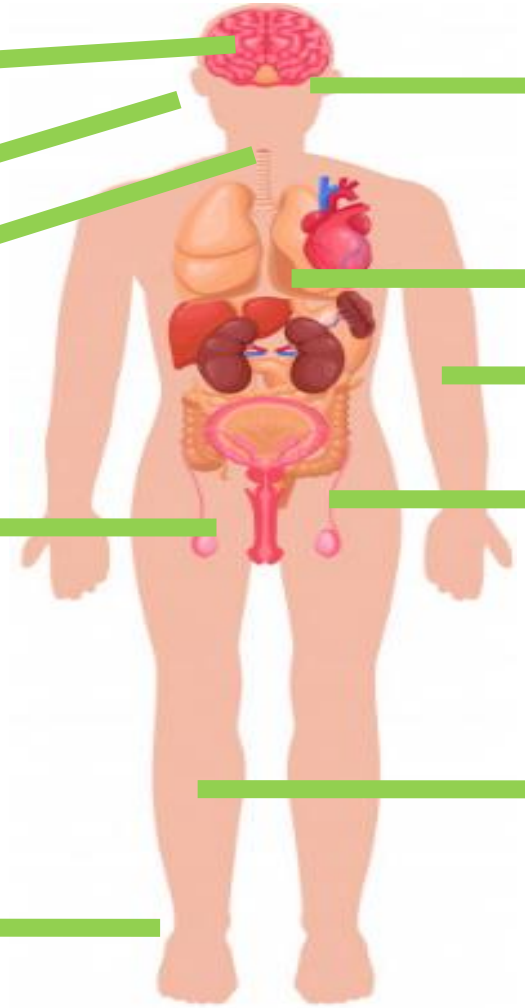
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, “iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

Diabetes is a Global Crisis



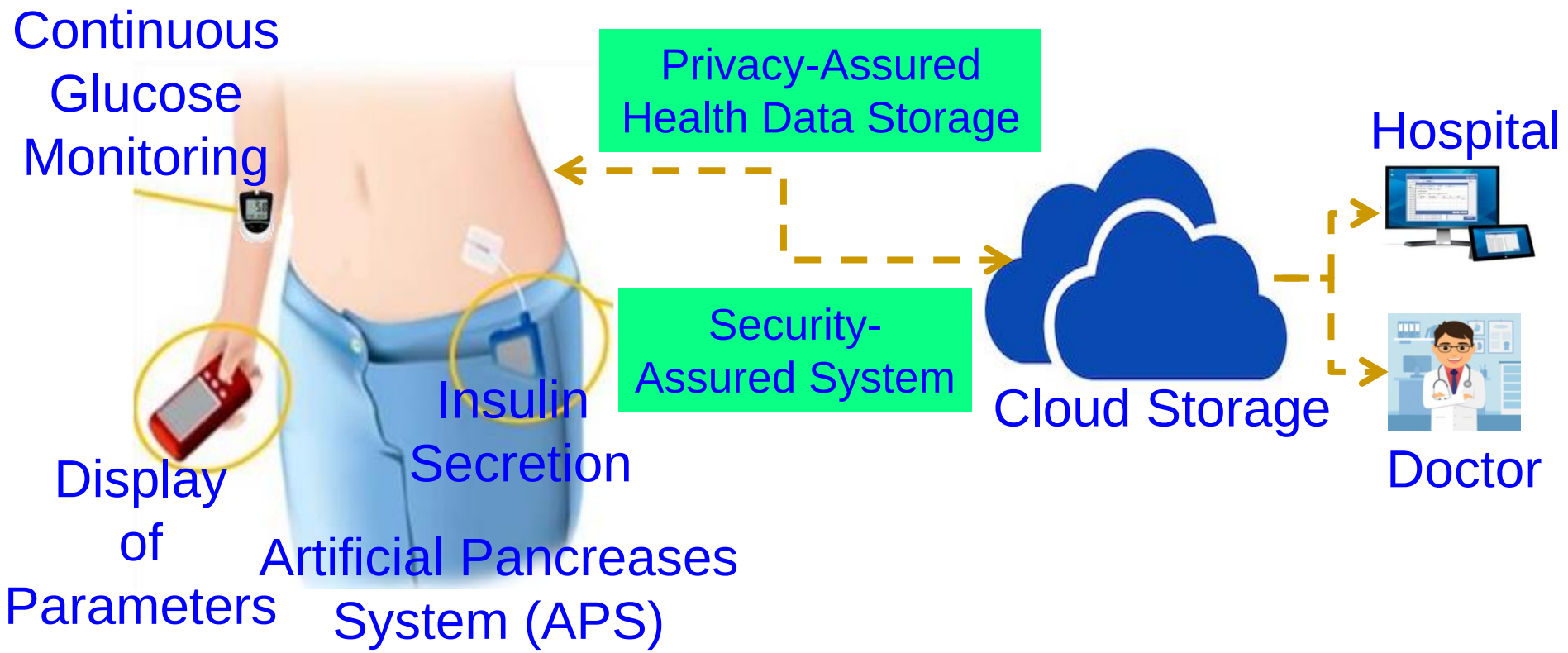
Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

Diabetes – Impact on Human Body

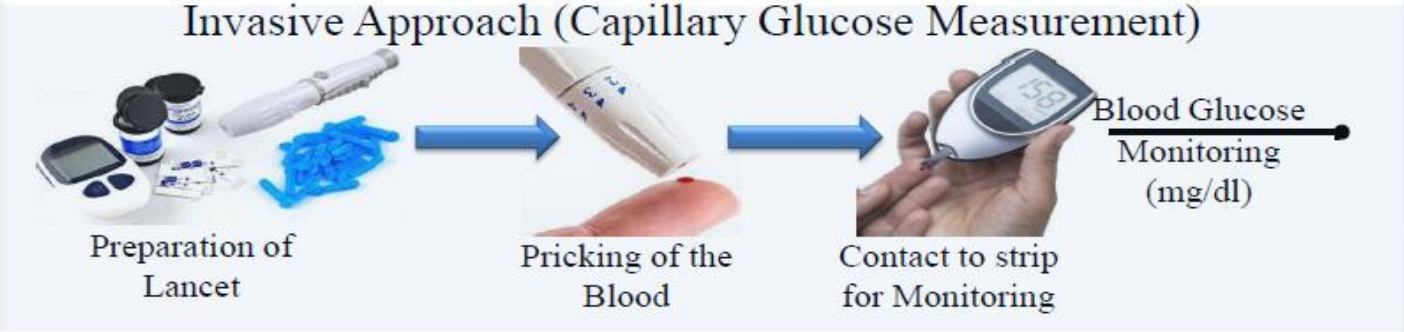


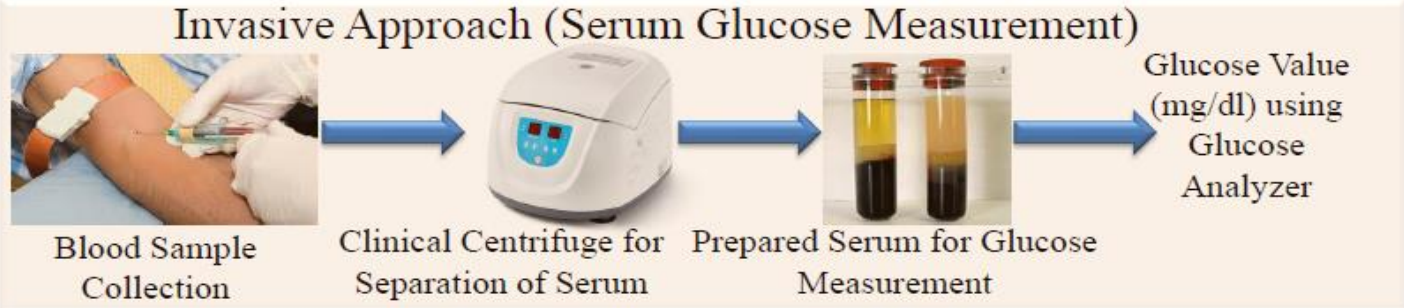
- Alzheimer's disease
- Hearing impairment
- Gum Disease & Other Dental Problems
- Sexual, & Bladder Problems
- Foot damage
- Eye damage (retinopathy)
- Cardiovascular disease
- Skin conditions
- Kidney damage (nephropathy)
- Nerve damage (neuropathy)

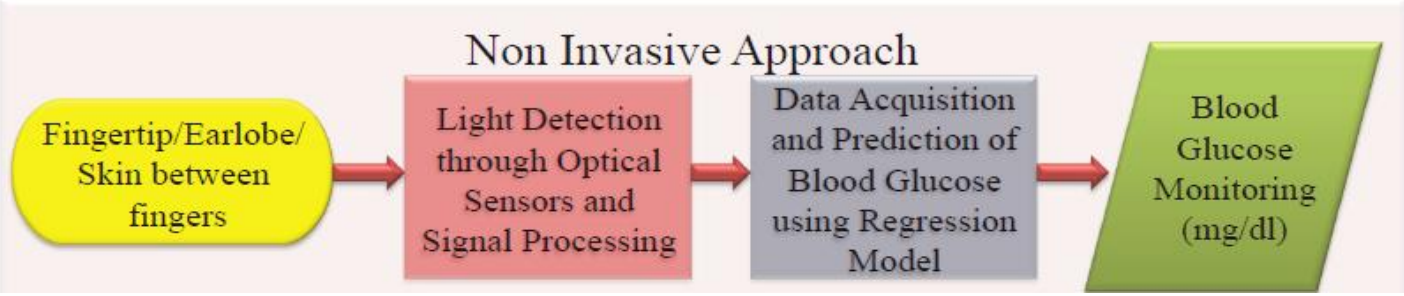
Automatic Glucose Monitoring and Control - Our Vision - iGLU (Intelligent Noninvasive)



Blood Glucose Monitoring – Invasive Vs Noninvasive







Traditional – Finger Pricking

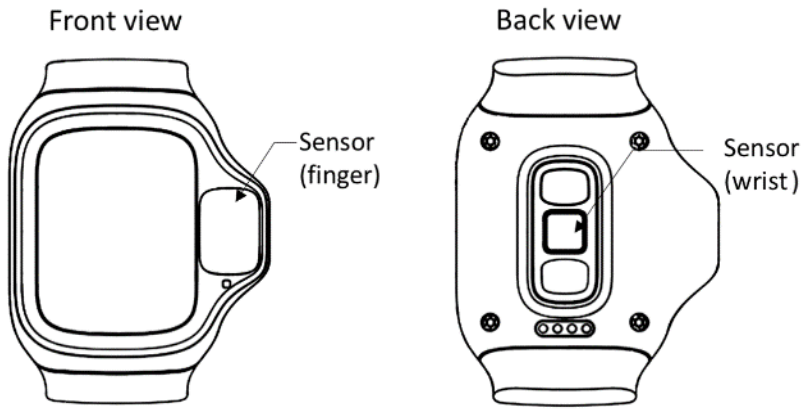
Invasive Approach – Processing Blood/Serum

Noninvasive – Wearable

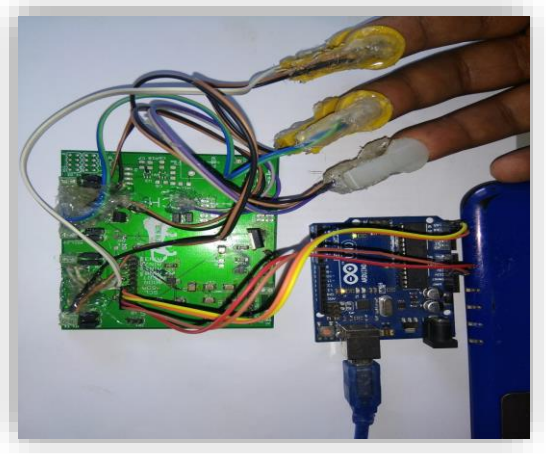
Noninvasive Approach – Processing Light

Source: P. Jain, A. M. Joshi, and S. P. Mohanty, "Everything You Wanted to Know About Noninvasive Glucose Measurement and Control", *arXiv Physics*, arXiv:2101.08996, January 2021, 51-pages.

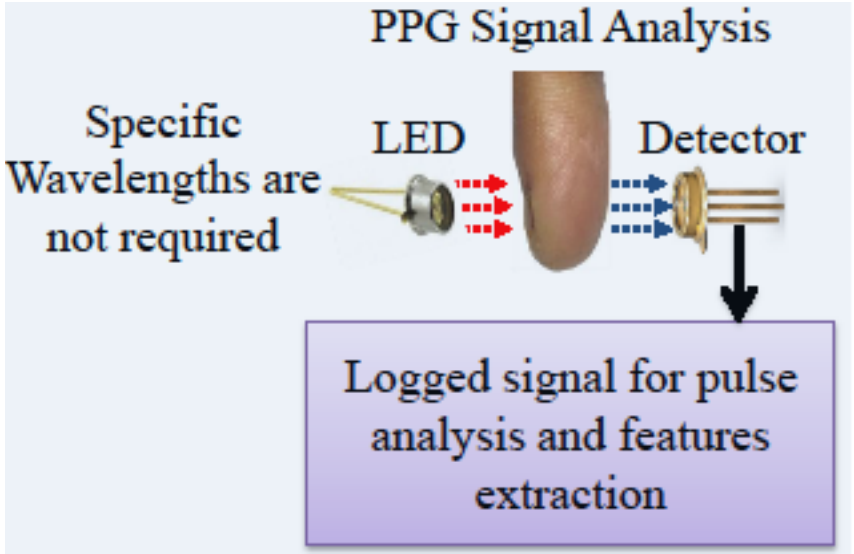
Noninvasive Glucose-Level Monitoring

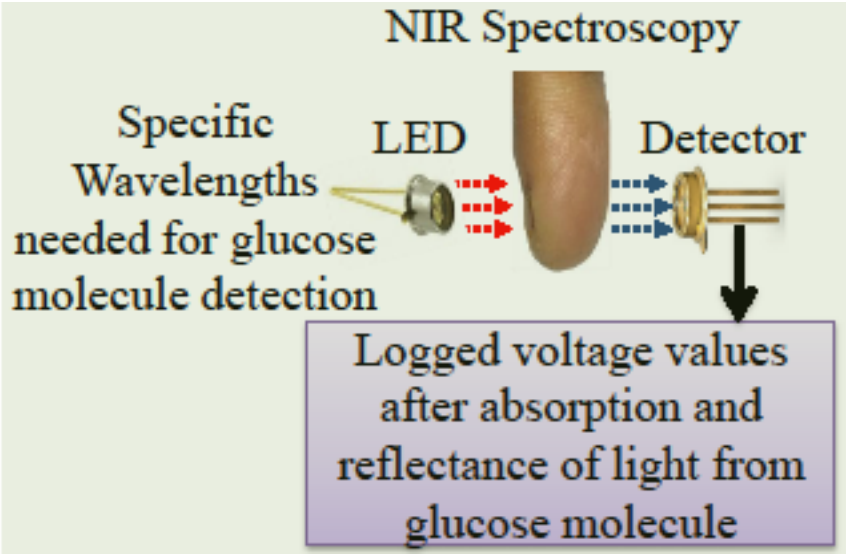


Photoplethysmogram (PPG)

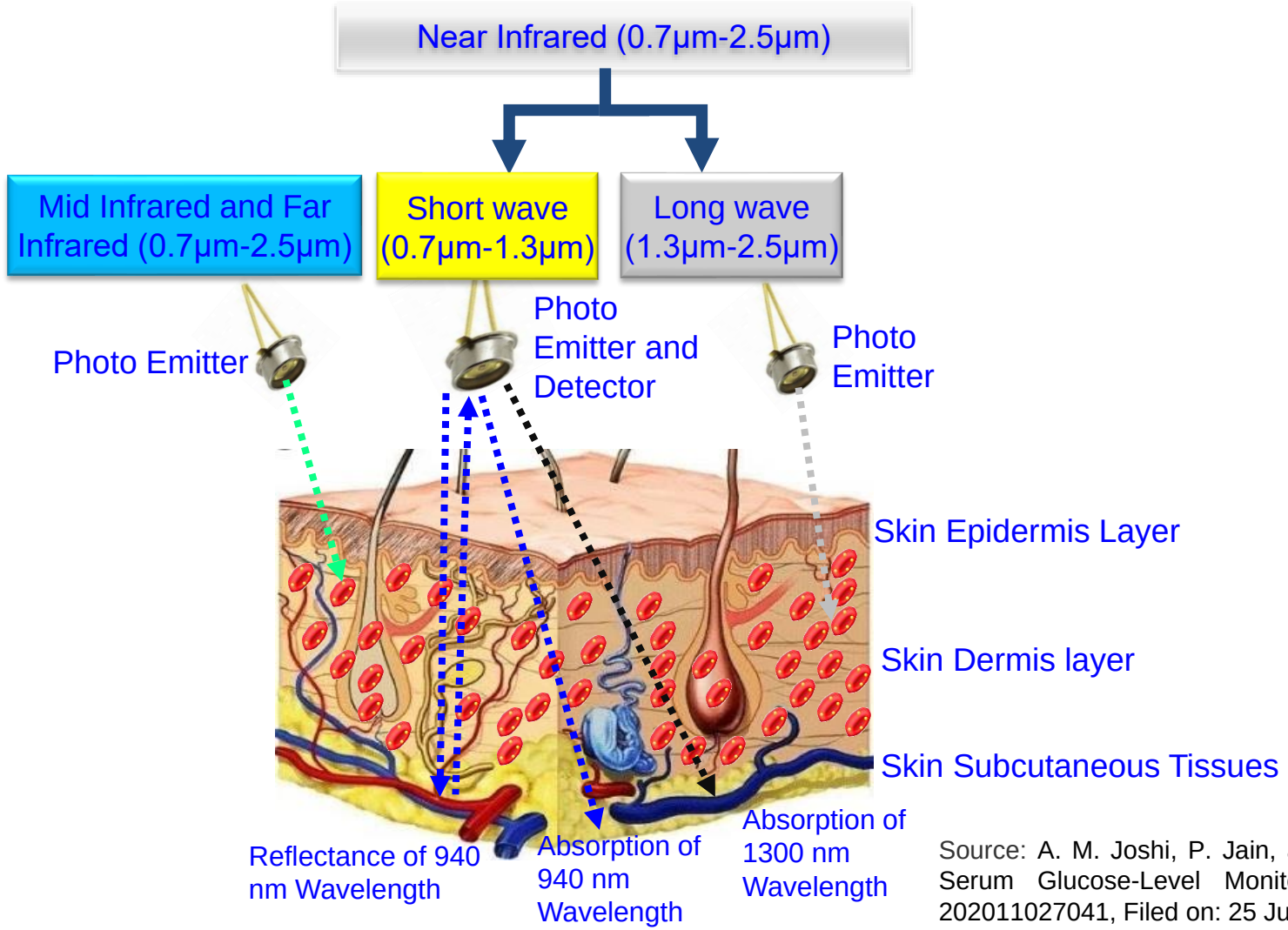


Near Infrared (NIR)



