Smart Healthcare – Demystified

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Saraju P. Mohanty

University of North Texas, USA.

Email: saraju.mohanty@unt.edu

More Info: http://www.smohanty.org

Outline

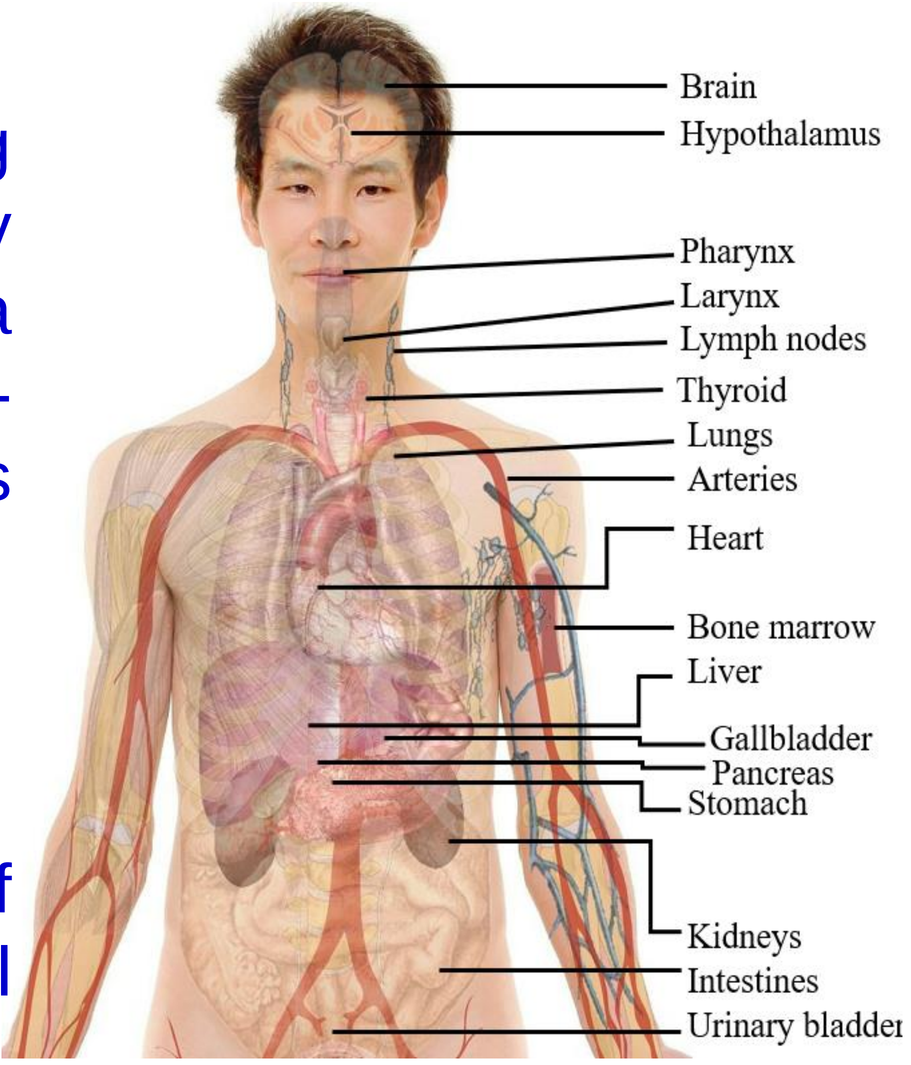
- Healthcare → Smart Healthcare
- Smart Healthcare - Characteristics
- Smart Healthcare - Components and Technologies
- Smart Healthcare - Challenges and Solutions
- Smart Healthcare - Selected Examples

Healthcare
to
Smart Healthcare

Human Body and Health

Human Body

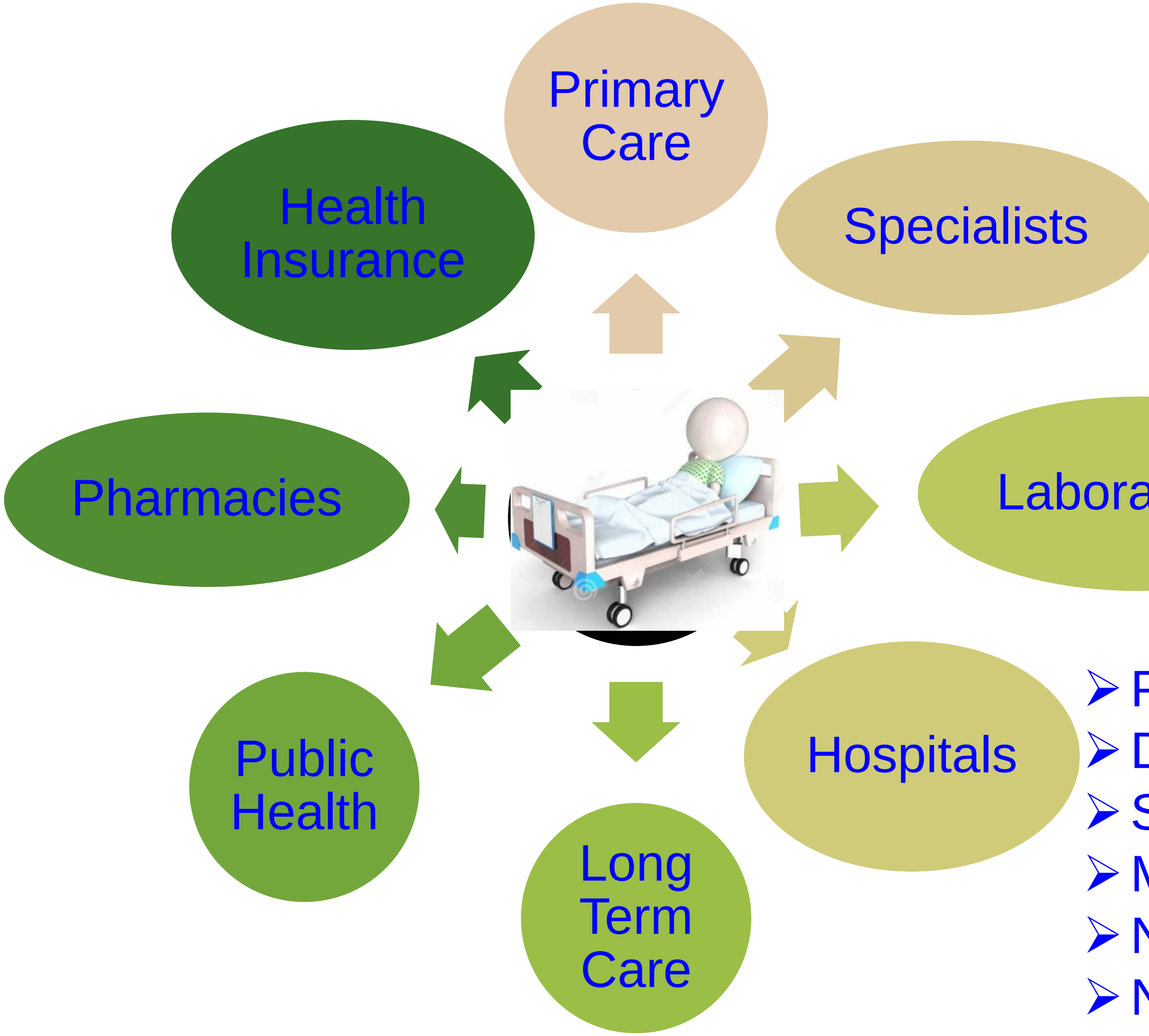
- From an engineering perspective, the human body can be defined as a combination of multi-disciplinary subsystems (electro-mechanical-chemical…).