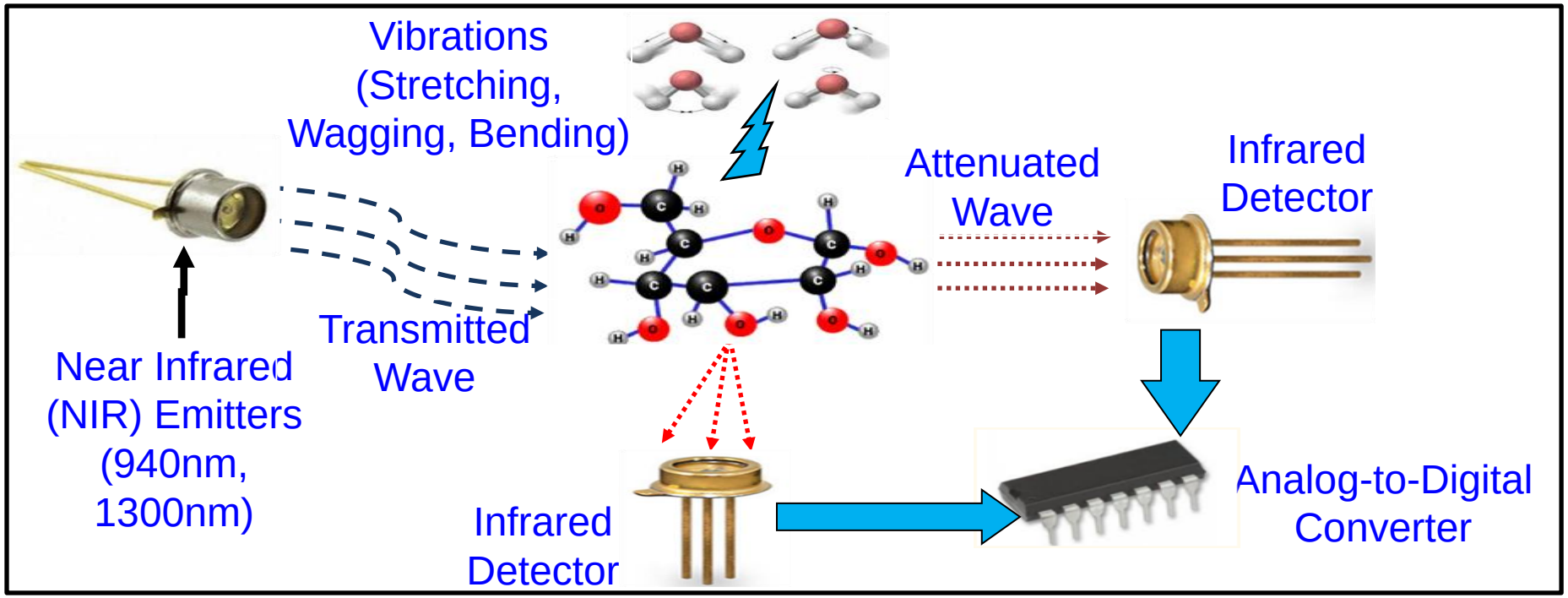


Unique Near Infrared Spectroscopy for iGLU



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

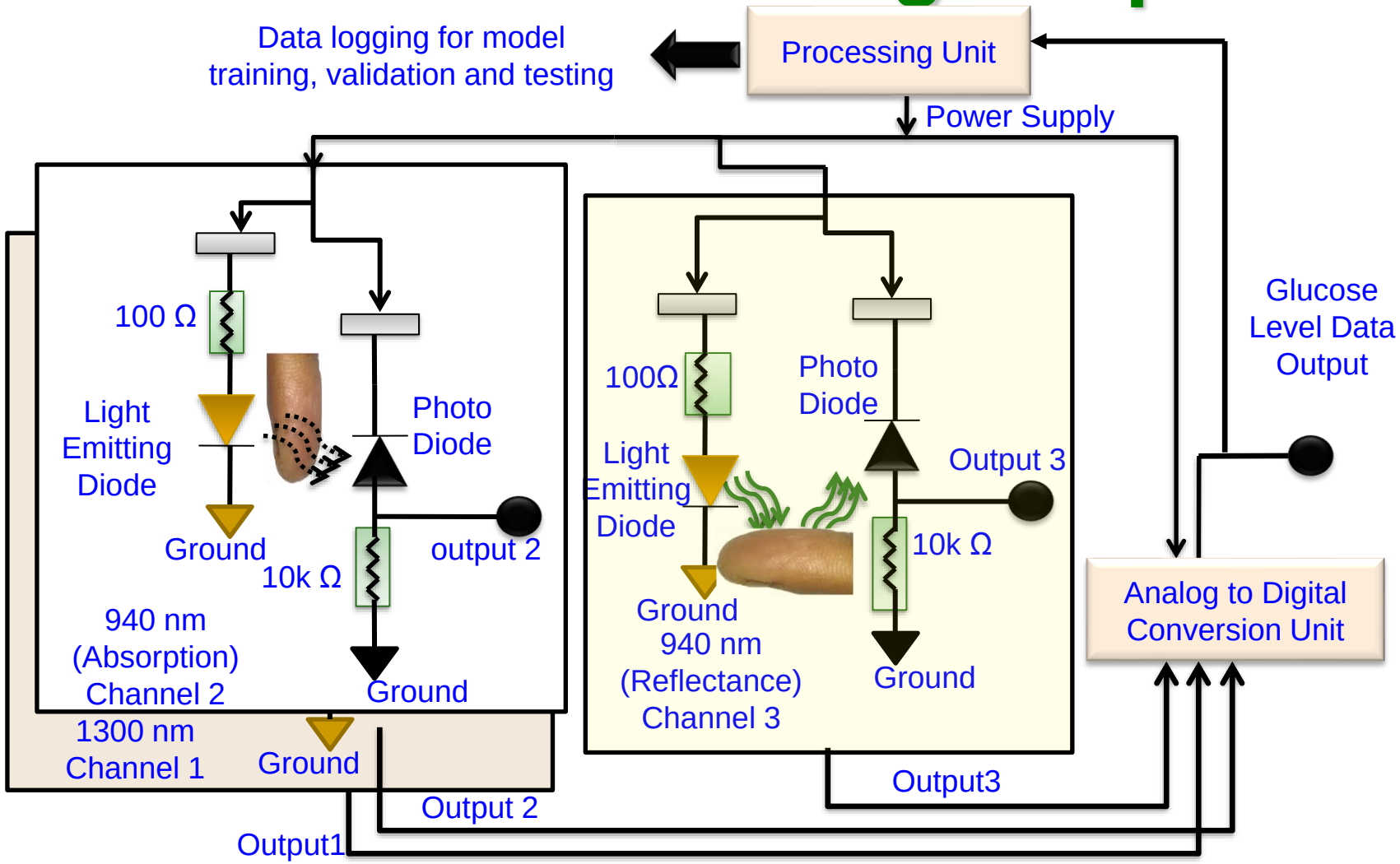


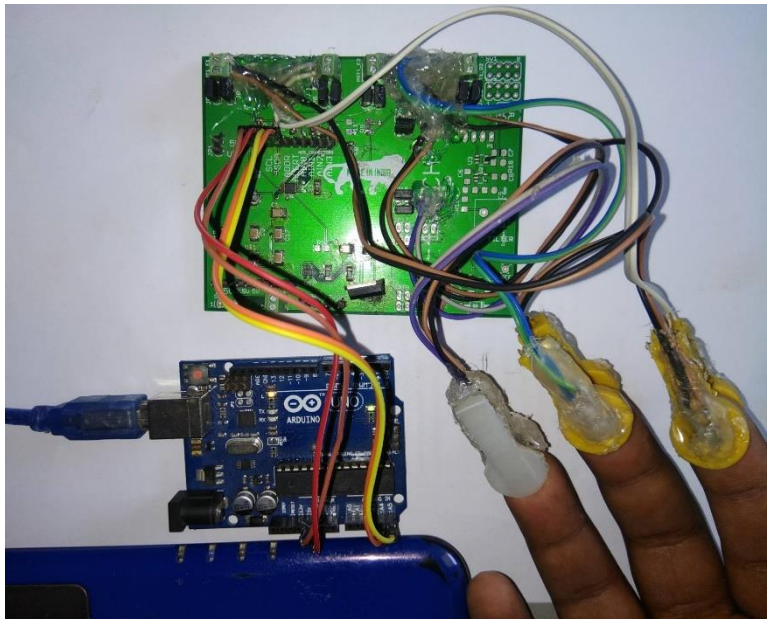
Clinically tested in an hospital.

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 – Design Implementation



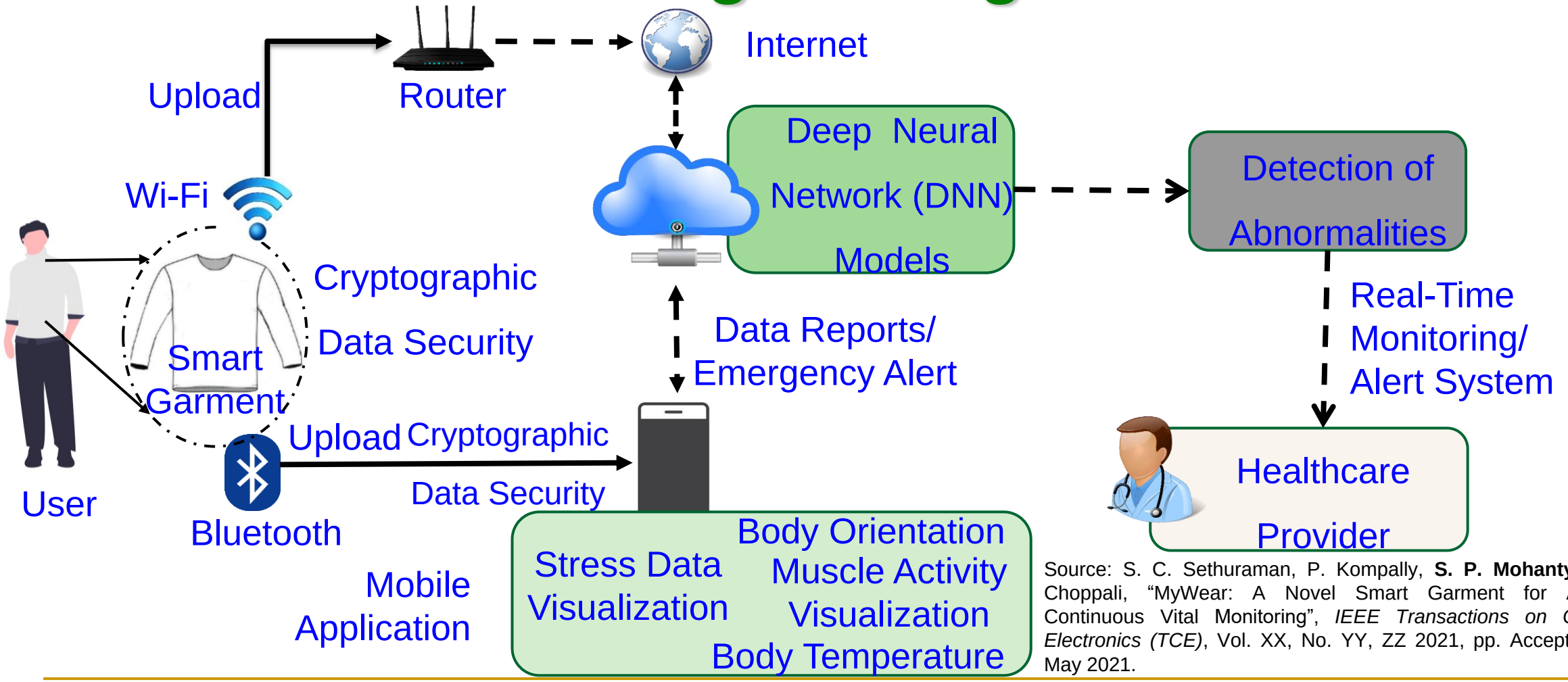


Clinically tested in an hospital.

Cost - US$ 20
Accuracy - 100%

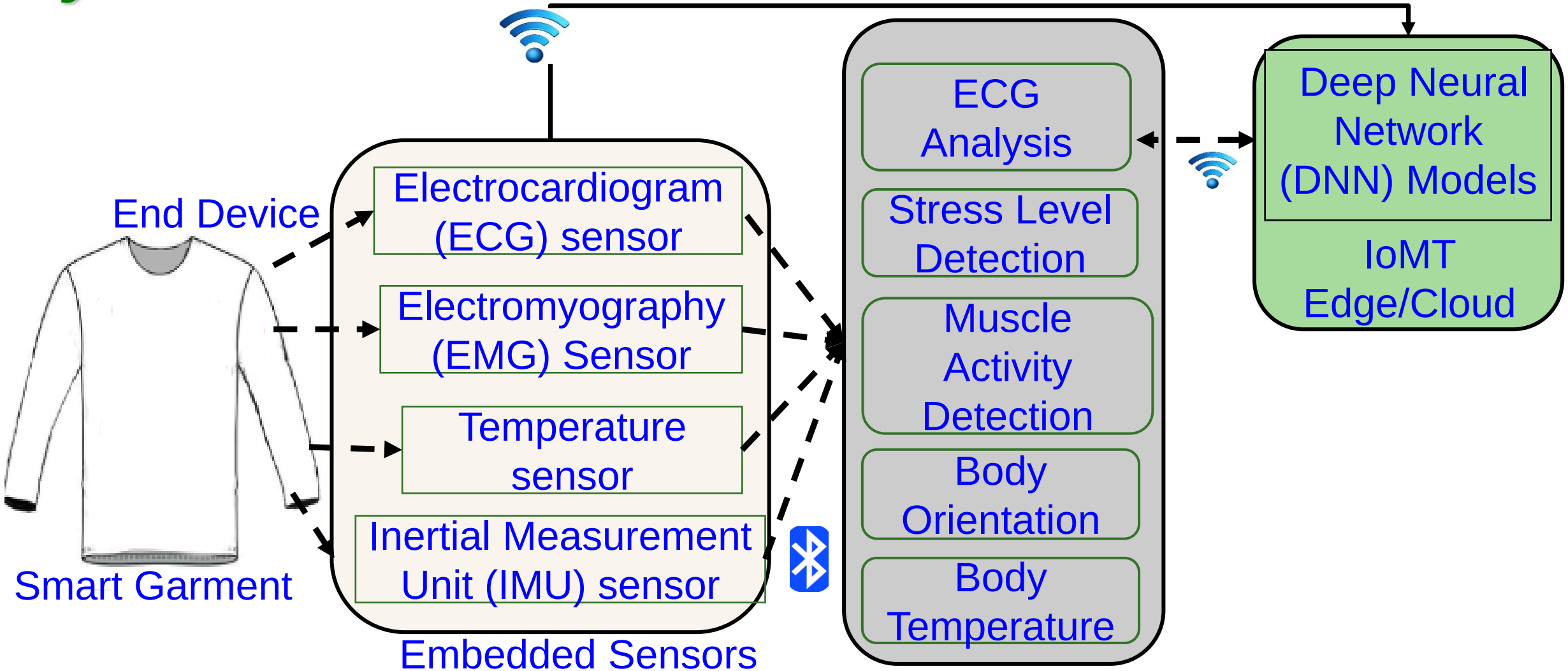
Source: A. M. Joshi, P. Jain, and S. P. Mohanty, A Device For Non-Invasive Blood and Serum Glucose-Level Monitoring and Control, India Patent Application Number: 202011027041, Filed on: 25 June 2020.

MyWear – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG



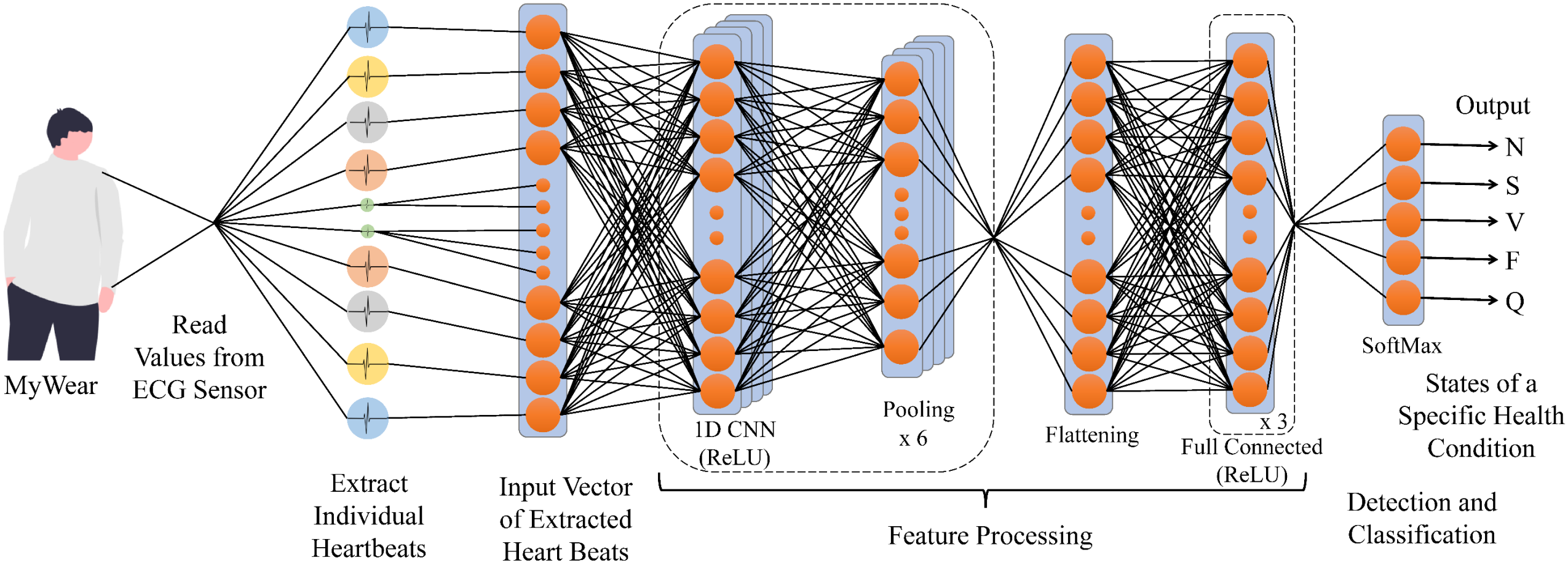
Source: S. C. Sethuraman, P. Kompally, **S. P. Mohanty**, and U. Choppali, "MyWear: A Novel Smart Garment for Automatic Continuous Vital Monitoring", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 30 May 2021.

MyWear – Architecture with Multimodal Sensors



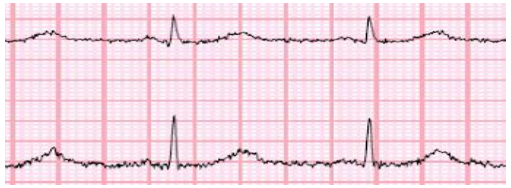
Source: S. C. Sethuraman, P. Kompally, S. P. Mohanty, and U. Choppali, "MyWear: A Smart Wear for Continuous Body Vital Monitoring and Emergency Alert", *arXiv Electrical Engineering and Systems Science*, arXiv:2005.06342, Oct 2020, 25-pages.

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

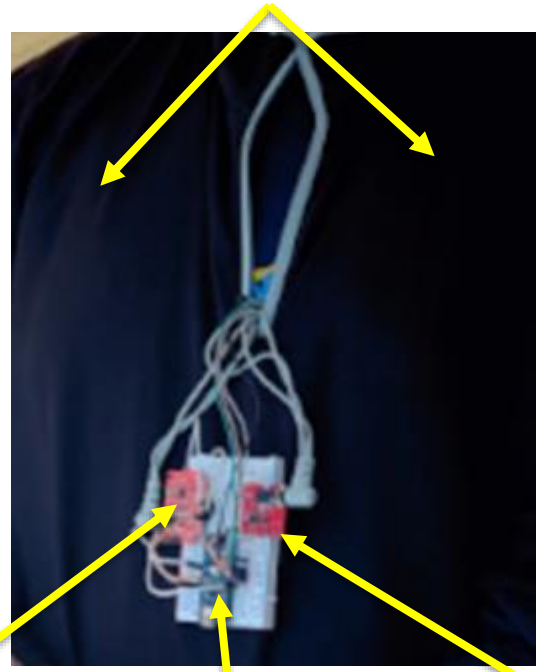
Obtain the Stress Level of the User

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 – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG

Embedded Electrodes inside MyWear



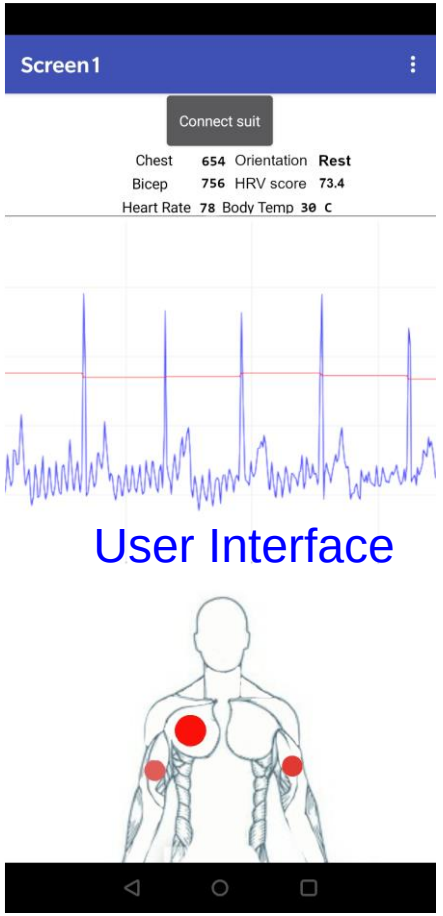
ECG Sensor

Micro-controller

EMG Sensor

MyWear Prototype Results:

→ Heartbeat Classification - Accuracy - 97%
→ Myocardial Infarction (Heart Attack) - Accuracy - 98%
→ Stress Level Detection - Accuracy - 97%
→ Muscle Activity Detection - Accuracy - 96%
→ Fall Detection - Accuracy - 98.5%

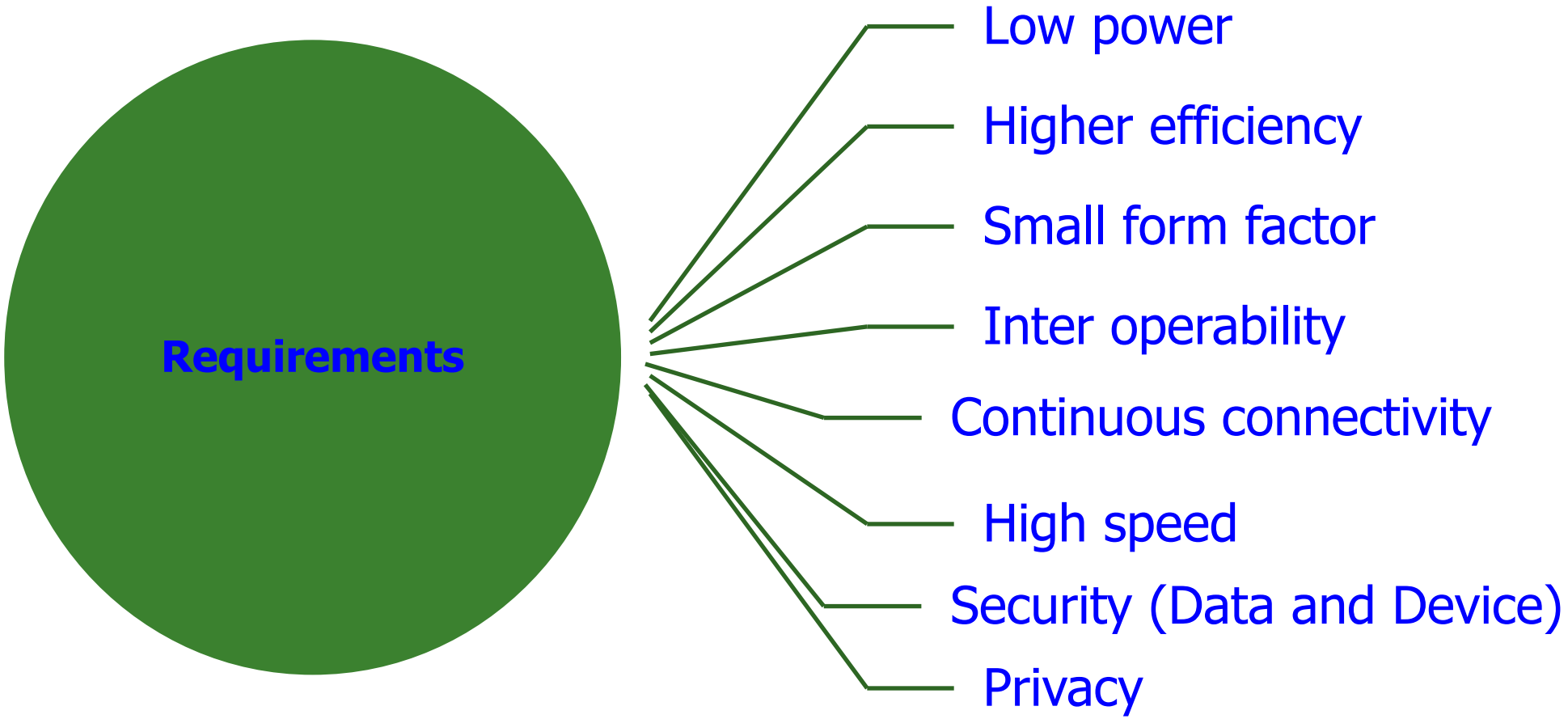


User Interface

Source: S. C. Sethuraman, P. Kompally, **S. P. Mohanty**, and U. Choppali, "MyWear: A Novel Smart Garment for Automatic Continuous Vital Monitoring", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 30 May 2021.

Smart Healthcare – Some Challenges

Smart Healthcare Architecture – Requirements



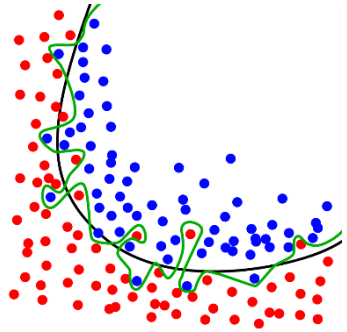
Smart Healthcare – Data Quality

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

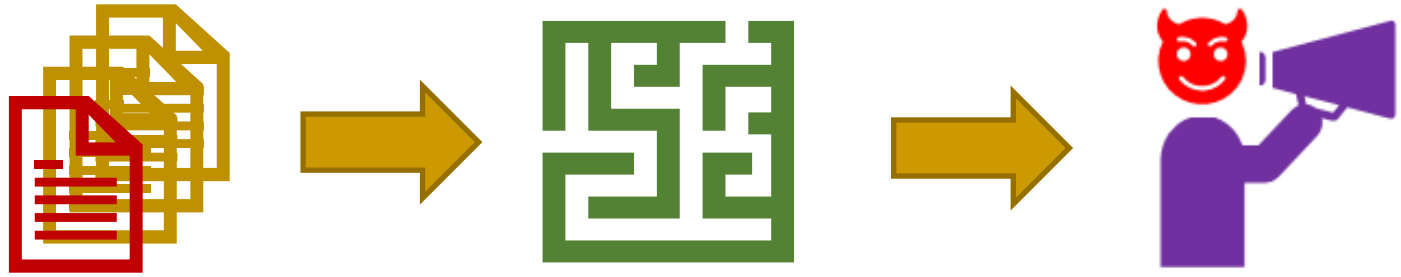
Machine Learning Issues

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



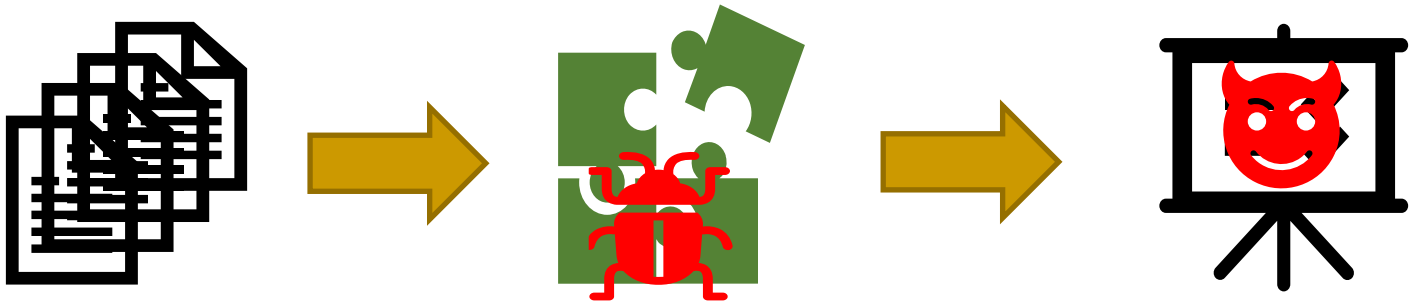
Source: Mohanty ISCT Keynote 2019

AI/ML – Cybersecurity Issue



Corrupted Input Dataset → Predictive modelling → Corrupted Decision/ Prediction

Input attack in machine learning

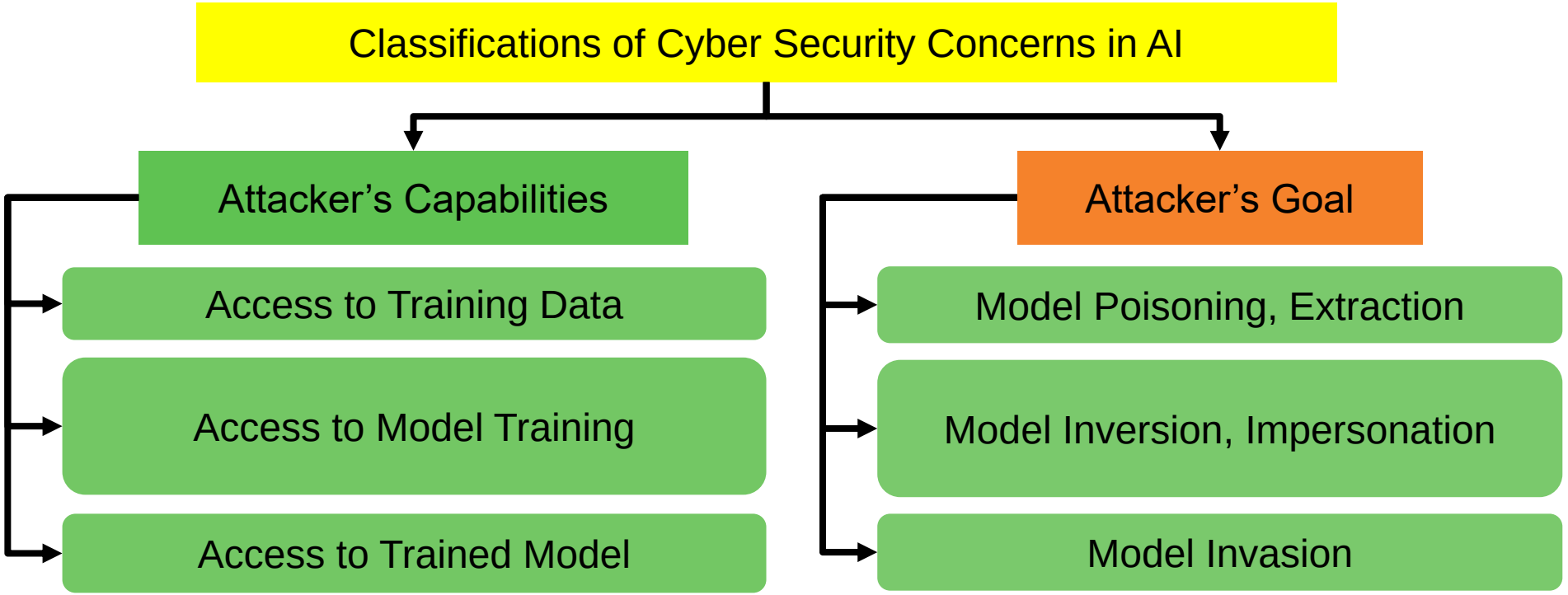


Input Dataset → Attacked training Process → Corrupt Classifications

Poisoning attack in training process

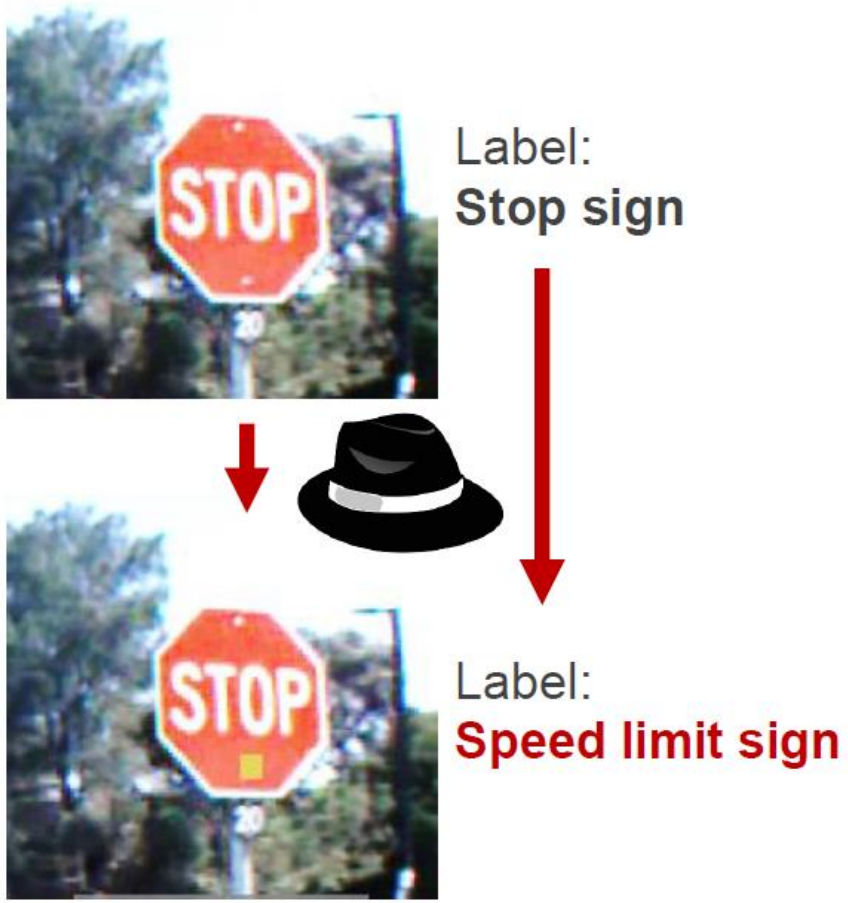
Source: D. Puthal, and **S. P. Mohanty**, "Cybersecurity Issues in AI", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 4, July 2021, pp. 33--35.

AI/ML – Cybersecurity Issue



Source: D. Puthal, and **S. P. Mohanty**, "Cybersecurity Issues in AI", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 10, No. 4, July 2021, pp. 33--35.

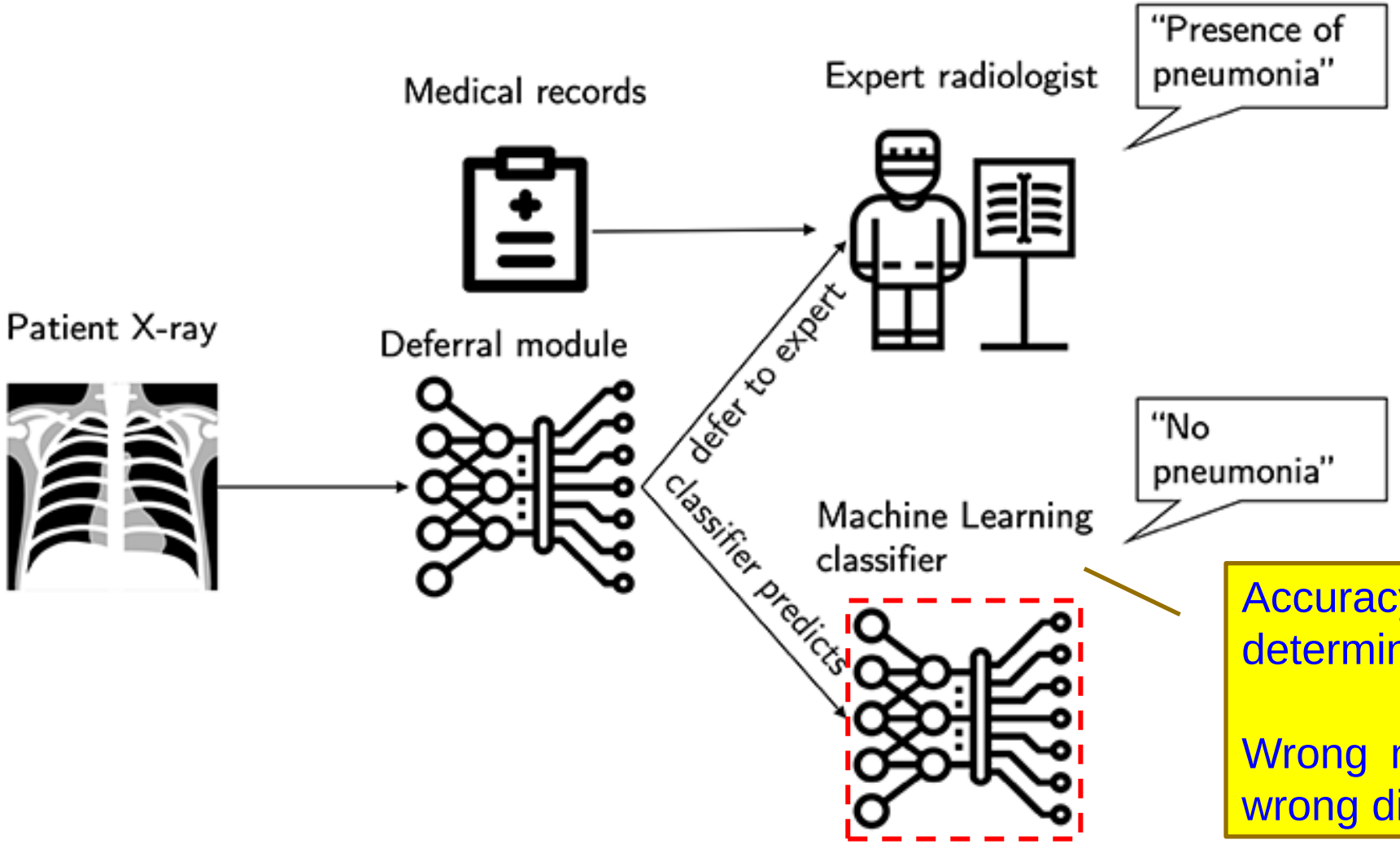
AI Security - Trojans in Artificial Intelligence (TrojAI)



Adversaries can insert **Trojans** into AIs, leaving a trigger for bad behavior that they can activate during the AI's operations

Source: https://www.iarpa.gov/index.php?option=com_content&view=article&id=1150&Itemid=448

Wrong ML Model → Wrong Diagnosis



Accuracy is important determine pneumonia

Wrong model can lead to wrong diagnosis altogether

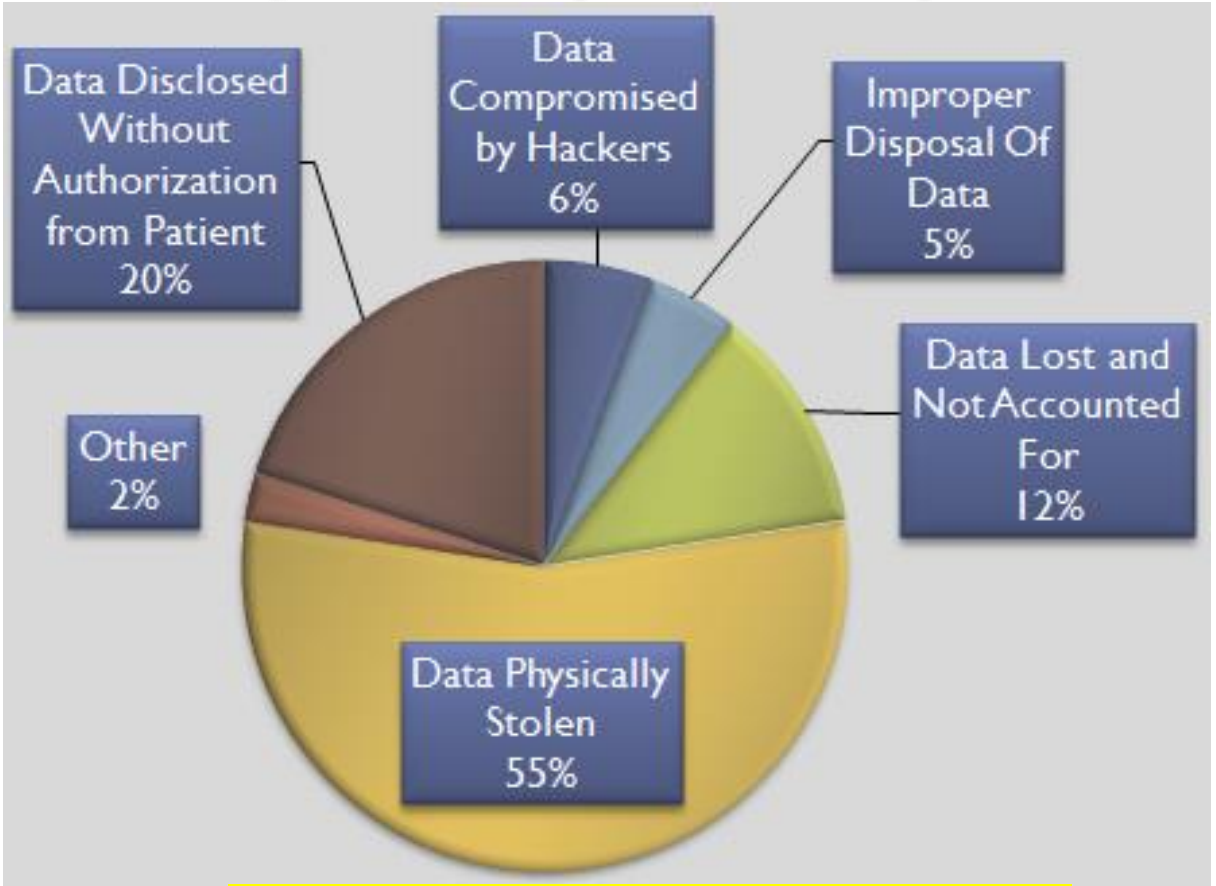
Source: https://www.healthcareitnews.com/news/new-ai-diagnostic-tool-knows-when-defer-human-mit-researchers-say

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.