Health

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

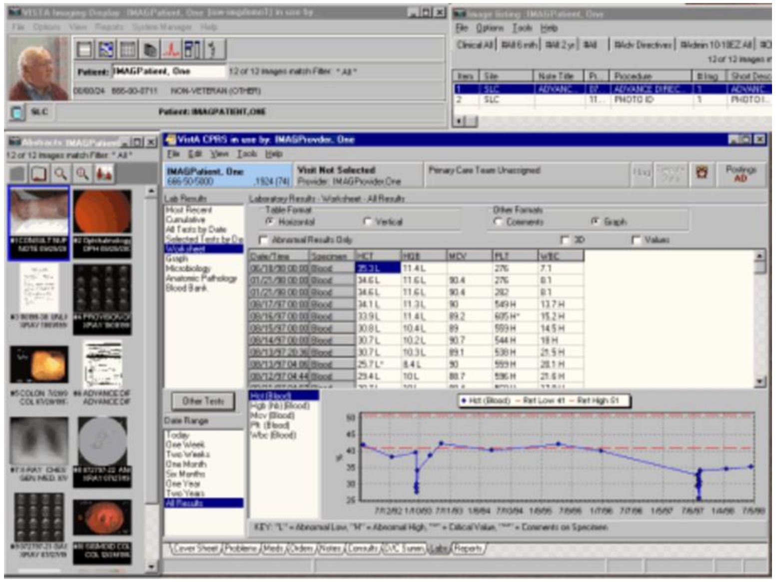
Traditional Healthcare



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

Electronic Health (eHealth)

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



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.

Telemedicine

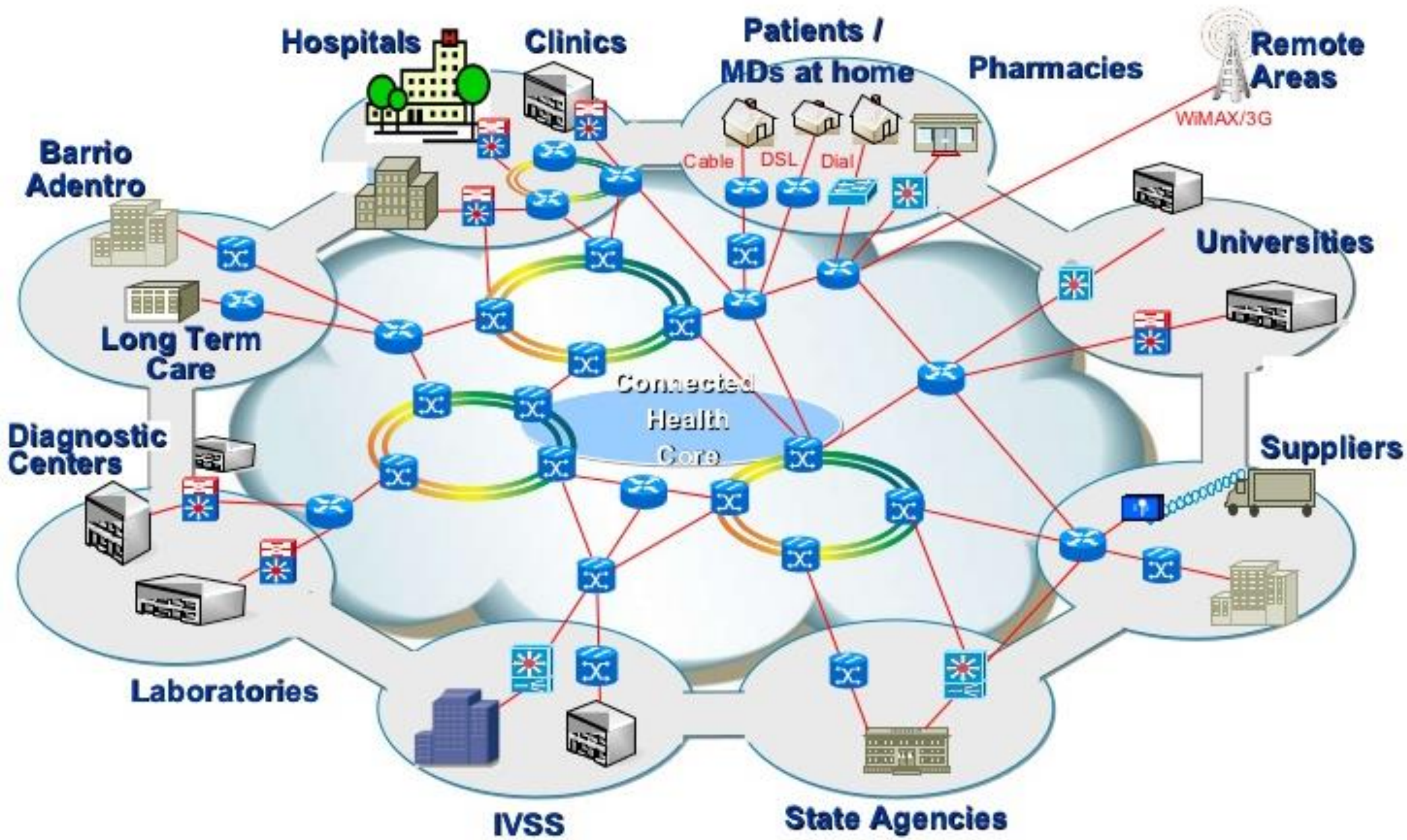
Telemedicine is the use of telecommunication and information technology to provide clinical health care from a distance.

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.

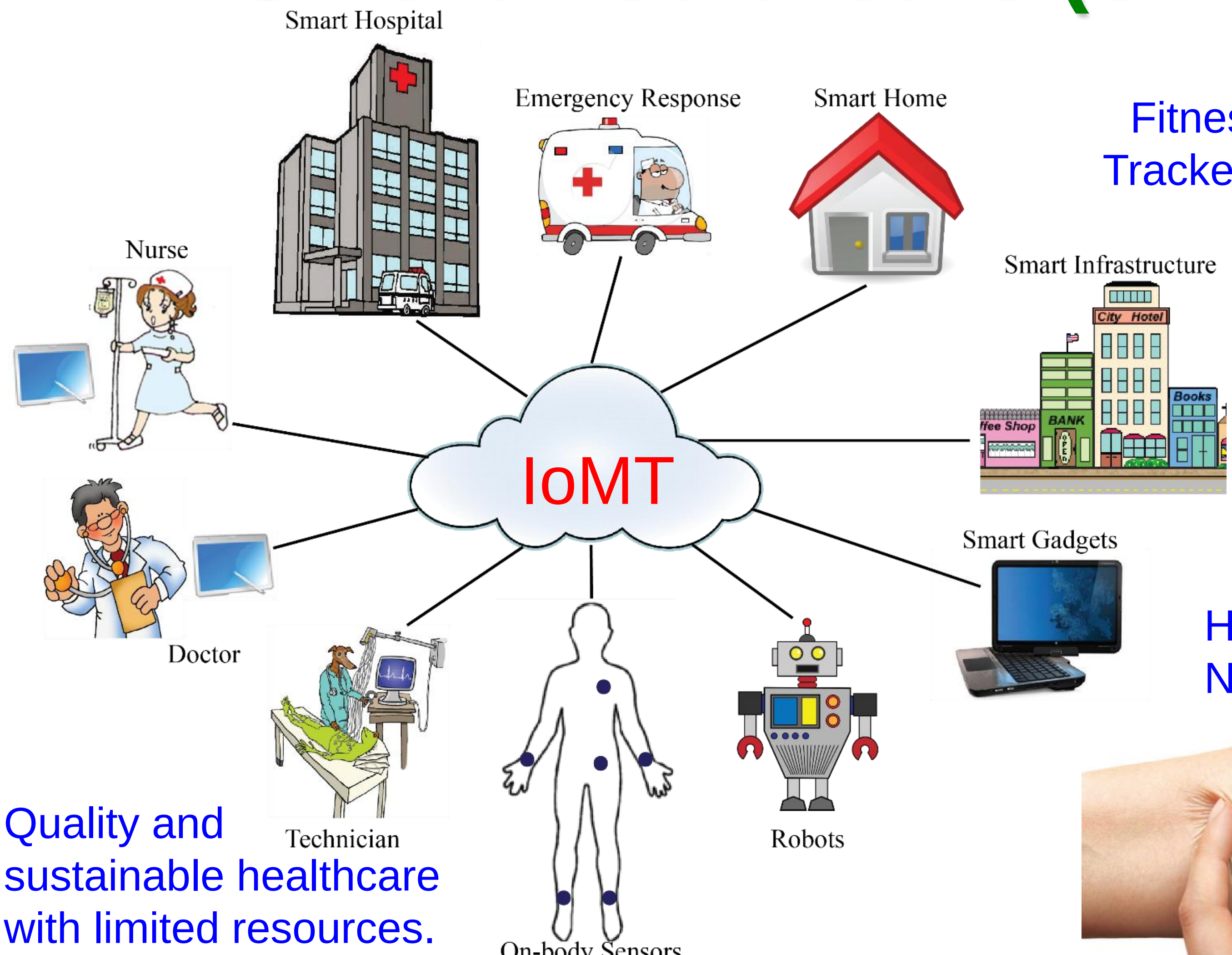
Source: H. Zhu, C. K. Wu, C. H. KOO, Y. T. Tsang, Y.Liu, H. R. Chi, and K. F. Tsang, "Smart Healthcare in the Era of Internet-of-Things", *IEEE Consumer Electronics Magazine*, vol. 8, no. 5, pp. 26-30, Sep 2019.

Connected Health (cHealth)



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

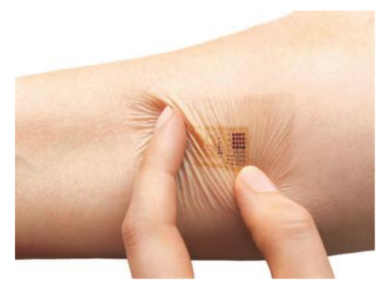
Smart Healthcare (sHealth)



Fitness Trackers

Headband with Embedded Neurosensors

Embedded Skin Patches



Quality and sustainable healthcare with limited resources.

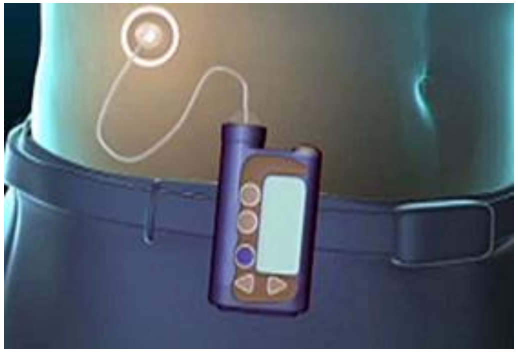
Sethi 2017: JECE 2017

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.

Wearable Medical Devices (WMDs)

Fitness Trackers

Headband with Embedded Neurosensors

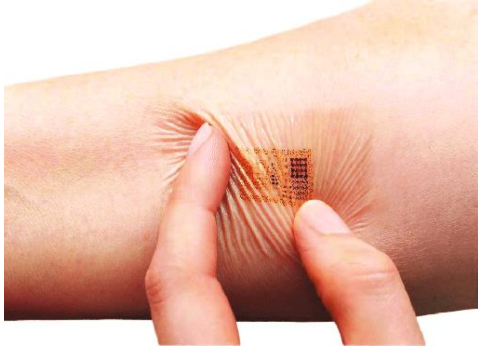


Source: https://www.webmd.com

Insulin Pump

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

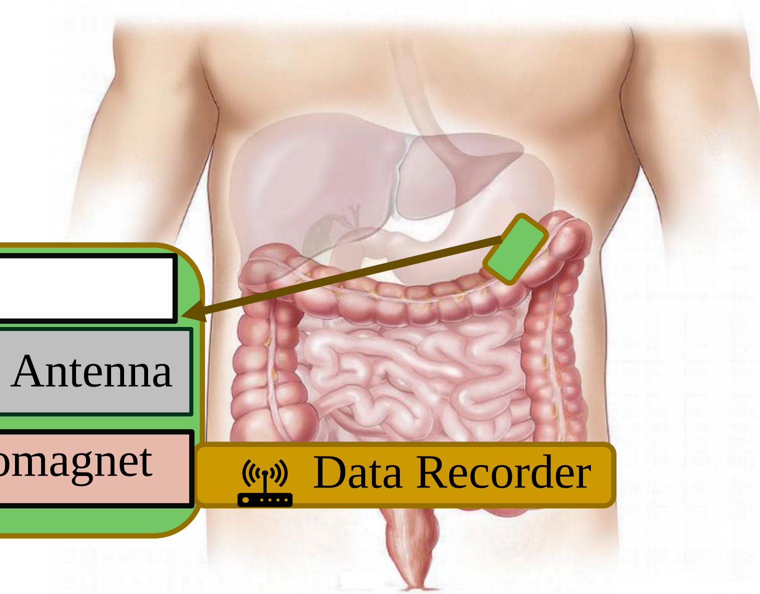
Medical grade smart watch to detect seizure

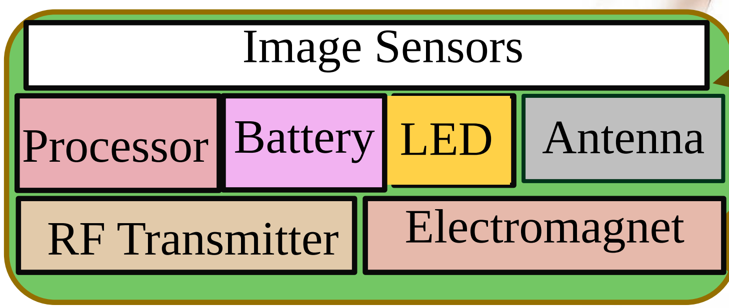


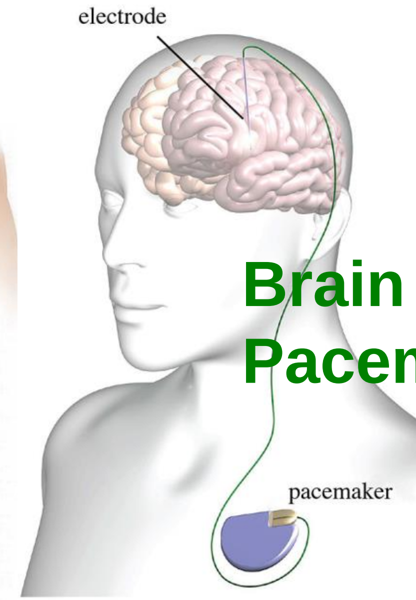
Embedded Skin Patches

Implantable Medical Devices (IMDs)

Pill Camera





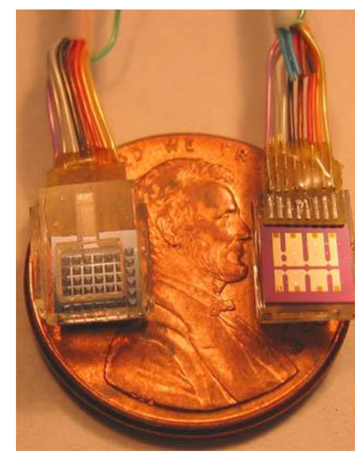


Brain Pacemaker

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

What is Smart Healthcare?