Health Insurance Portability and Accountability Act (HIPPA)

HIPAA
Health Insurance Portability and Accountability Act



HIPPA Privacy Violation by Types

IoMT Device Security Issue is Scary

- Insulin pumps are vulnerable to hacking, FDA warns amid recall:

https://www.washingtonpost.com/health/2019/06/28/insulin-pumps-are-vulnerable-hacking-fda-warns-amid-recall/

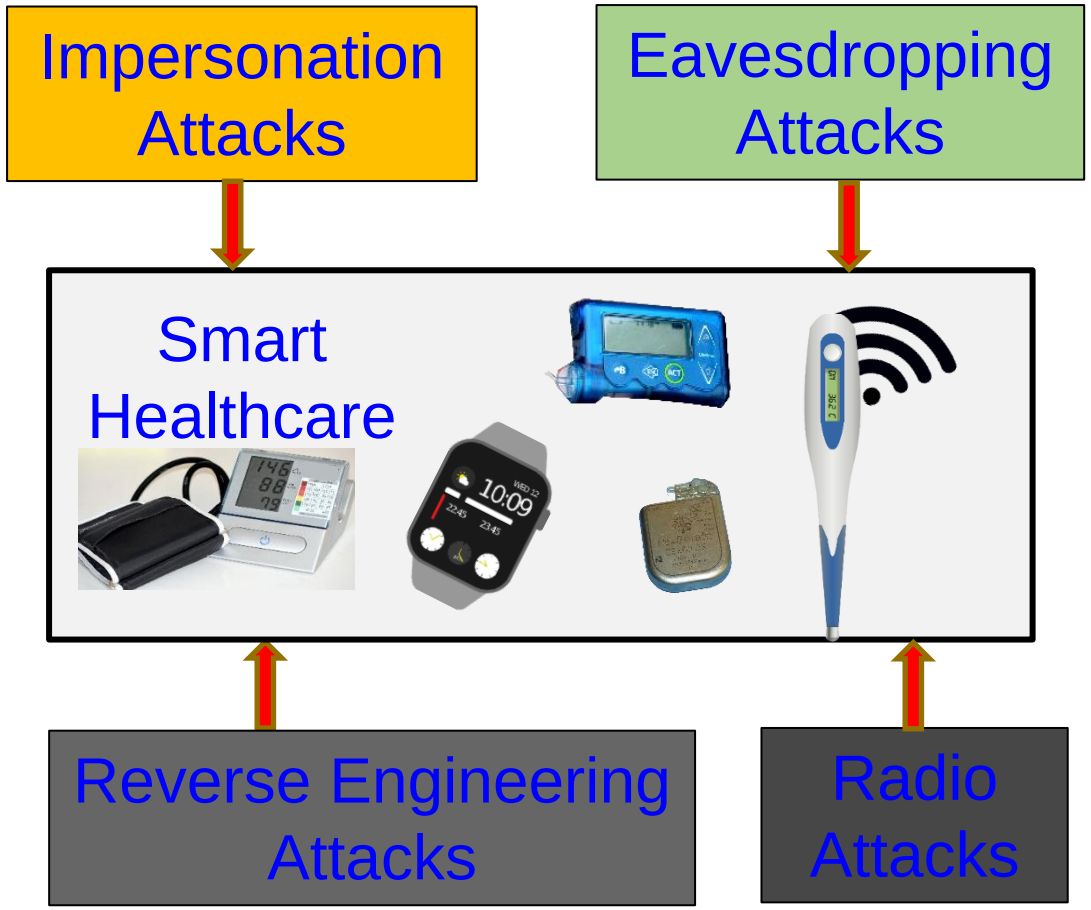
- Software vulnerabilities in some medical devices could leave them susceptible to hackers, FDA warns:

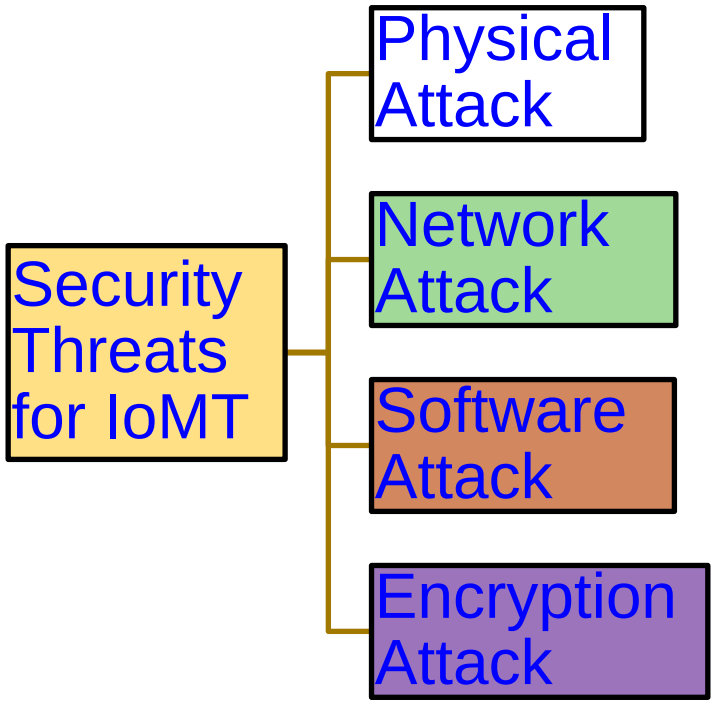
https://www.cnn.com/2019/10/02/health/fda-medical-devices-hackers-trnd/index.html

- FDA Issues Recall For Medtronic mHealth Devices Over Hacking Concerns:

https://mhealthintelligence.com/news/fda-issues-recall-for-medtronic-mhealth-devices-over-hacking-concerns

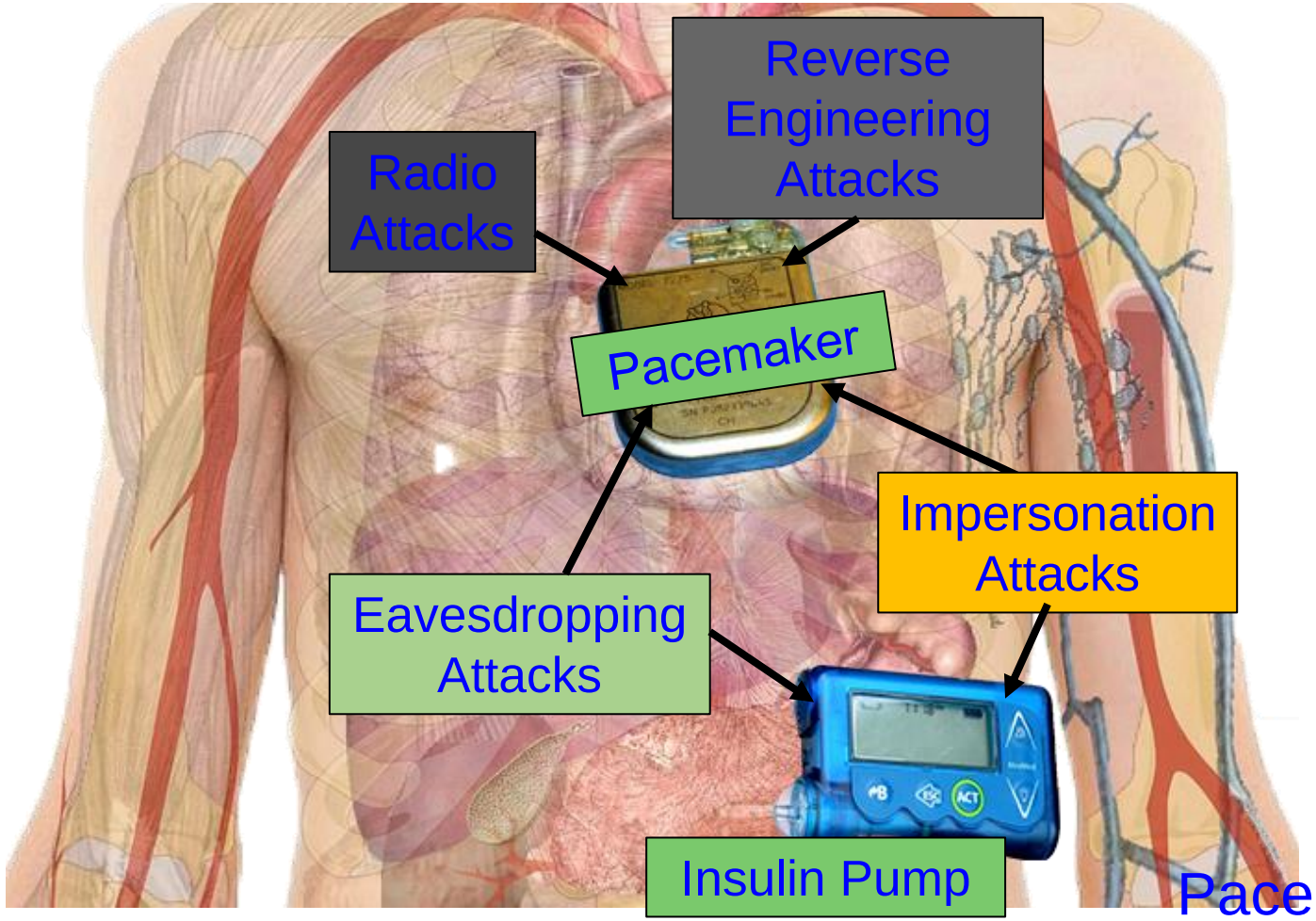
IoMT Security – Selected Attacks





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 – Resource Constrained

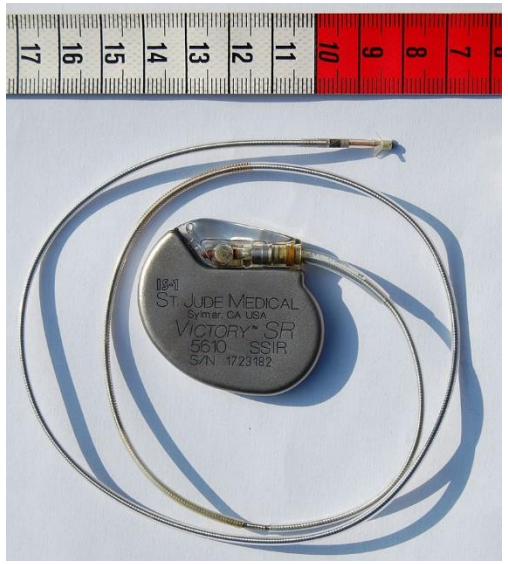


Collectively (WMD+IMD): Implantable and Wearable Medical Devices (IWMDs)

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

Pacemaker Battery Life - 10 years

IoMT Security Measures is Hard – Energy Constrained



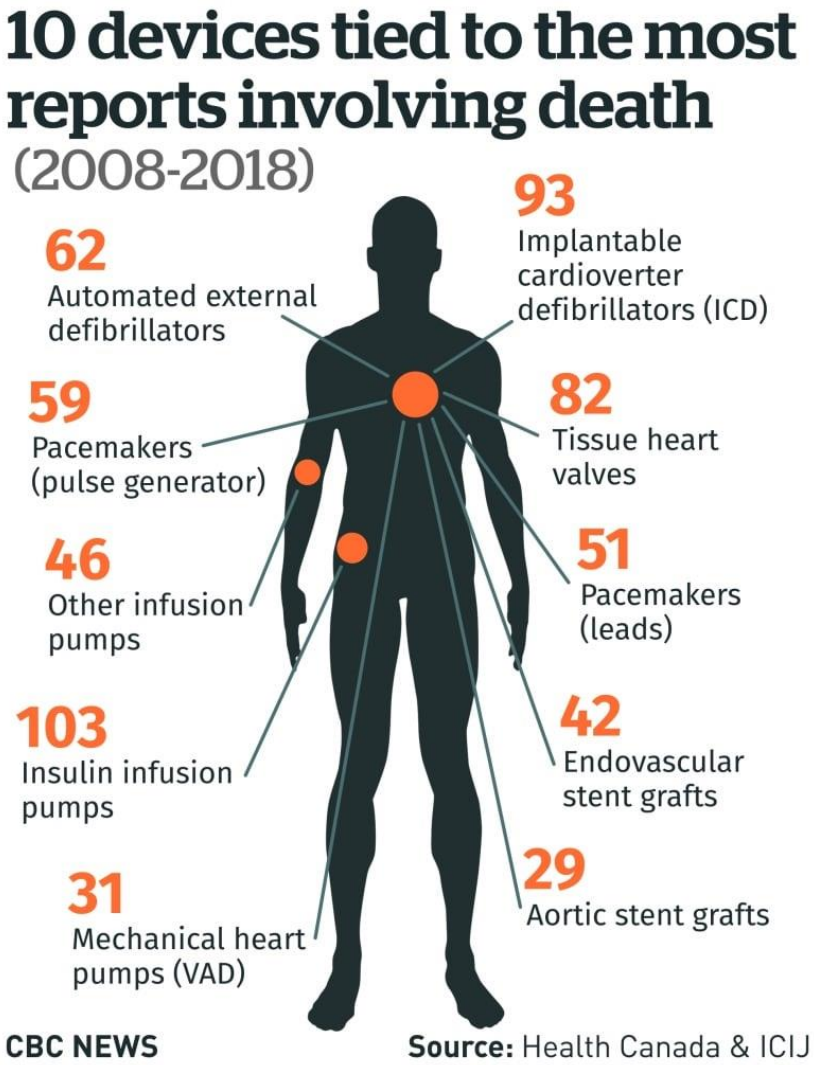
Pacemaker
Battery Life
- 10 years

Neurostimulator
Battery Life
- 8 years

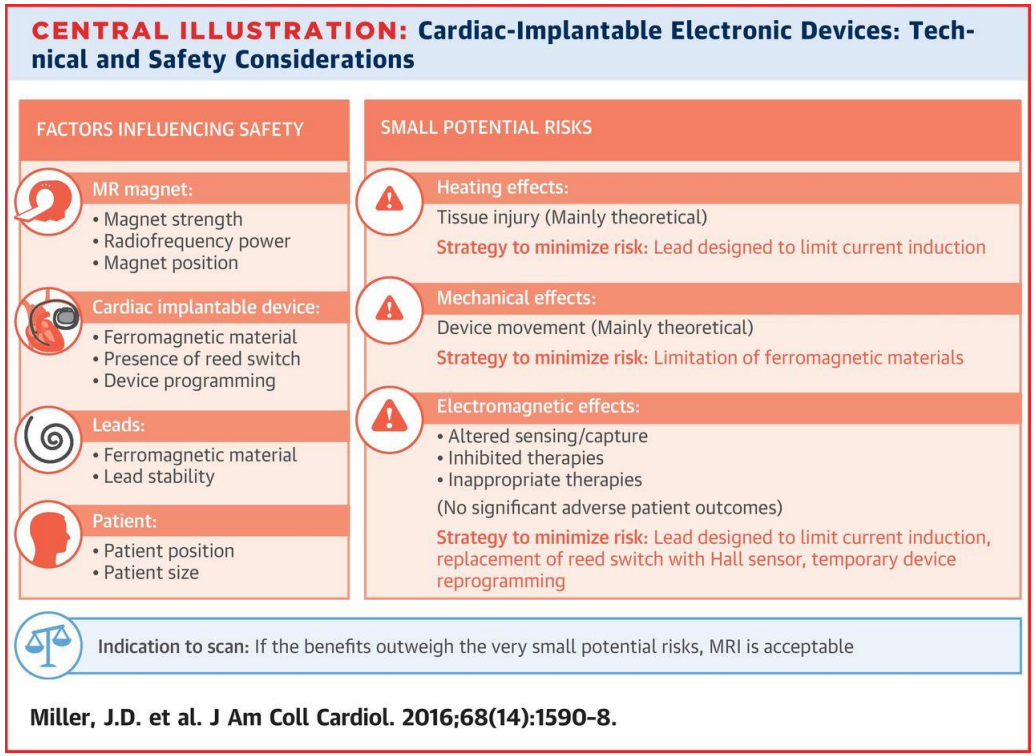
- Implantable Medical Devices (IMDs) have integrated battery to provide energy to all their functions → Limited Battery Life depending on functions
- Higher battery/energy usage → Lower IMD lifetime
- Battery/IMD replacement → Needs surgical risky procedures

Source: Carmen Camara, PedroPeris-Lopeza, and Juan E.Tapiadora, "Security and privacy issues in implantable medical devices: A comprehensive survey", *Elsevier Journal of Biomedical Informatics*, Volume 55, June 2015, Pages 272-289.

Smart Healthcare - Safety



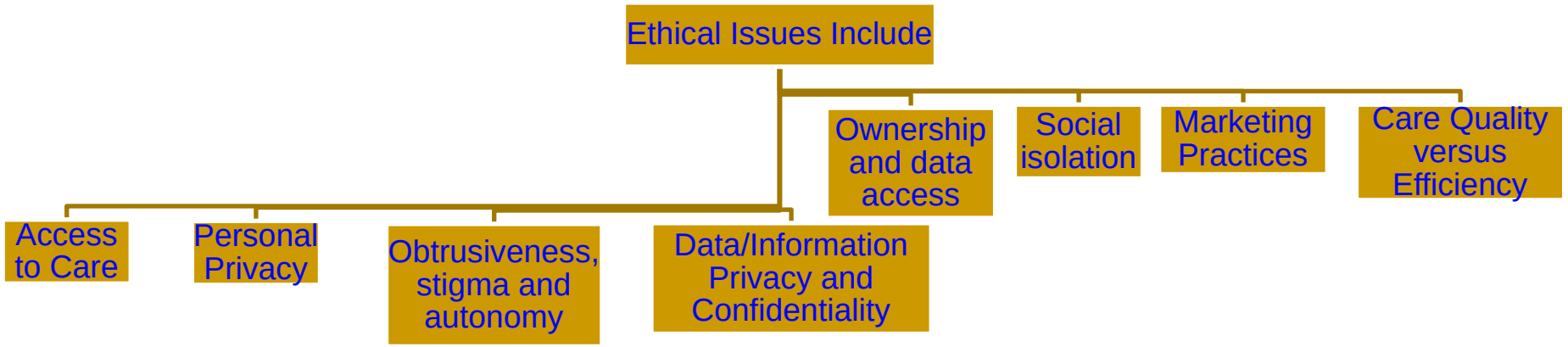
Source https://planet-report.com/canadian-advocates-call-for-all-medical-implants-to-be-registered-cbc-news/



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 - 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 – Some Solutions

IoT/CPS Design – Multiple Objectives

Non-recurring Design Cost

Recurring Operational Cost

Energy Consumption, Battery Life

Ethics, Safety

Security, Privacy, IP Rights

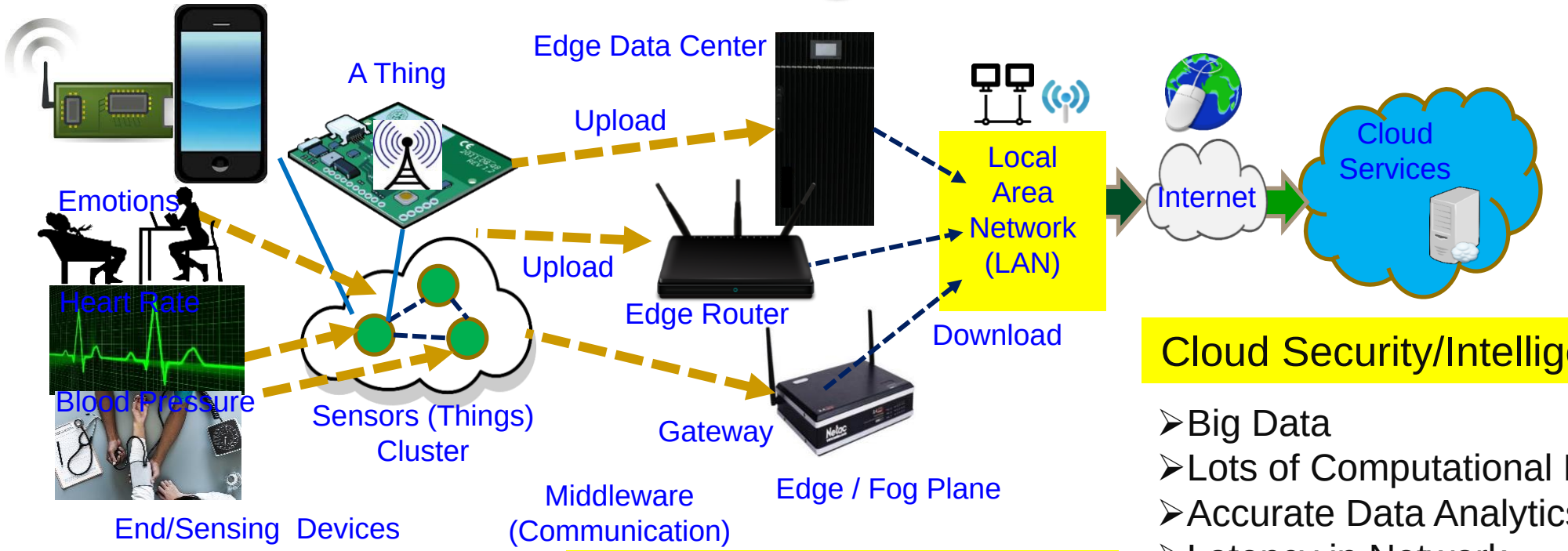
Smart Cities
Vs
Smart Villages

Performance, Latency

Intelligence

Source: Mohanty ICCE 2019 Keynote

CPS – IoT-Edge Vs IoT-Cloud



End Security/Intelligence

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

Edge Security/Intelligence

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

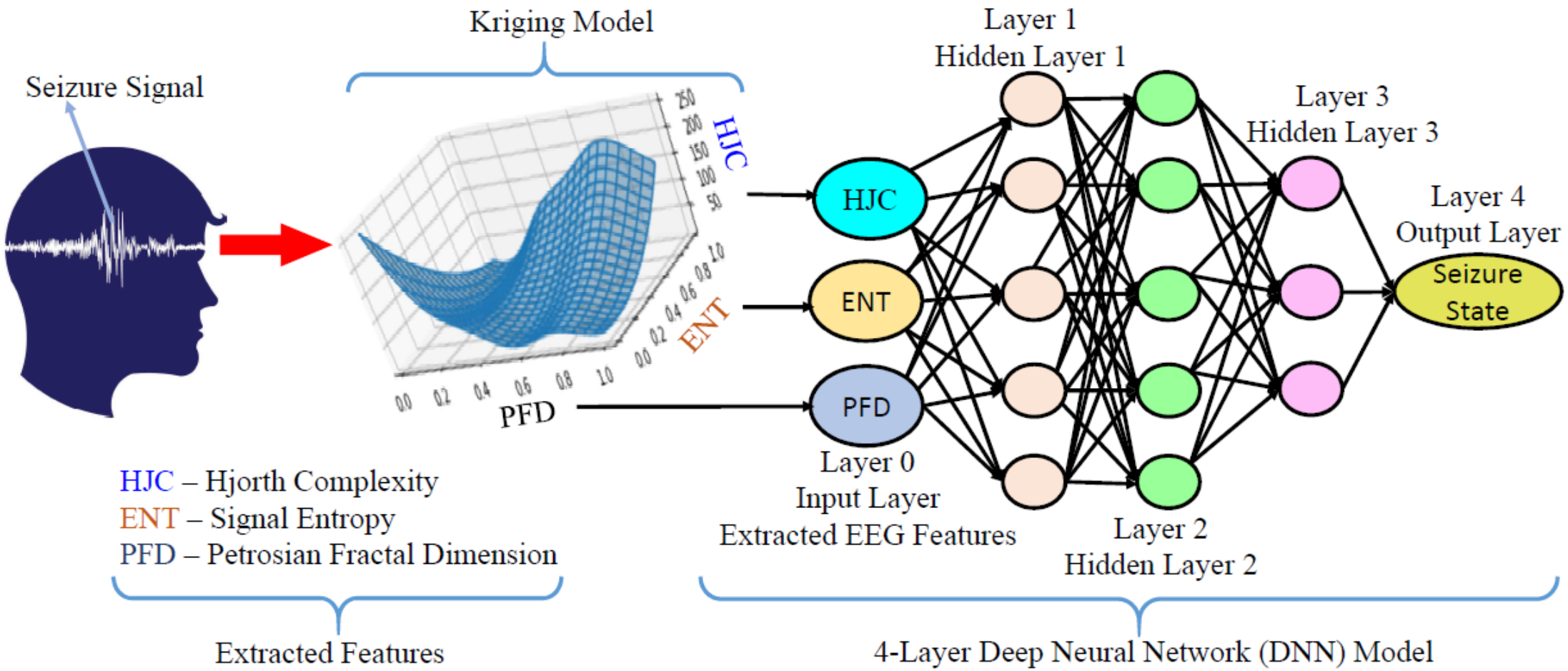
Cloud Security/Intelligence

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

TinyML at End and/or Edge is key for smart villages.