Smart Healthcare ← Conventional Healthcare

+ Body sensors
+ Smart Technologies
+Information & Communication Technology (ICT)
+ AI/ML

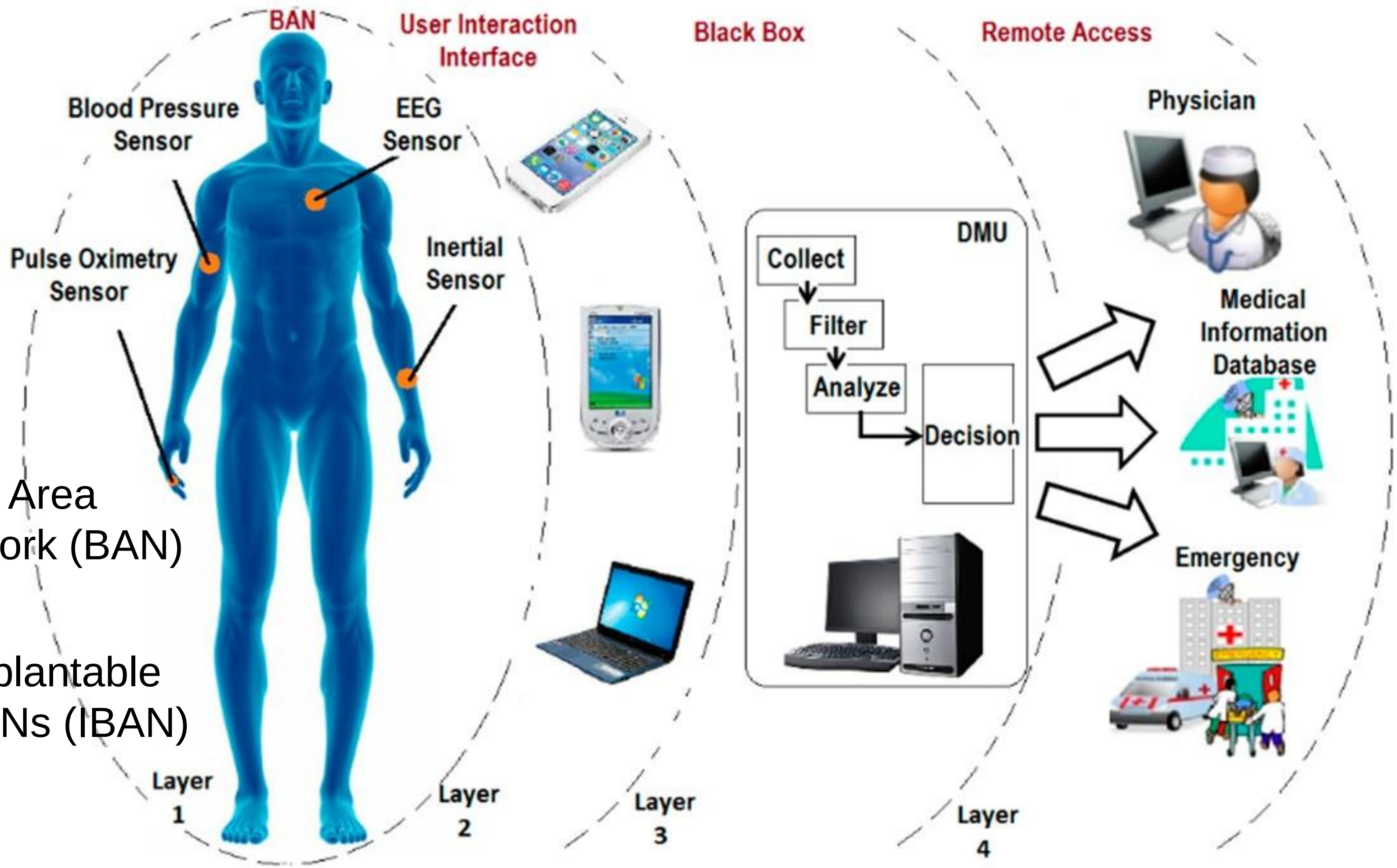
Internet of Medical Things (IoMT)

Internet of Health Things (IoHT)

Healthcare Cyber-Physical Systems (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



Body Area Network (BAN)

Implantable BANs (IBAN)

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.

Smart Healthcare - Characteristics

Smart Healthcare

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

Internet of Medical Things (IoMT)

Frost and Sullivan predict smart health-care 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.

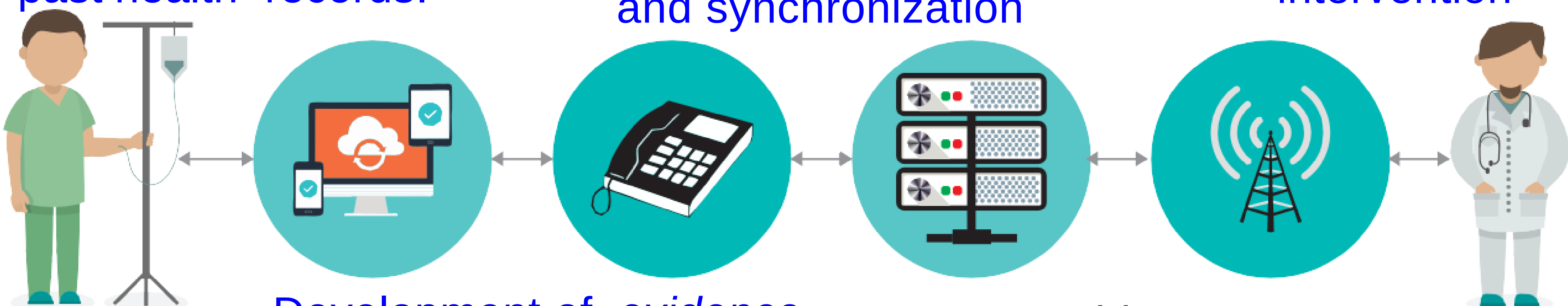
January 2018

IoMT - Impacts

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.