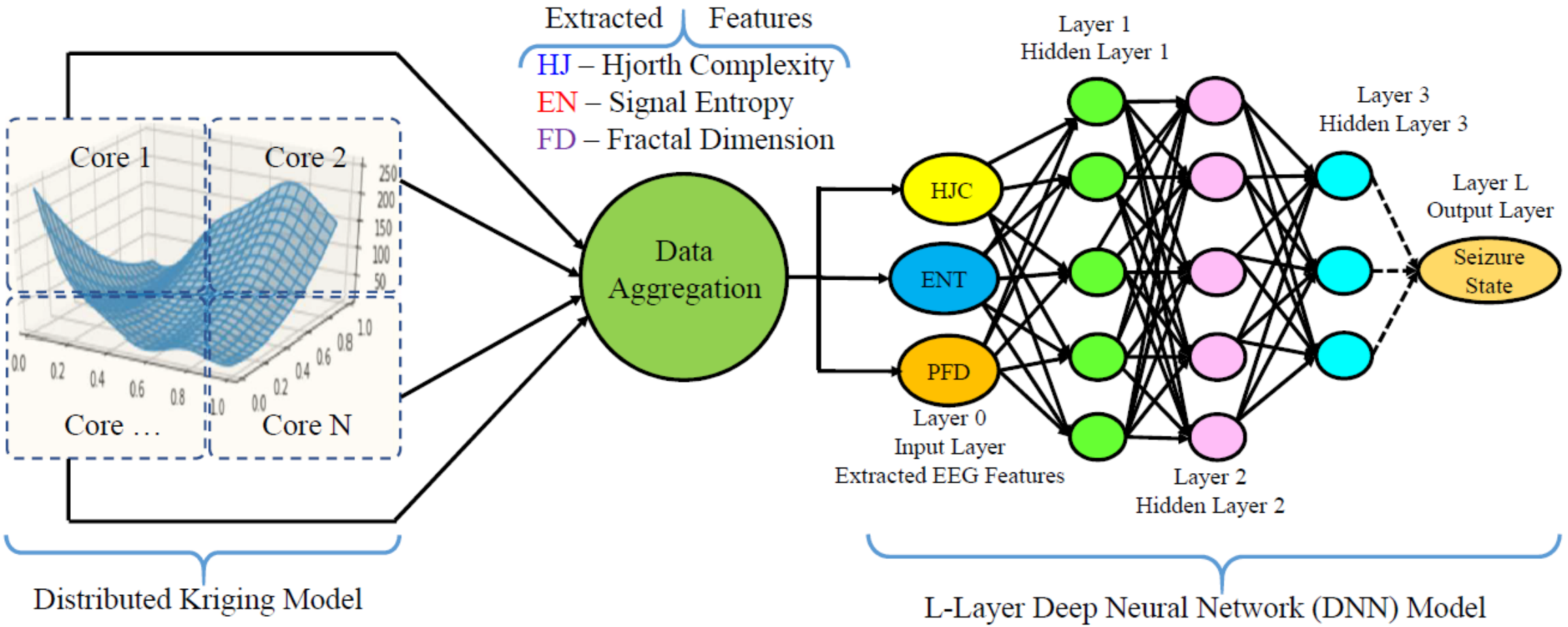
Heavy-Duty ML is more suitable for smart cities

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

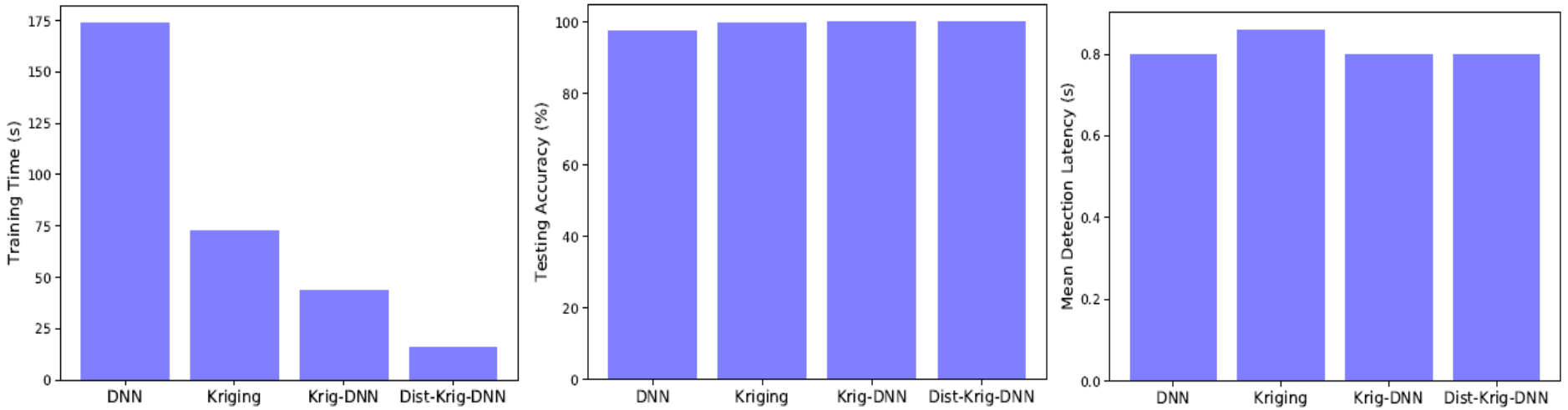
Our Distributed Kriging-Bootstrapped DNN Model



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.

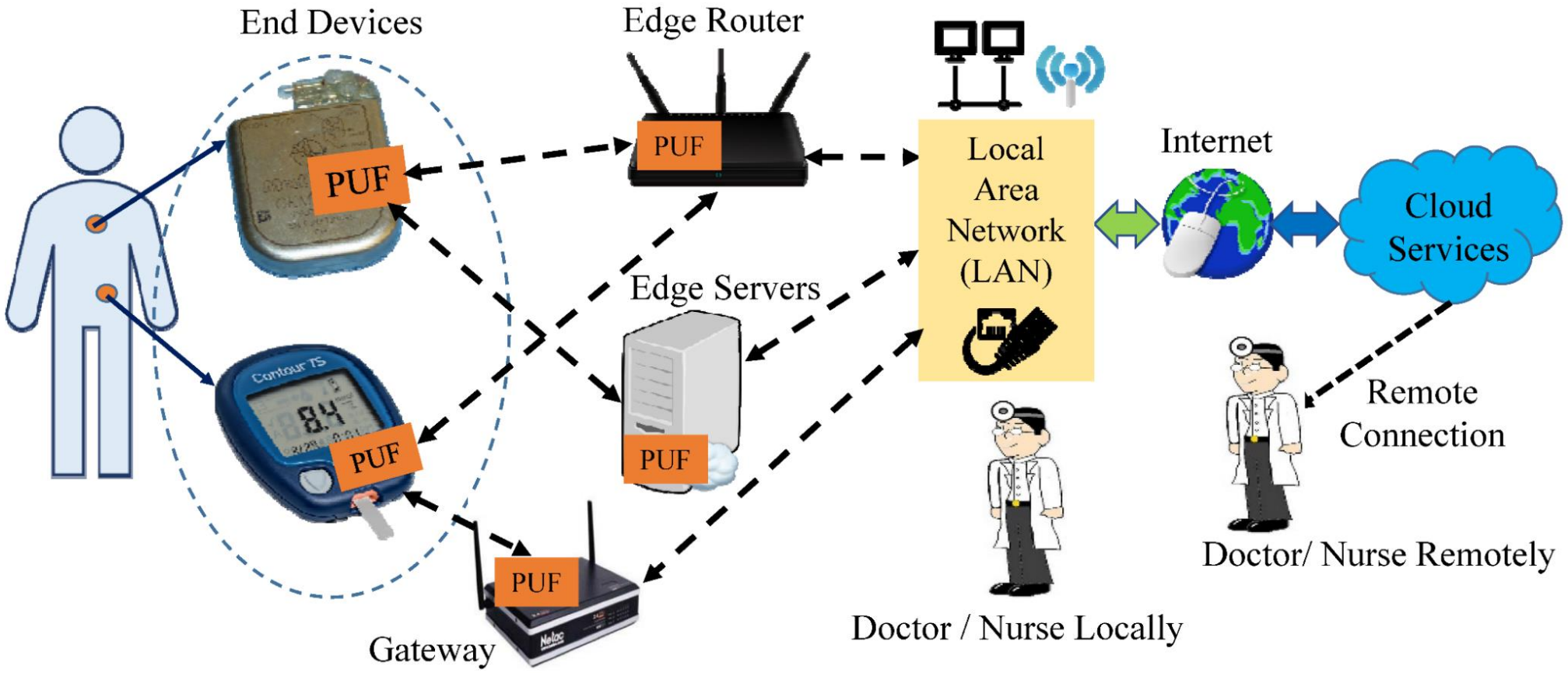
Experimental Results: Dataset A

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



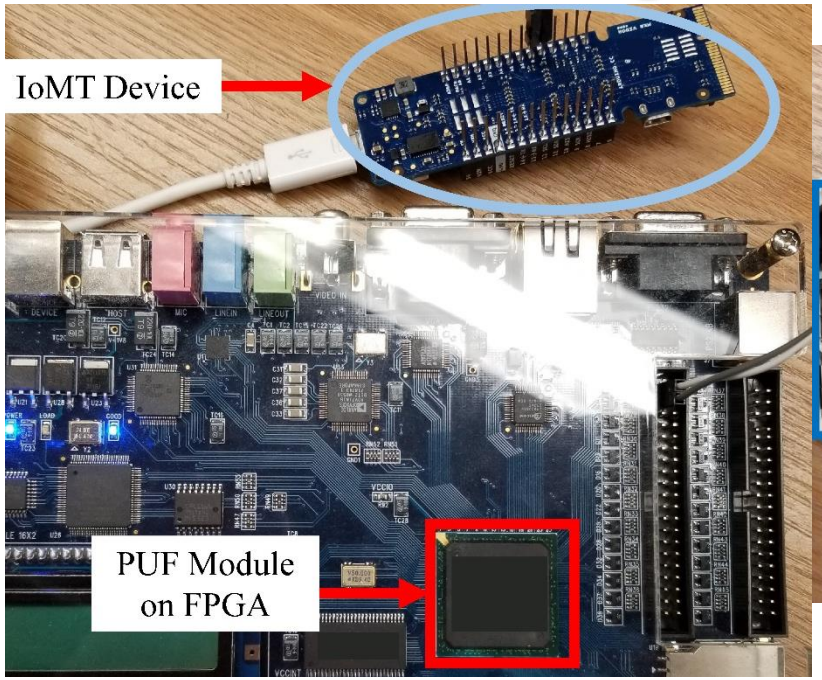
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

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.

IoMT Security – Our Proposed PMsec

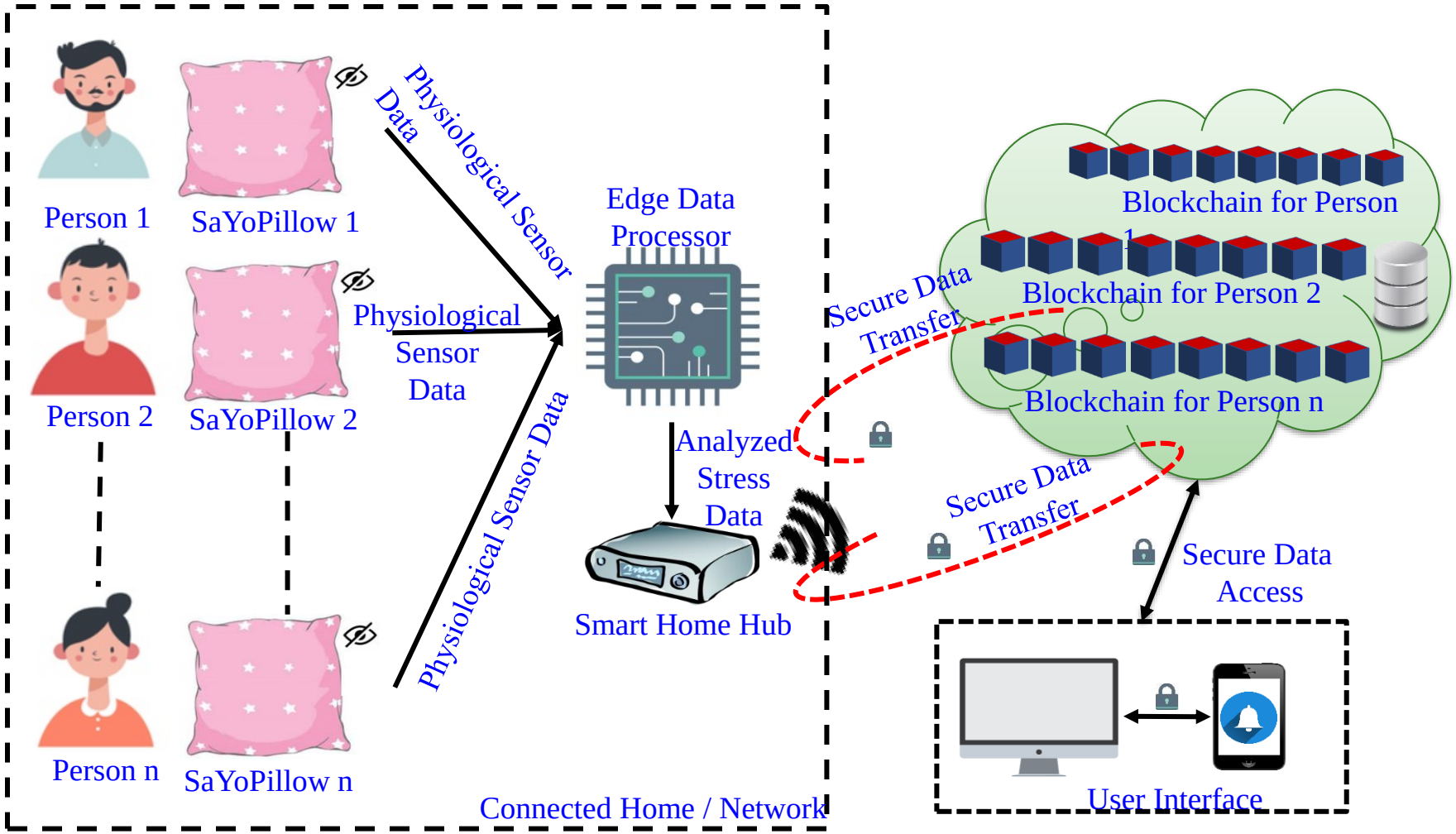


Average Power Overhead –
~ 200 μW or 0.2 mW

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

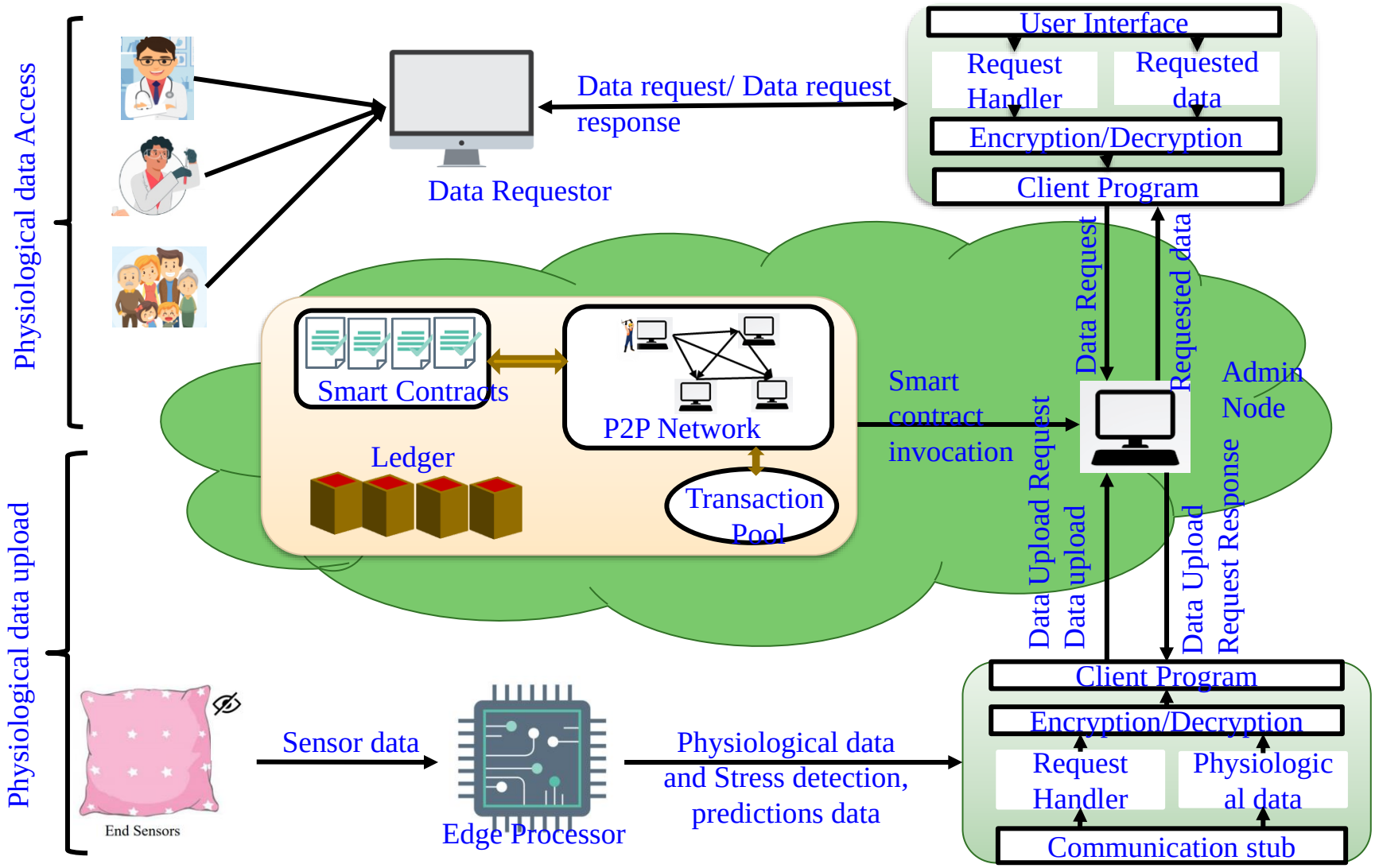
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

Our Smart-Yoga Pillow (SaYoPillow)