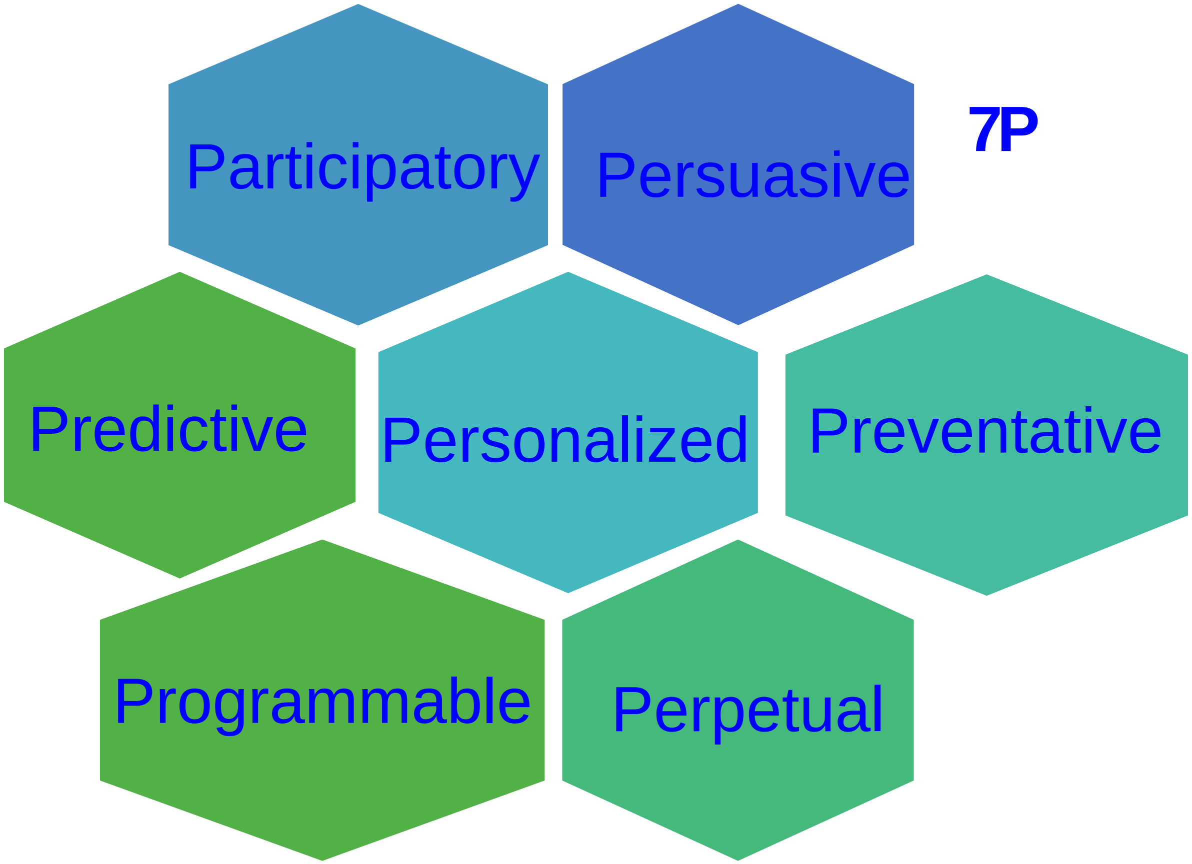
Data driven health *prediction*

Healthcare Provider

Healthcare Cyber-Physical Systems (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

Smart Healthcare - Tasks

Daily Healthcare | **Clinical Boundary** | **Clinical Healthcare**

(ii) Daily Diagnosis

- Wearable Medical Sensor (WMS)-based diagnosis

(i) Daily Prevention

- Fitness checkup
- Activity tracking
- Emotion analysis
- Disease risk prediction

(v) Daily Treatment

- Out-patient therapy
- Ambient healthcare
- Disease status monitoring
- Precision medicine

(iii) Clinical Diagnosis

- Physician variance reduction
- Personalized diagnosis

(iv) Clinical Treatment

- Treatment plan selection
- Treatment method evaluation
- In-patient monitoring
- Precision medicine

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

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

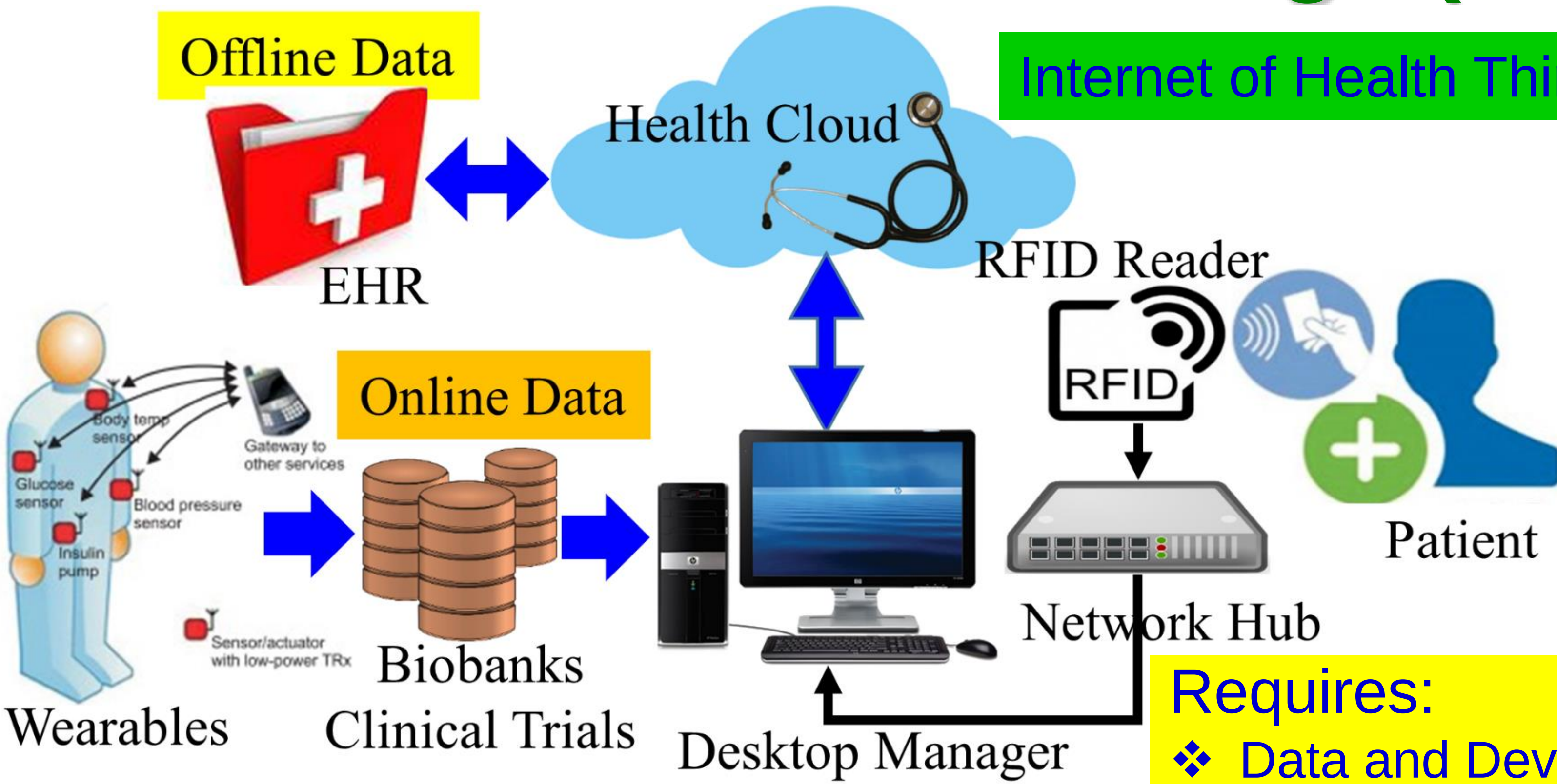
- Physician compliance
- Data overload on healthcare facility
- Mobile hesitation
- Security policy compliance

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)

Internet of Health Things (IoHT)