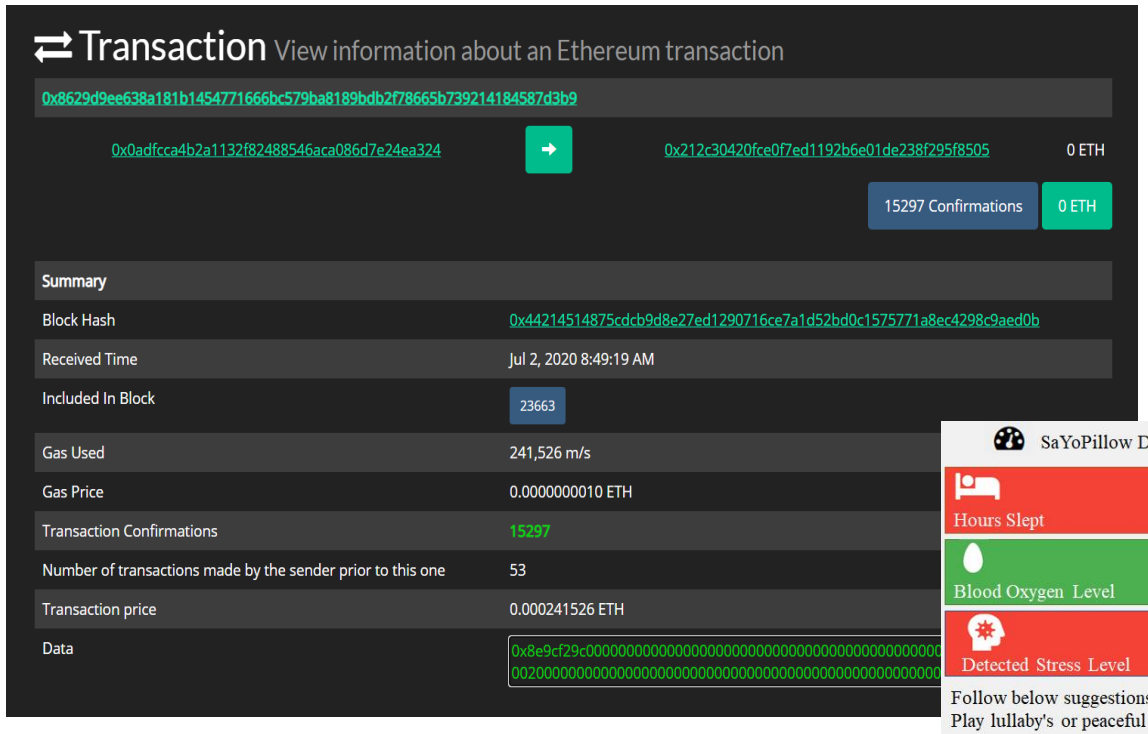
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

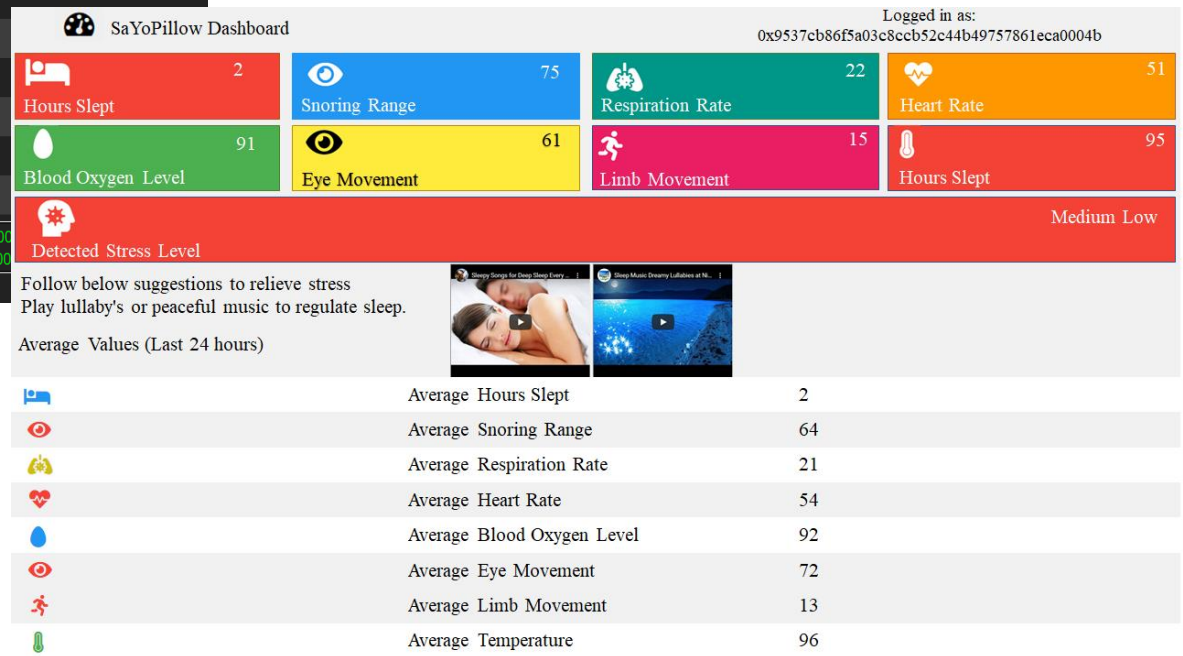
SaYoPillow: Blockchain Details



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.

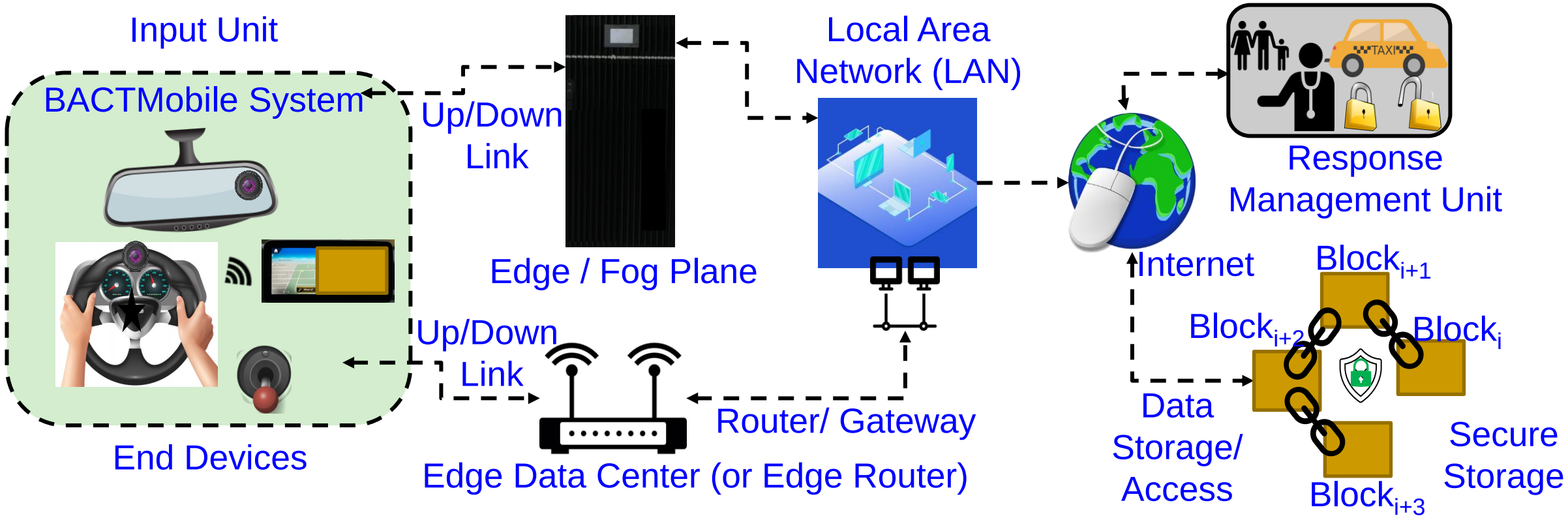
SaYoPillow: Prototyping





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.

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.

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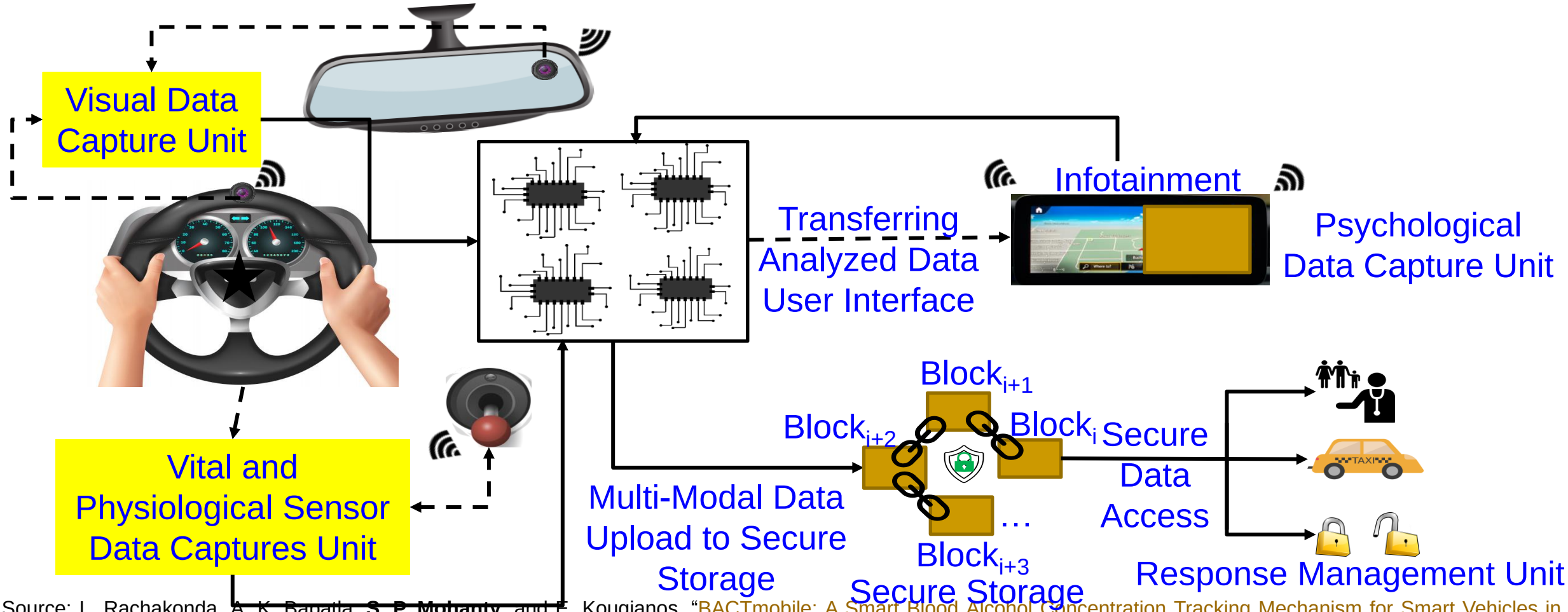

Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

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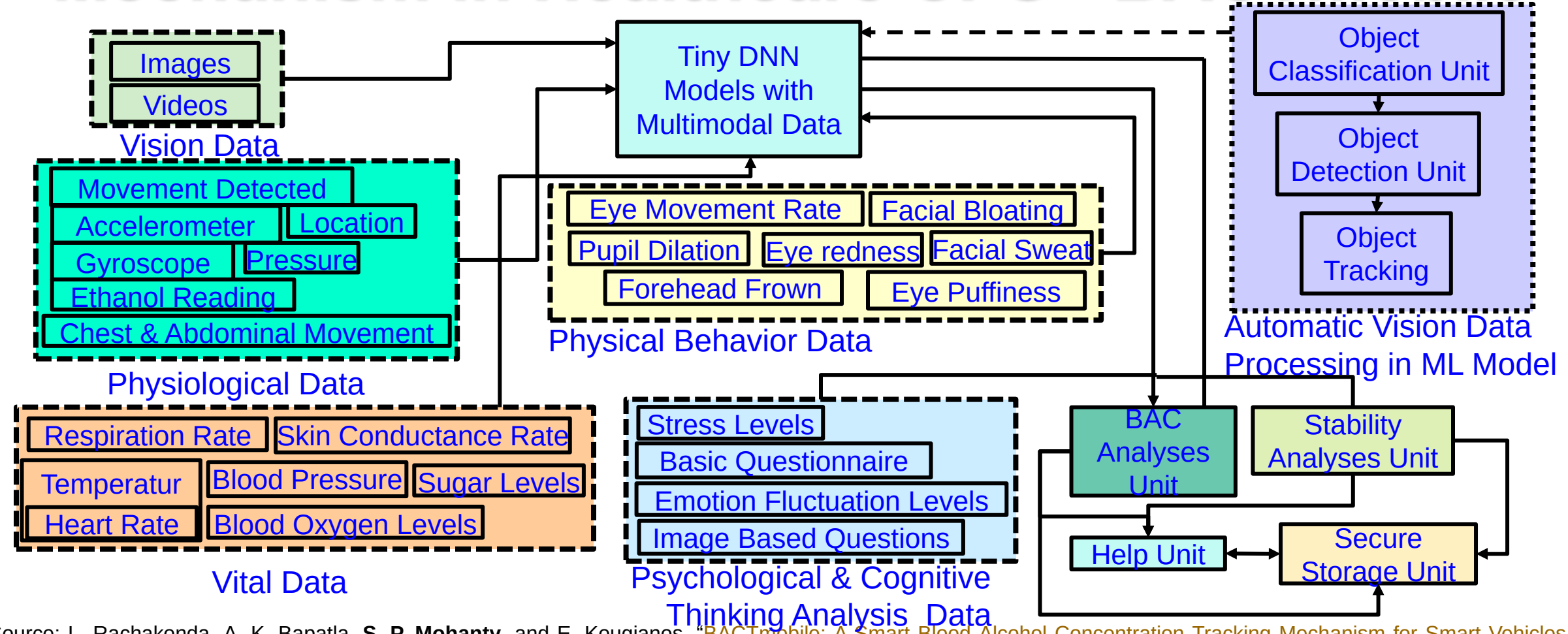

Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

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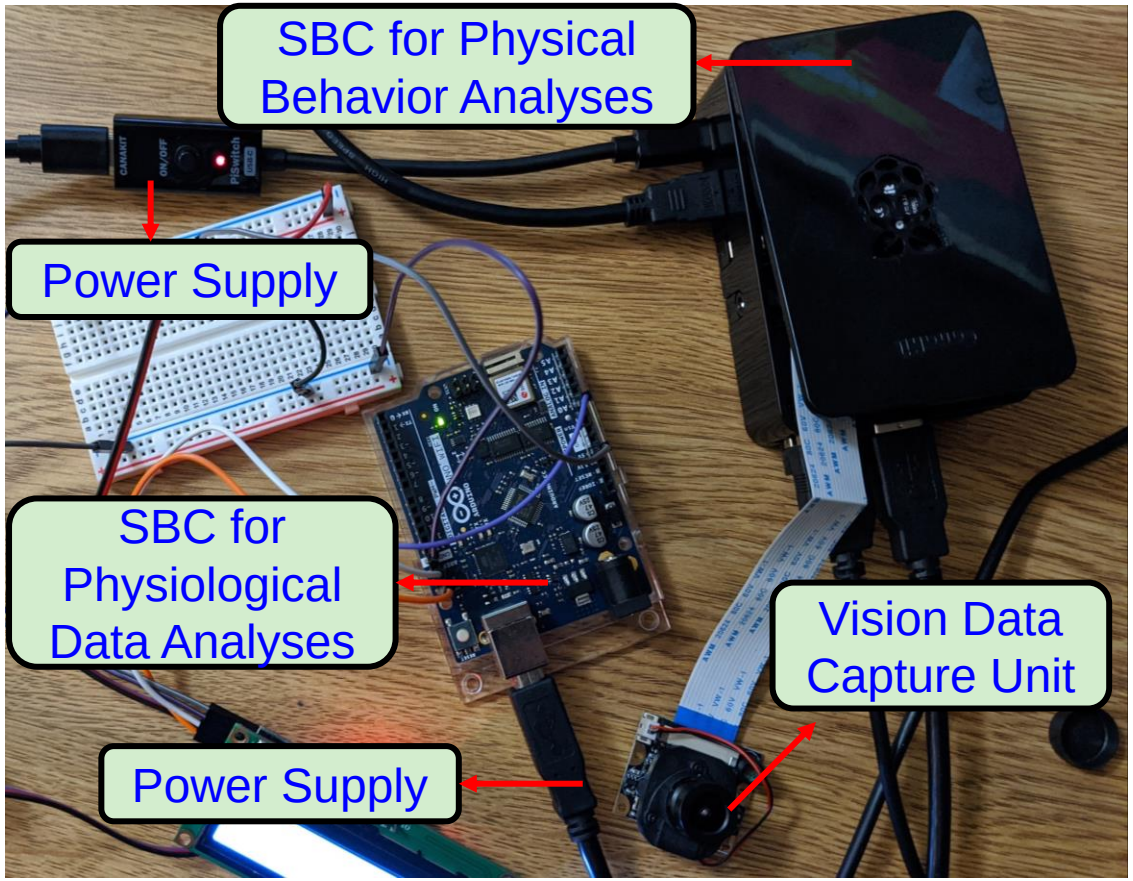

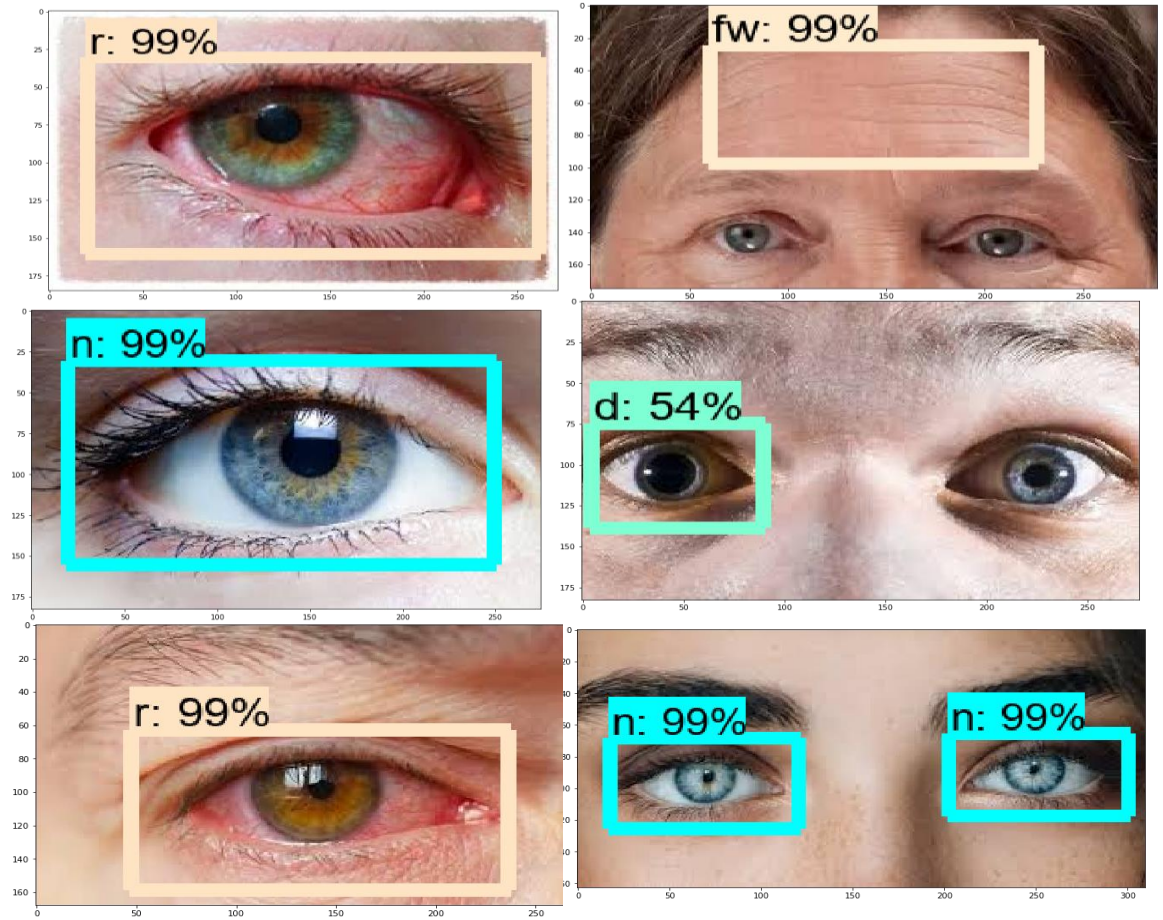

Source: L. Rachakonda, A. K. Bapatla, **S. P. Mohanty**, and E. Kougianos, "BACTmobile: A Smart Blood Alcohol Concentration Tracking Mechanism for Smart Vehicles in Healthcare CPS Framework", *Springer Nature Computer Science (SN-CS)*, Vol. 3, No. 3, May 2022, Article: 236, 24-pages, DOI: https://doi.org/10.1007/s42979-022-01142-9.

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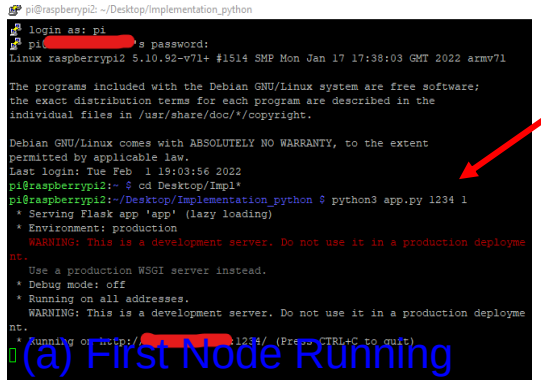
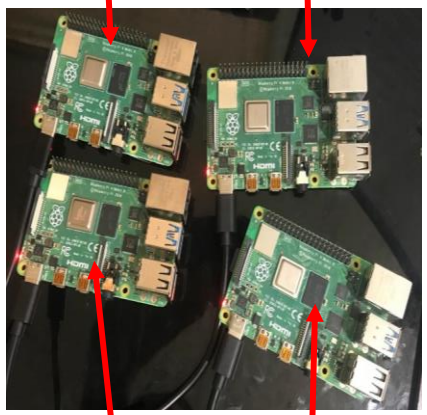
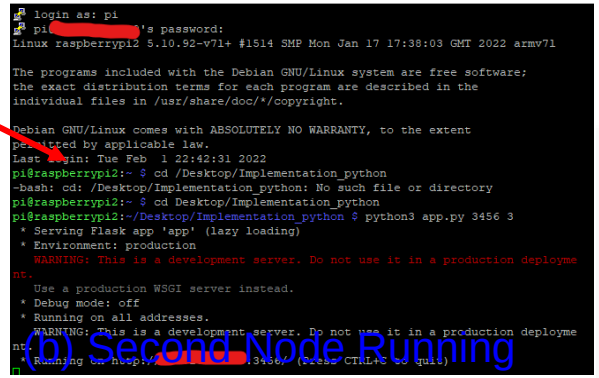


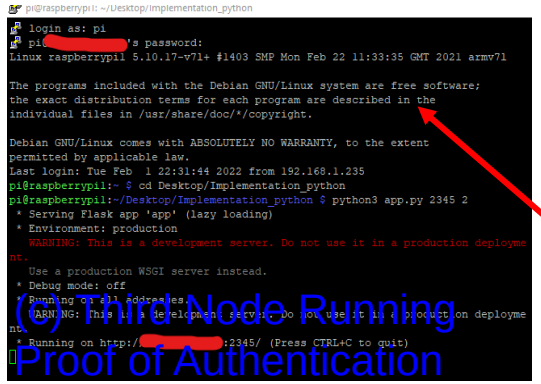
(a) First Node Running Proof of Authentication Based Blockchain



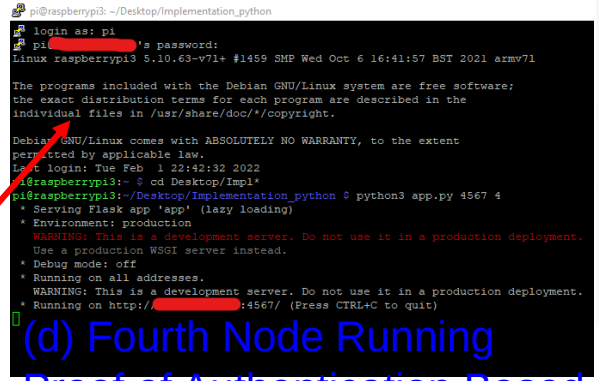
(e) Prototype of 4-Node Blockchain Network



(b) Second Node Running Proof of Authentication Based Blockchain



(c) Third Node Running Proof of Authentication Based Blockchain



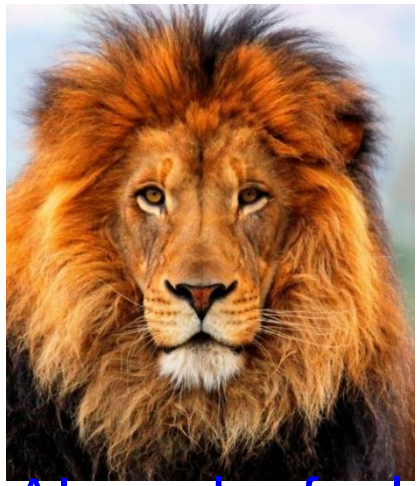
(d) Fourth Node Running Proof of Authentication Based Blockchain

Operation Performed	Average Operation Time (ms)
Node Registration and Broadcasting	447
Transaction Creation and Broadcasting	645
Mining New Block	434
Accessing Data from Blockchain	220

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.

Smart Healthcare – Trustworthy Pharmaceutical Supply Chain

Fake Data and Fake Hardware – Both are Equally Dangerous in CPS

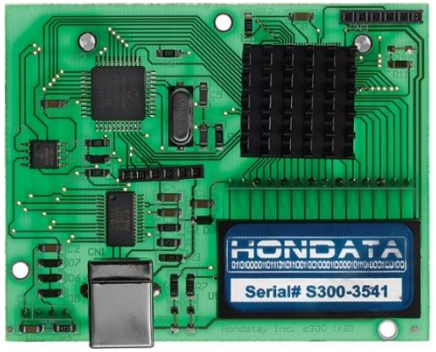


AI can be fooled by fake data

AI can create fake data (Deepfake)

Authentic Fake

An implantable medical device



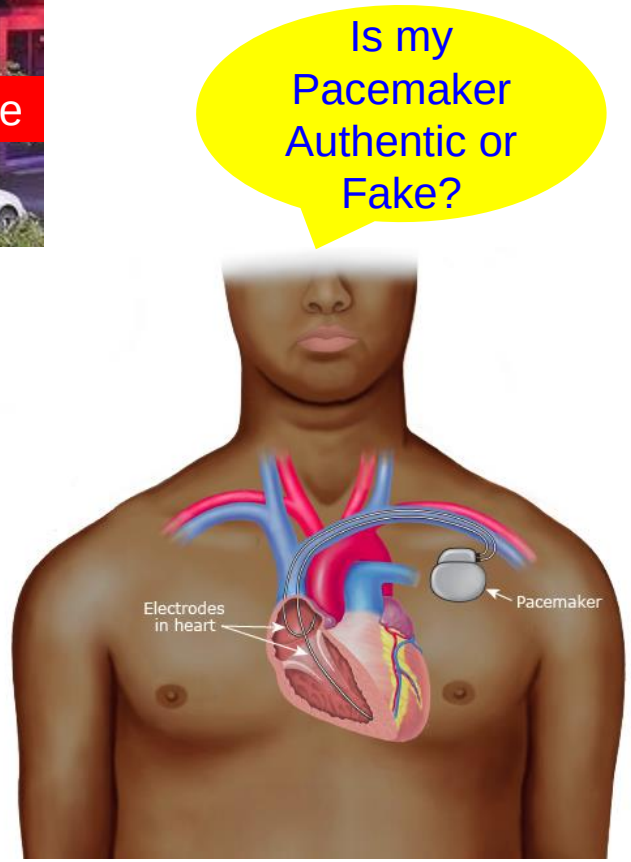
Authentic Fake

A plug-in for car-engine computers

Fake is Cheap – Why not Buy?

Source: https://www.quora.com

Source: https://nypost.com/



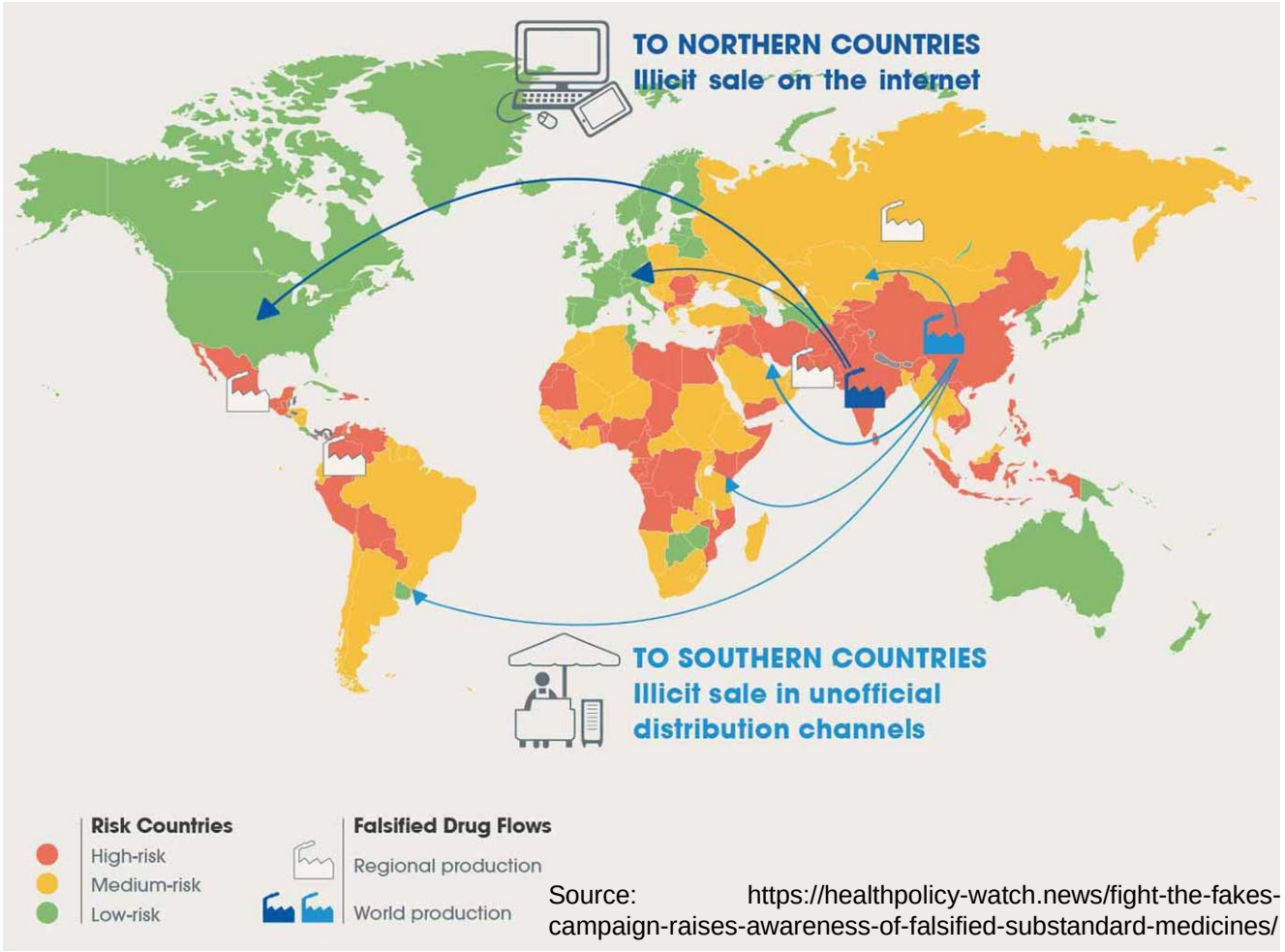
Source: https://apro.ipsf.org/

Fake Medicine - Serious Global Issue

- It is estimated that close to $83 billion worth of counterfeit drugs are sold annually.
- One in 10 medical products circulating in developing countries are substandard or fake.
- In Africa: Counterfeit antimalarial drugs results in more than 120,000 deaths each year.
- USA has a closed drug distribution system intended to prevent counterfeits from entering U.S. markets, but it isn't foolproof due to many reason including illegal online pharmacy.

Source: https://fraud.org/fakerx/fake-drugs-and-their-risks/counterfeit-drugs-are-a-global-problem/

Source: https://allaboutpharmacovigilance.org/be-aware-of-counterfeit-medicine/

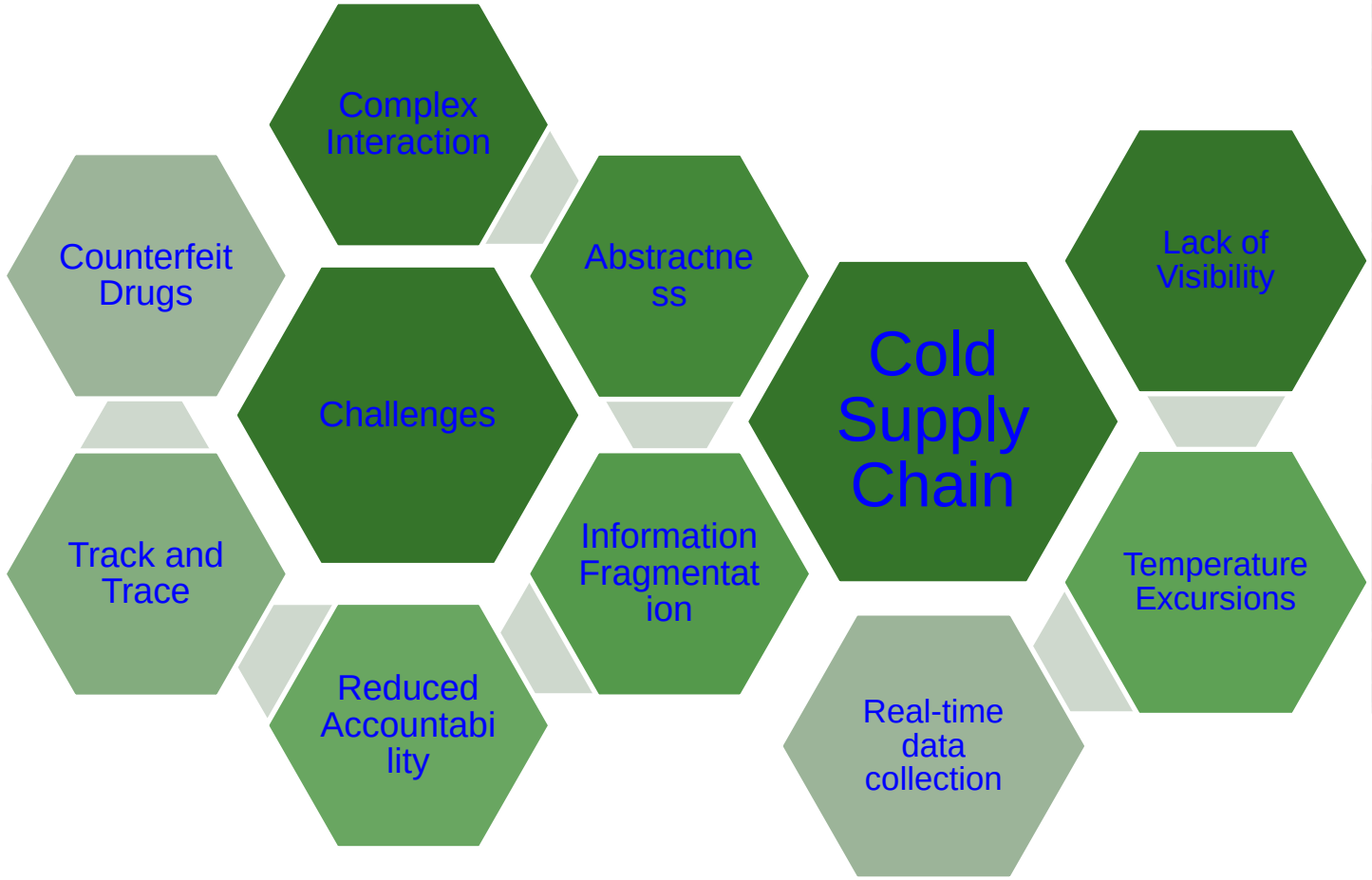


Source: https://healthpolicy-watch.news/fight-the-fakes-campaign-raises-awareness-of-falsified-substandard-medicines/

Typical Pharmaceutical Supply Chain

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041. (Dataset for Research: GitHub)

Issues in Traditional PSC



08/22/2022

BEAUMONT, Texas – A Florida-based pharmaceutical president has pleaded guilty to federal drug trafficking violations in the Eastern District of Texas, announced U.S. Attorney Brit Featherston toda

11/12/2021

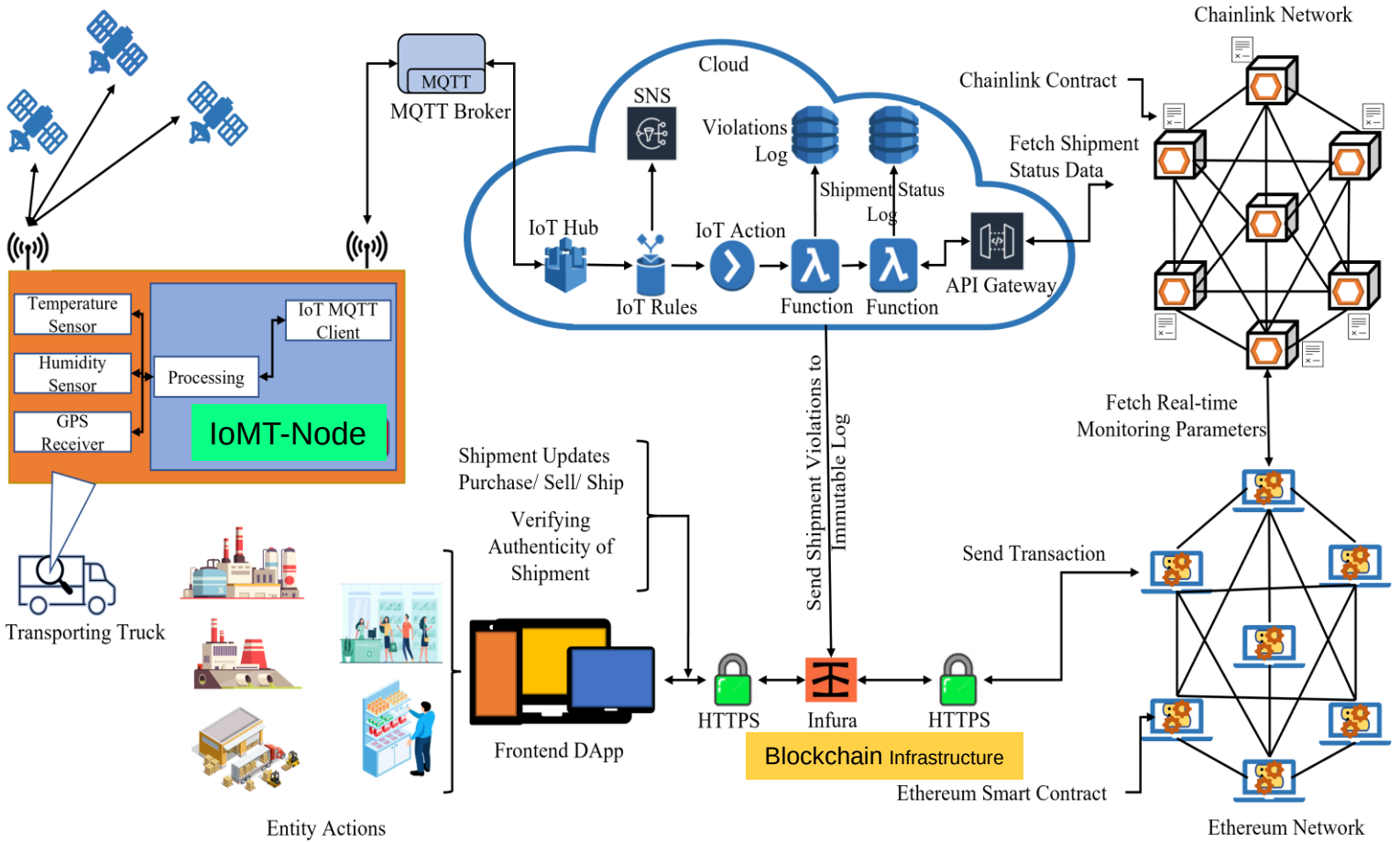
A federal grand jury in Beaumont has returned a three-count indictment charging nine individuals in drug trafficking conspiracy in the Eastern District of Texas, announced Acting U.S. Attorney Nicholas J. Ganjei today

08/24/2021

ALEX NDRIA, Va. – An Inverness, Florida, man was sentenced today to three years in prison for selling hundreds of thousands of counterfeit prescription drug pills through the Internet.