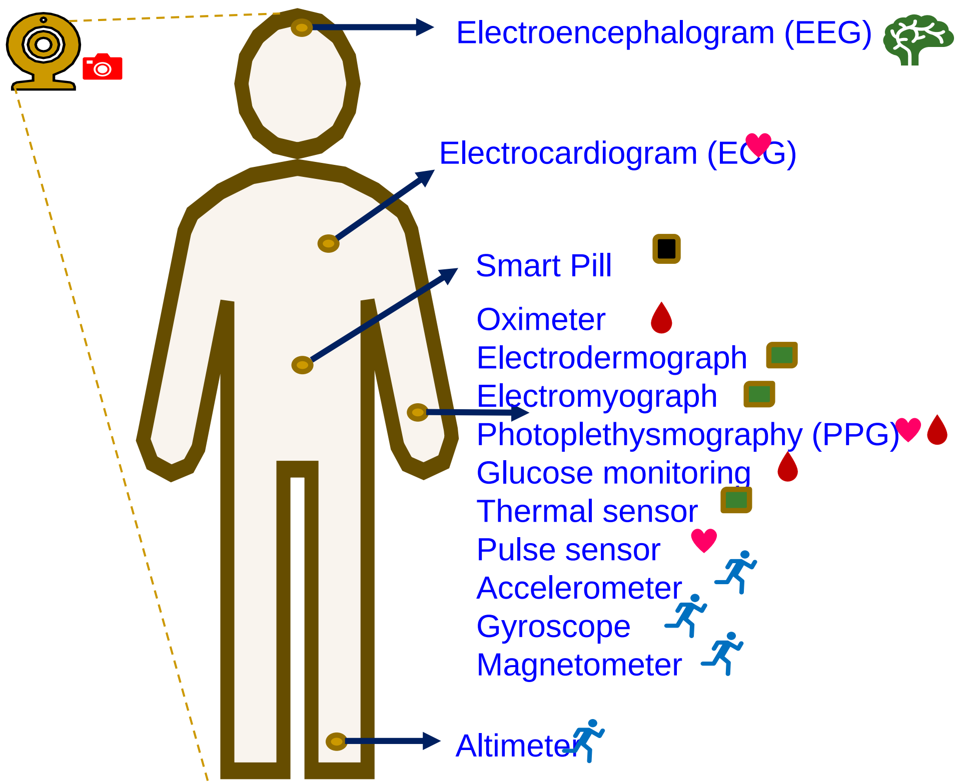
Requires:

- ❖ 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.

Smart Healthcare - Framework

Smart Healthcare - System and Data Analytics : To Perform Tasks

Systems & Analytics
- Health cloud server
- Edge server
- Implantable Wearable Medical Devices (IWMDs)

Machine Learning Engine

Data
- Physiological data
- Environmental data
- Genetic data
- Historical records
- Demographics

Systems & Analytics
- Clinical Decision Support Systems (CDSSs)
- Electronic Health Records (EHRs)

Machine Learning Engine

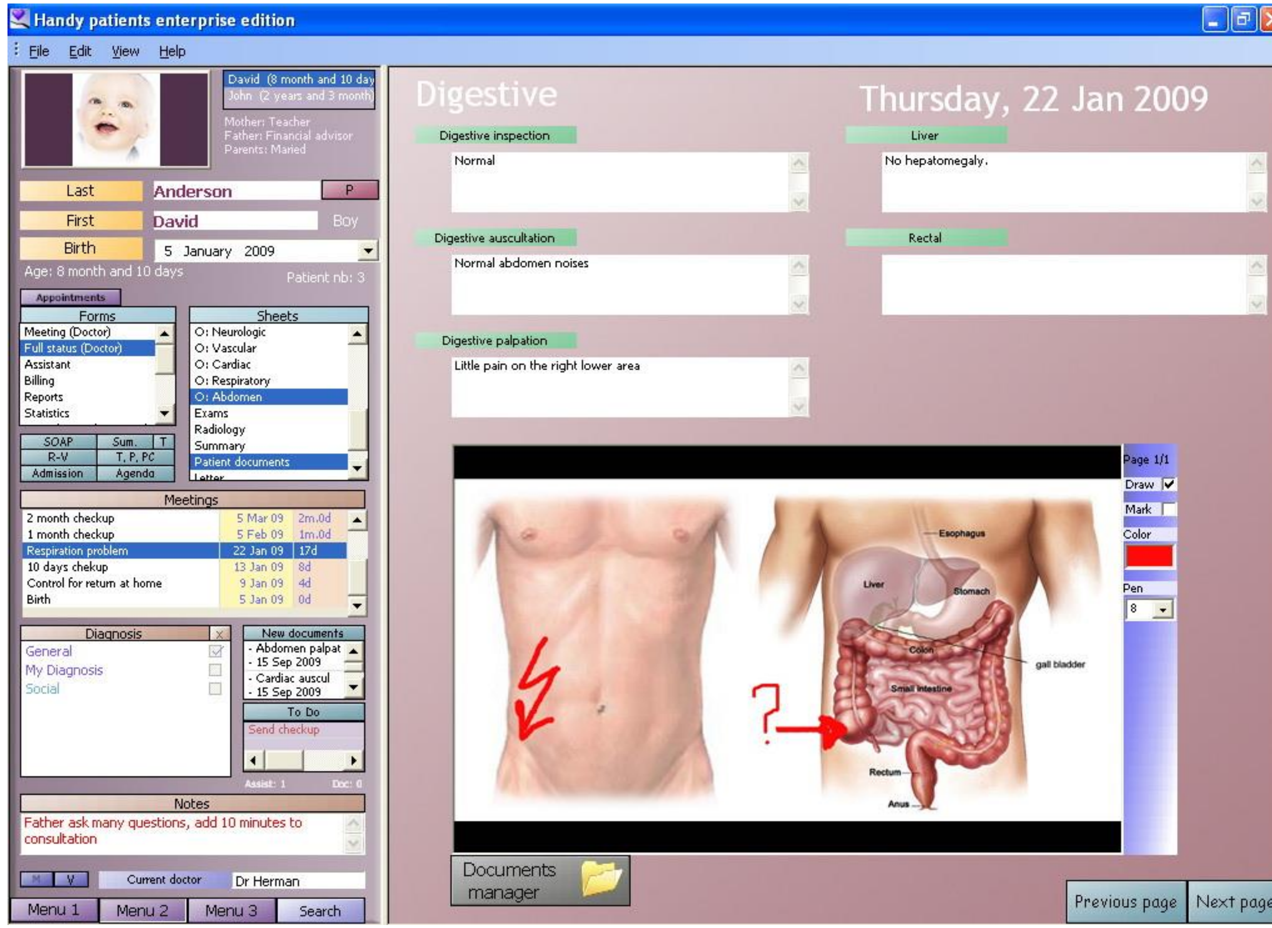
Data
- Physician observations
- Laboratory test results
- Genetic data
- Historical records
- Demographics

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)

Machine Learning (ML)

Supervised ML

- Data instance: features + label
- Data instance sets: training, testing
- Inference: Mathematical Model

Enhancement Techniques

- Ensemble method: base vs. meta
- Feature filtering: redundant vs. informative

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/

Virtual Reality in Healthcare

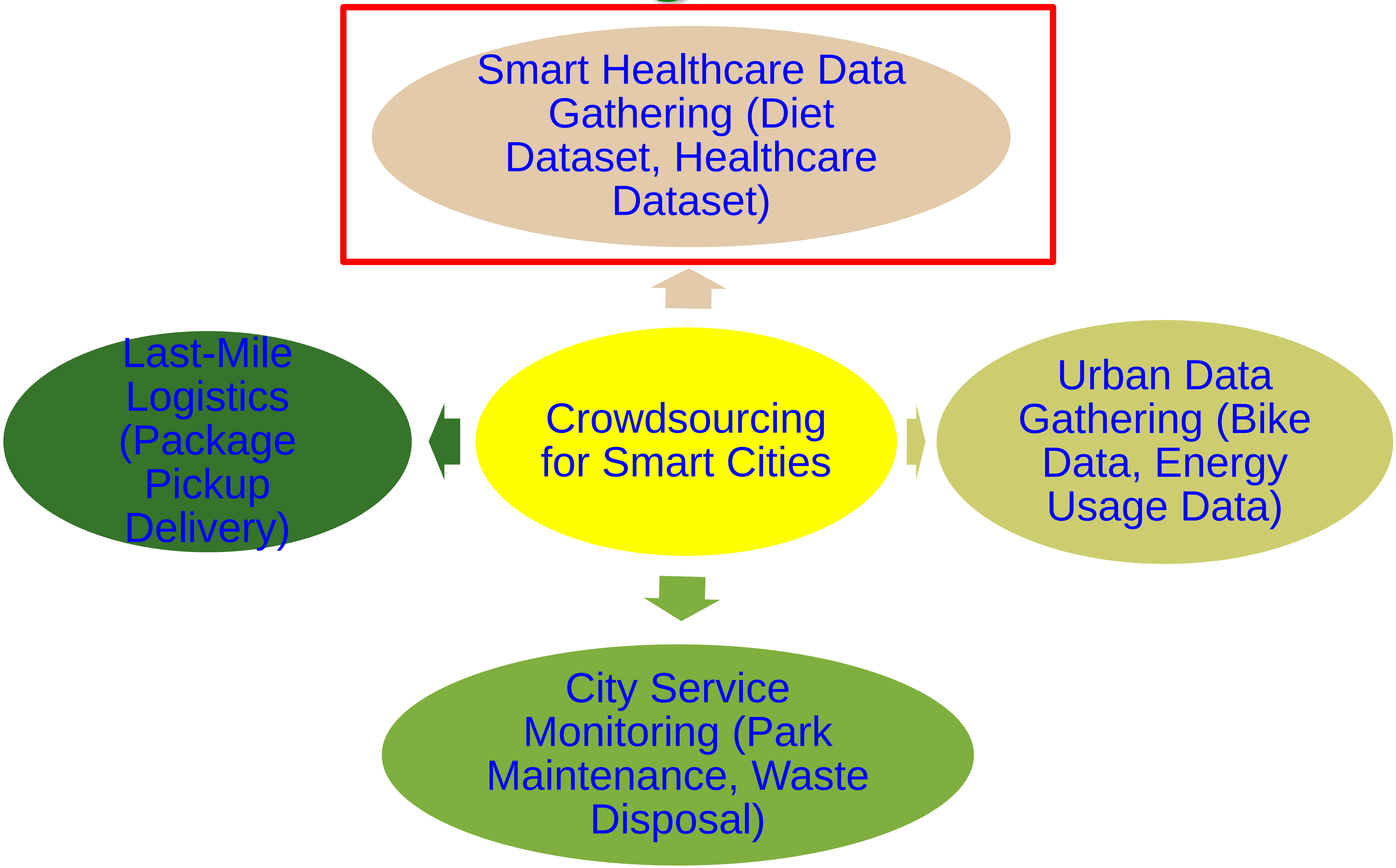
Source: https://touchstoneresearch.com/tag/applied-vr/

In Surgery

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

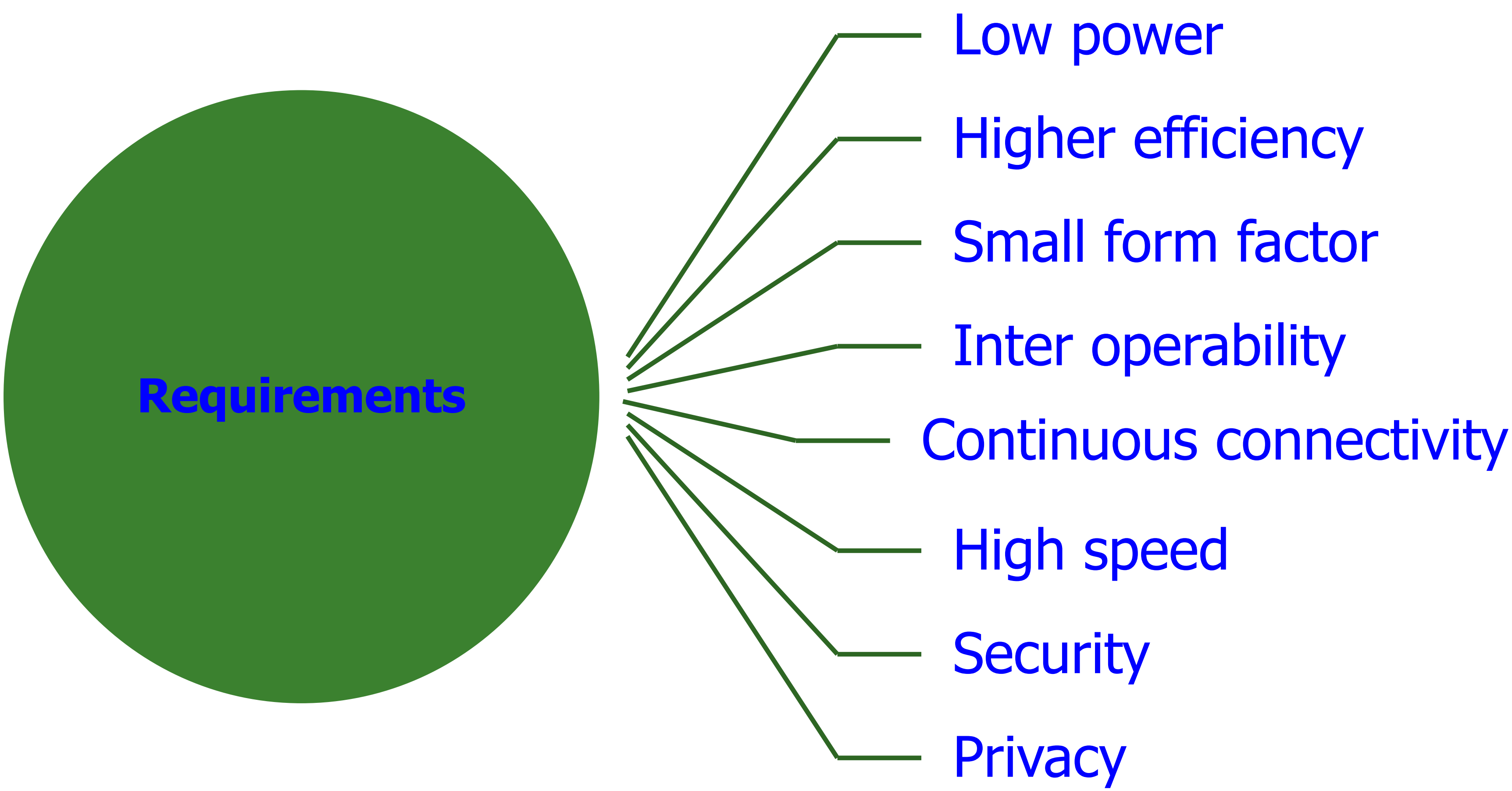
For Therapy

Crowdsourcing for Smart Cities



Smart Healthcare – Challenges and Solutions

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.