News Source: Affairs, O. of R. (n.d.). *Press releases*. U.S. Food and Drug Administration. Retrieved November 15, 2022, from https://www.fda.gov/inspections-compliance-enforcement-and-criminal-investigations/criminal-investigations/press-releases

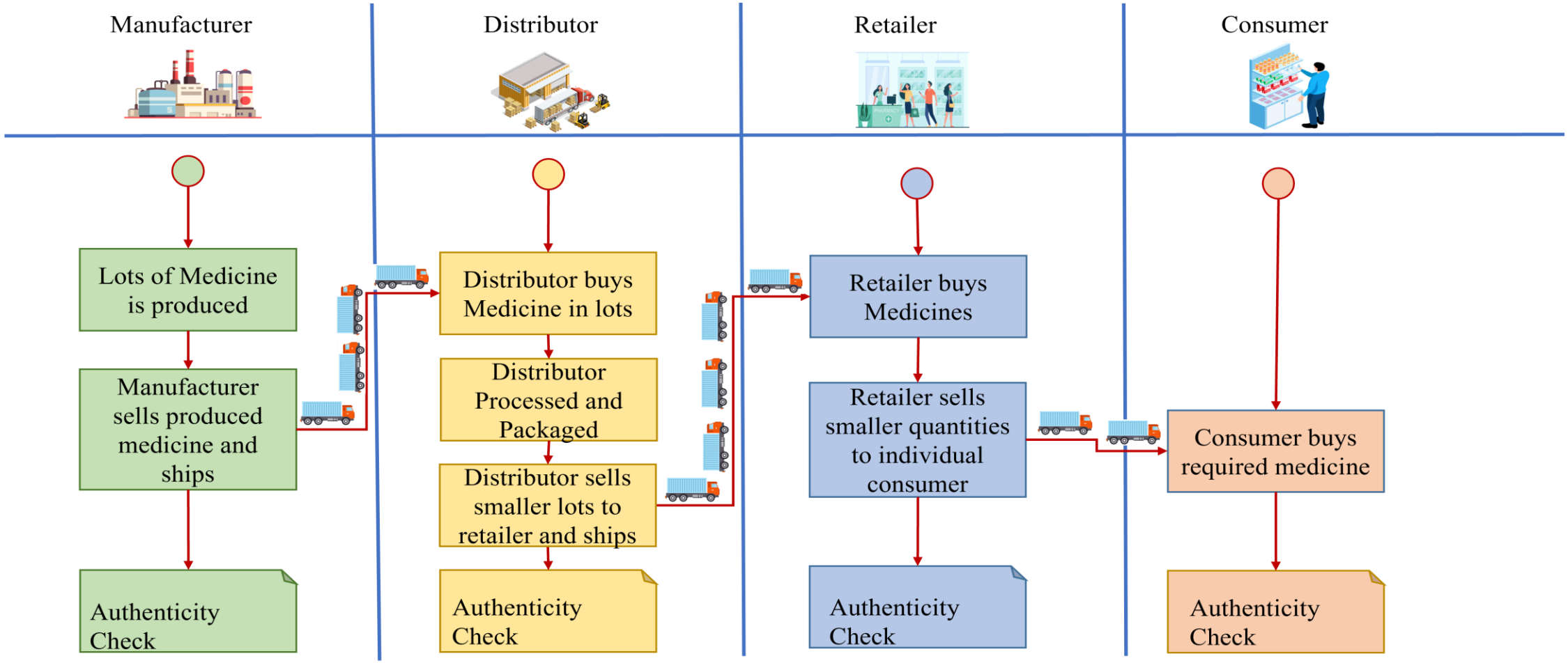
Architectural Overview of PharmaChain



- IoT sensing nodes placed in transport trucks
- Cloud component for off-chain storage of unimportant data
- Chainlink component for interfacing real-time monitoring parameters from the sensing nodes to Ethereum smart contracts
- Ethereum blockchain component for creating an immutable and transparent ledger
- Web DApp to interact

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041.

PharmaChain Entity Activity Diagram

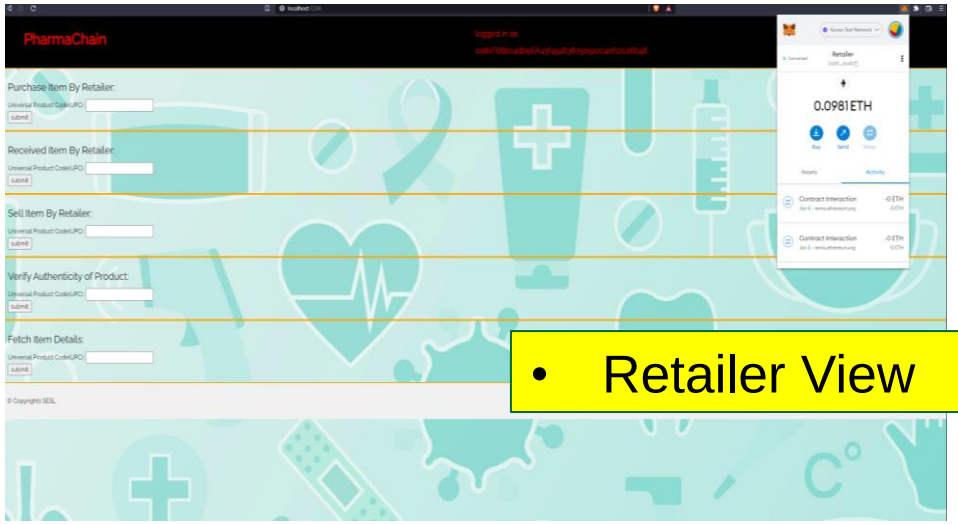


Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041.

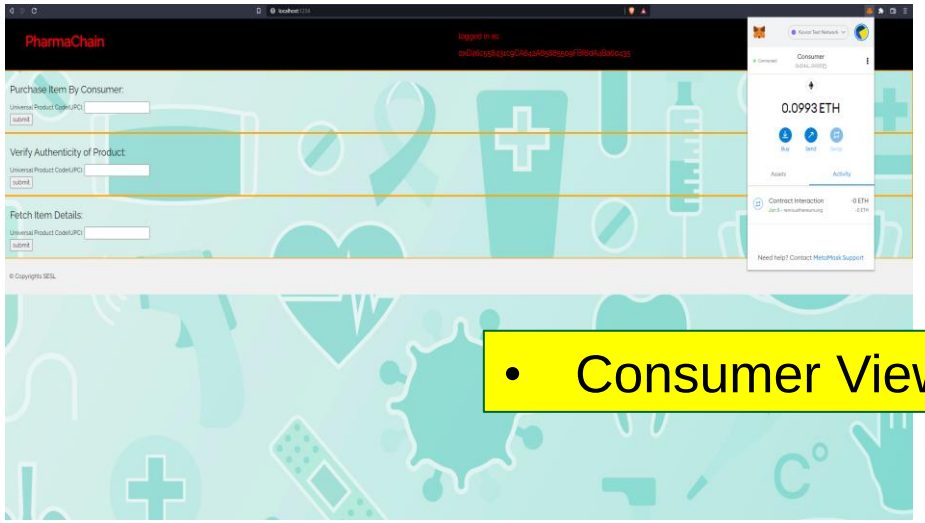
Web DApp Interface

- Manufacturer View

- Distributor View



- Retailer View



- Consumer View

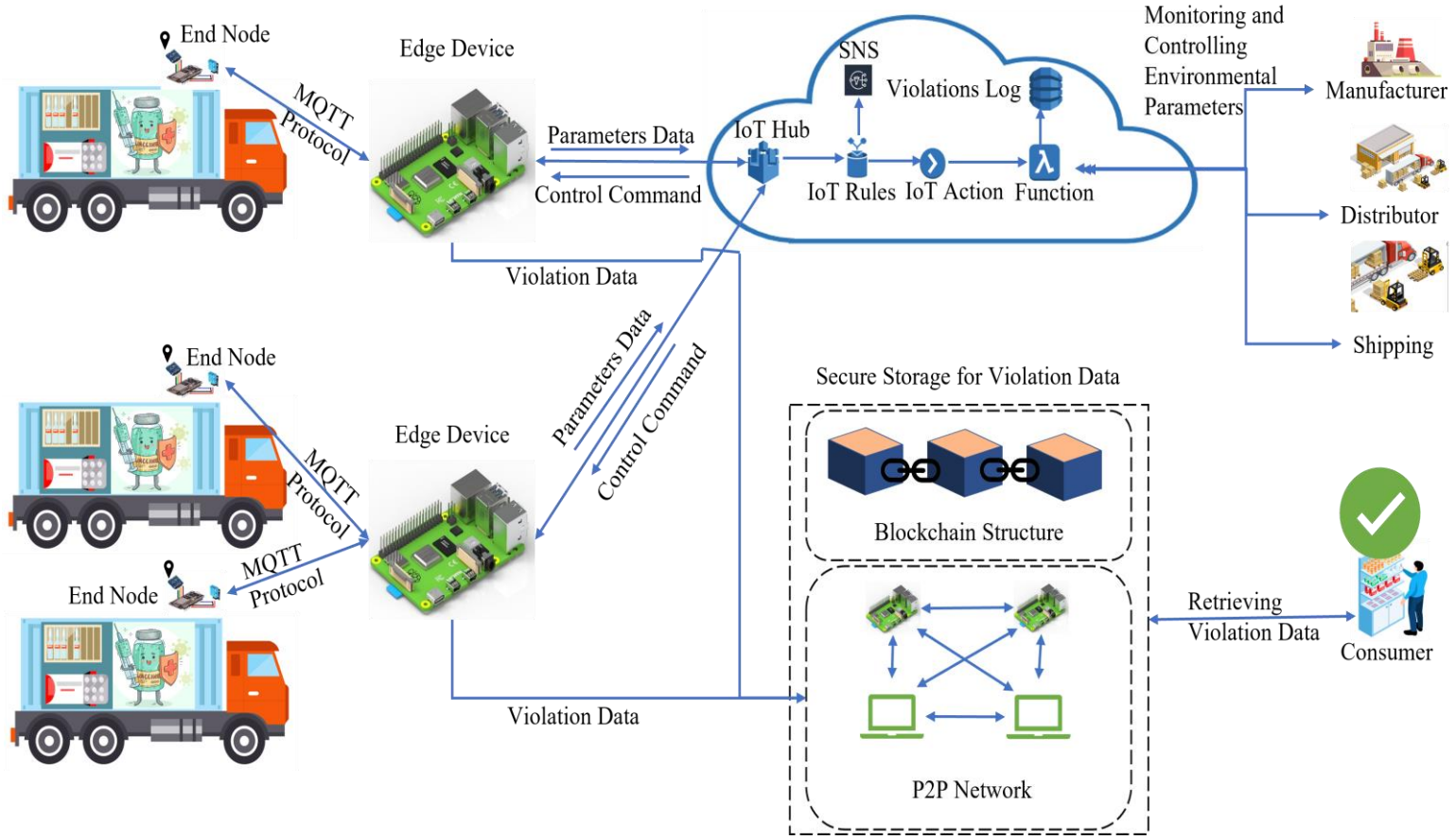
Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041.

Comparative Analysis With Existing Solutions

Parameter	Subramanian et.al. [30]	Bocek et.al. [31]	Kumar et.al. [32]	Huang et.al. [33]	Alhoori et.al. [36]	Our Solution
Blockchain Platform	New Economic Movement (NEM)	Ethereum	-	Bitcoin	Ethereum	Ethereum
Business Functions	Smart Contracts	Smart Contracts	-	UTXO Scripts	Smart Contracts	Smart Contracts
Consensus Mechanism	PoI	PoW	-	PoW	PoW	PoA
Data Integration from IoT	Cloud Functions	Centralized Database	[×]	[×]	Cloud Functions	Oracles
Transactions Re-playable	[×]	[×]	[×]	[×]	[×]	[✓]
IoT Integration	[✓]	[✓]	[×]	[×]	[✓]	[✓]
Scalability Analysis	[×]	[×]	[×]	[×]	[✓]	[✓]
Cost Analysis	[×]	[×]	[×]	[×]	[×]	[✓]
Security Analysis	[×]	[×]	[×]	[✓]	[×]	[✓]
User Friendly Interface	[✓]	[×]	[×]	[×]	[✓]	[✓]
Access Control Mechanism	[×]	[×]	[×]	[×]	[✓]	[✓]
Real-time Decision Support Tools	[×]	[×]	[×]	[×]	[✓]	[✓]
Throughput	Highest	Less	-	Least	Less	Higher

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, D. Puthal, and A. Bapatla, "PharmaChain: A Blockchain to Ensure Counterfeit-Free Pharmaceutical Supply Chain", *IET Networks*, Vol. XX, No. YY, ZZ 2022, pp. Accepted on 24 June 2022, DOI: https://doi.org/10.1049/ntw2.12041.

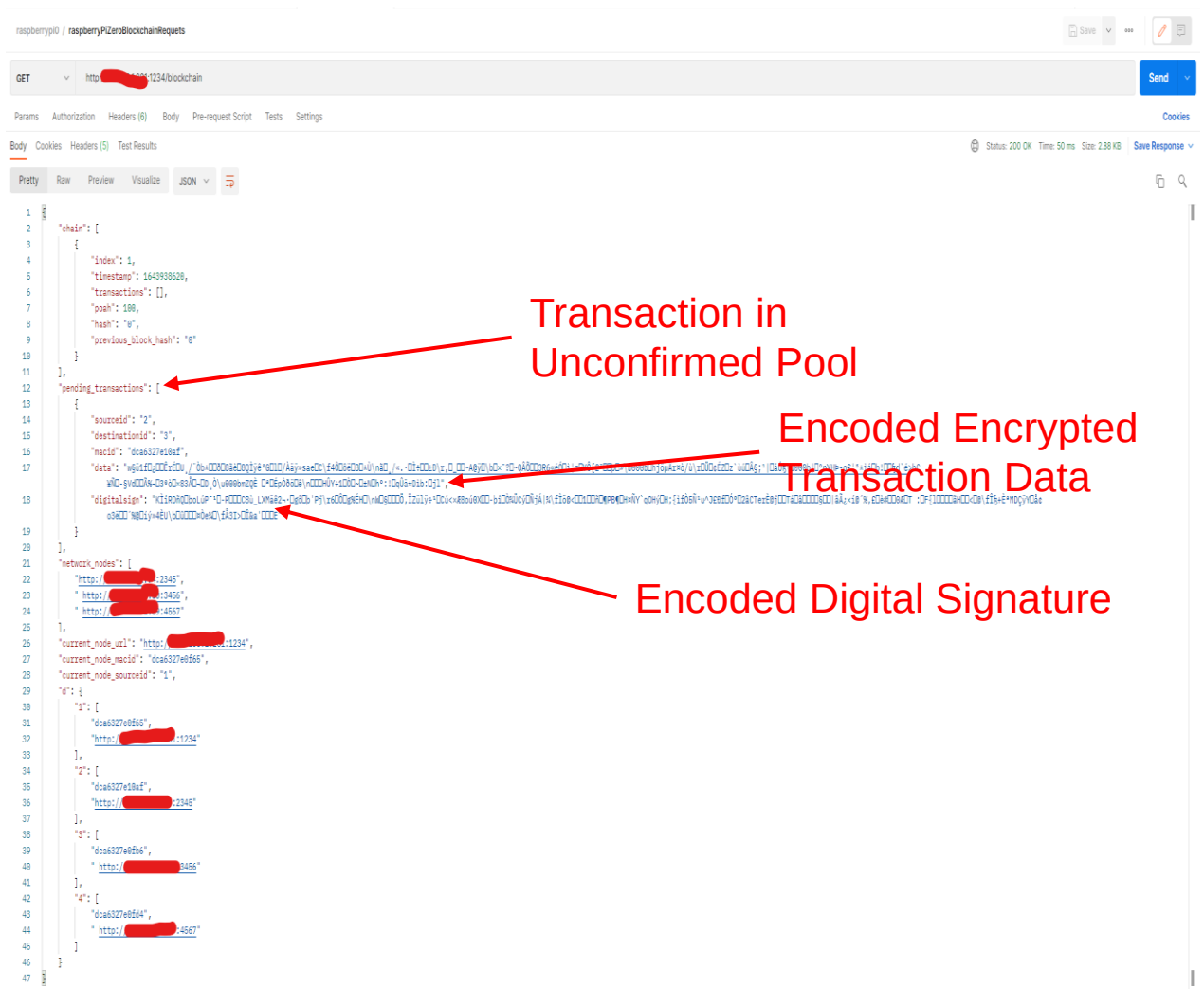
Architectural Overview of PharmaChain 2.0



- End nodes which are placed near the drug shipments
- Edge devices with higher storage capabilities and can perform lightweight computations
- Cloud layer is used in PharmaChain 2.0 for delivering the alerts and controlling the actuators
- Blockchain Layer consists of the P2P nodes deployed and managed by the multiple entities of the cold supply chain

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

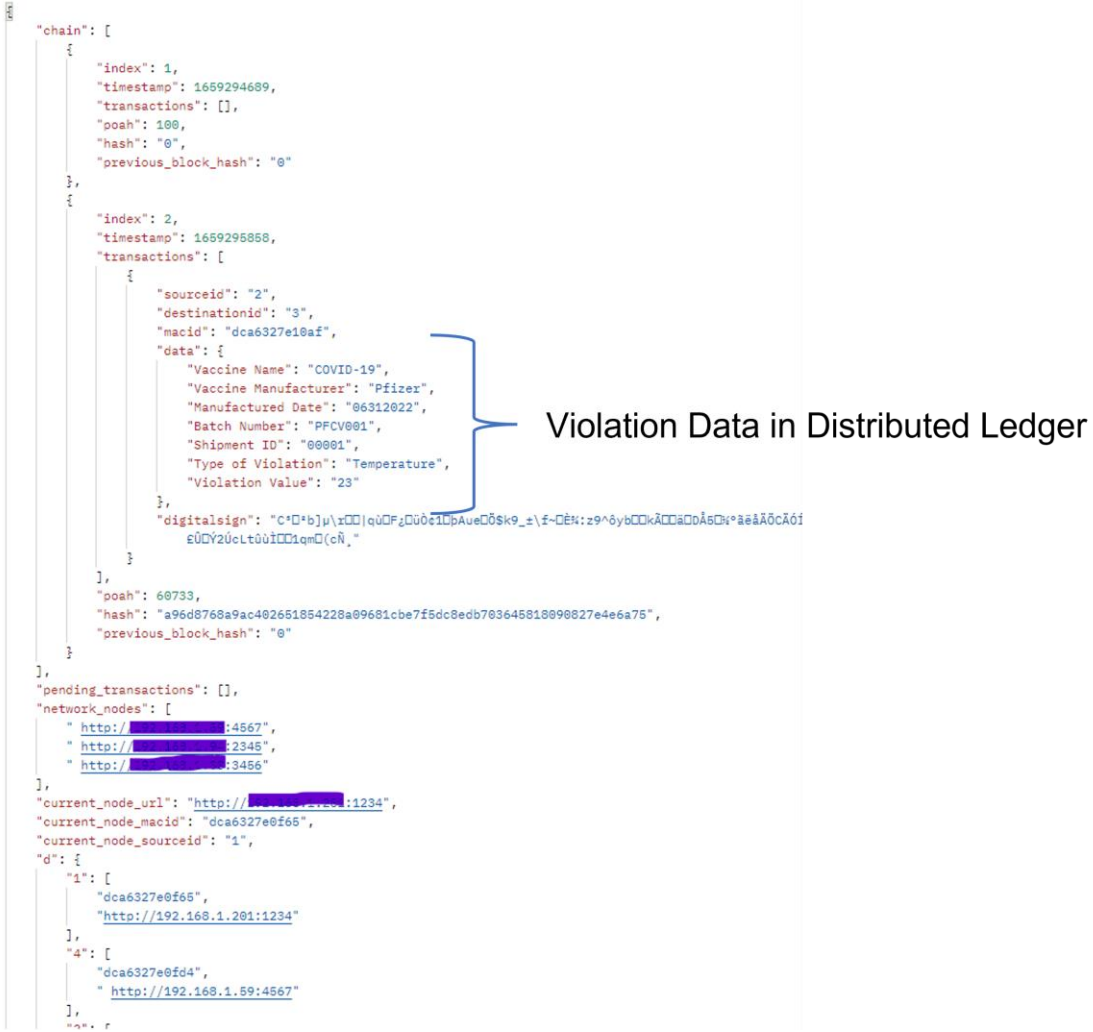
Pharmachain 2.0 Validation



Transaction in Unconfirmed Pool

Encoded Encrypted Transaction Data

Encoded Digital Signature



Violation Data in Distributed Ledger

Source: A. K. Bapatla, **S. P. Mohanty**, E. Kougianos, and D. Puthal, "PharmaChain 2.0: A Blockchain Framework for Secure Remote Monitoring of Drug Environmental Parameters in Pharmaceutical Cold Supply Chain", in *Proceedings of the IEEE International Symposium on Smart Electronic Systems (iSES)*, 2022, pp. Accepted.

Comparative Analysis with Existing Solutions

Parameter	CryptoCargo [15]	PharmaChain [9]	**Current Solution (PharmaChain 2.0)**
Blockchain	Ethereum	Ethereum	PoAh consensus based Blockchain
Consensus Protocol	Proof-of-Work (PoW)	Proof-of-Authority (PoA)	Proof-of-Authentication (PoAh)
Openness	Public	Private	Public
IoT Friendly Consensus	No	No	Yes
Average Time	43.36sec	5.6sec	322.28ms

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.
- AI/ML is a key component of smart healthcare.
- IoMT provides advantages but also has limitations in terms of cybersecurity and privacy.
- Edge-AI for smart healthcare needs research.

Future Research

- Smart Healthcare will need robust data, device, and H-CPS security need more research.
- Cybersecurity of IWMDs needs to have very 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.
- Privacy-aware limited healthcare data sharing in global scale to reduce spread of pandemic outbreak.
- Pharmaceutical supply chain needs research to ensure counterfeit free medicine and vaccinees.

Smart Healthcare – Reality?

- Short answer - Yes

Smart Healthcare – Hype?

- Still long way to go …

Acknowledgement(s)

This material is based upon work supported by the National Science Foundation under Grant Nos. OAC-1924112 and HBCU-EiR-2101181. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.