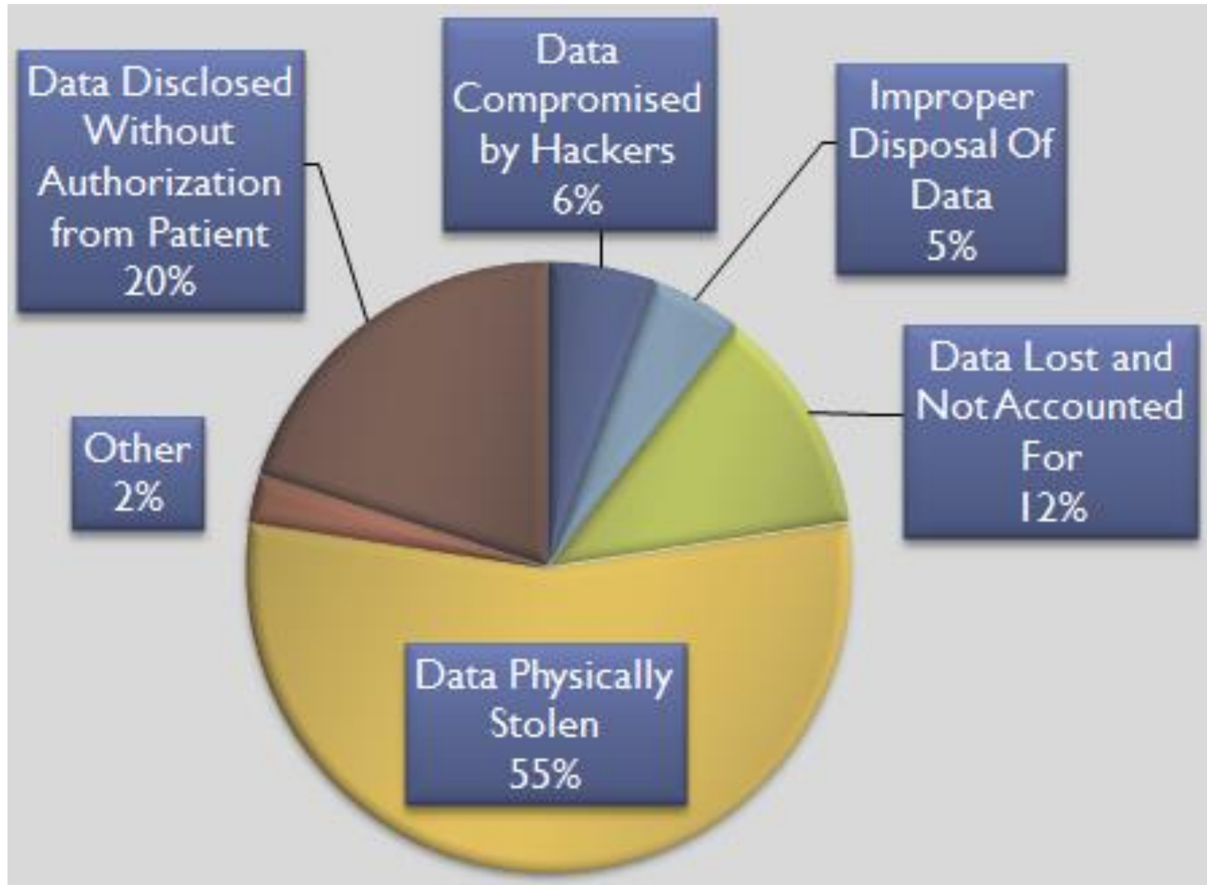
Smart Healthcare - Security Challenges

- Selected Smart Healthcare Security/Privacy Challenges
  - Data Eavesdropping
  - Data Confidentiality
  - Data Privacy
  - Location Privacy
  - Identity Threats
  - Access Control
  - Unique Identification
  - Data Integrity

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 Security Issue is Real & 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

Impersonation Attacks

Eavesdropping Attacks

Smart Healthcare

Reverse Engineering Attacks

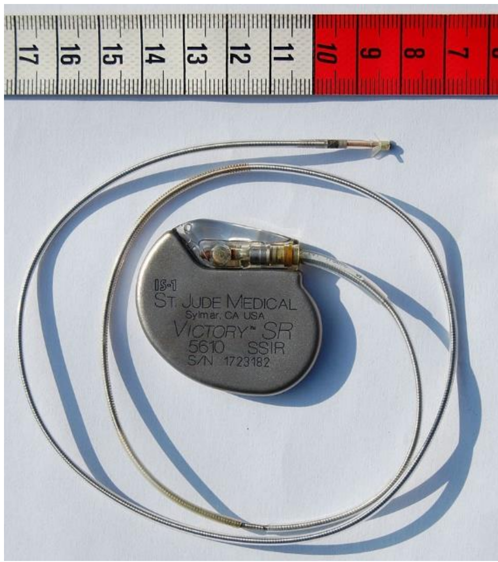
Radio Attacks

Security Threats for IoMT

- Physical Attack
- Network Attack
- Software Attack
- Encryption Attack

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 - Energy Constrained



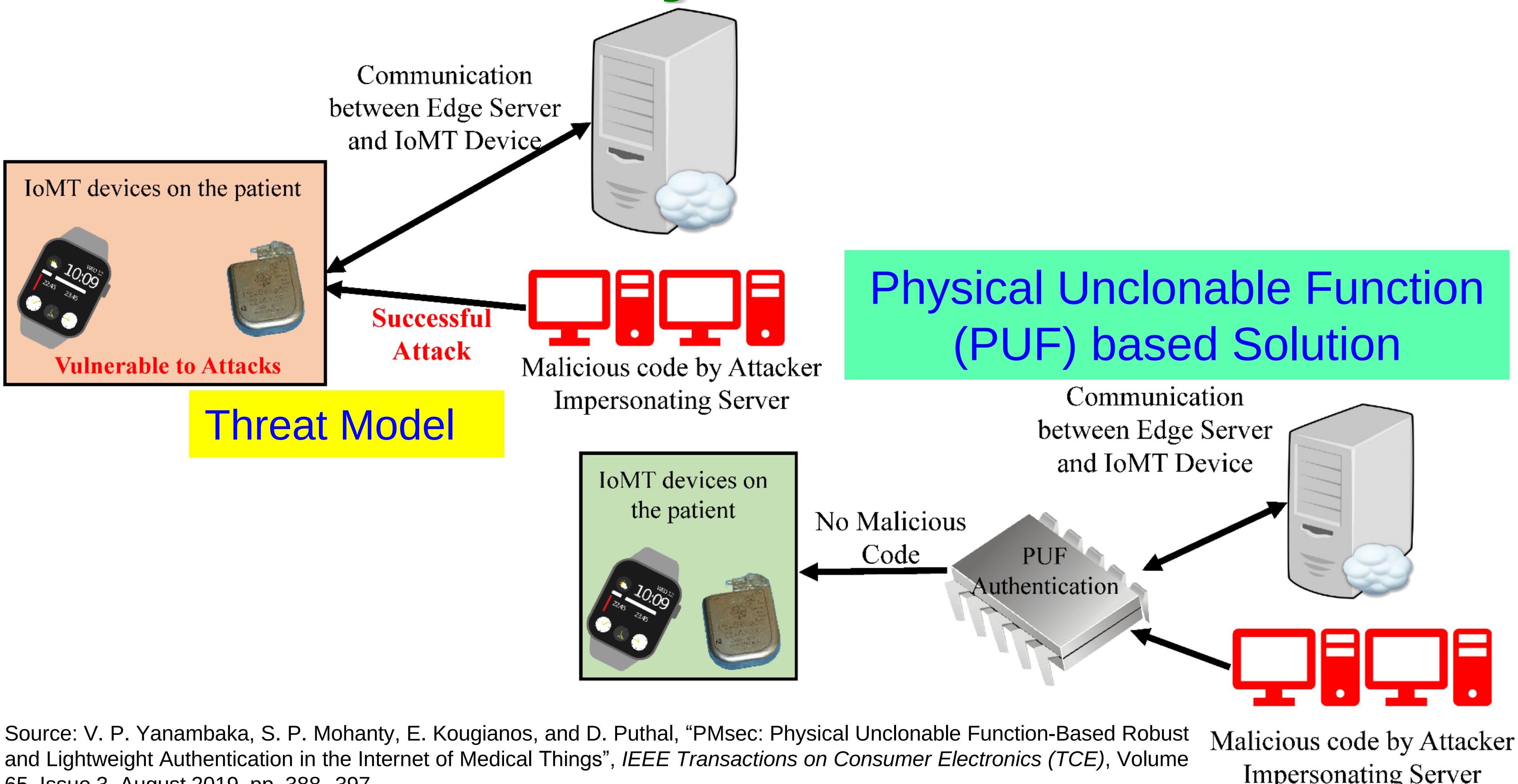
Pacemaker Battery Life - 10 years

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.

Our Secure by Design Approach for Robust Security in Healthcare CPS



Threat Model

Physical Unclonable Function (PUF) based Solution

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.

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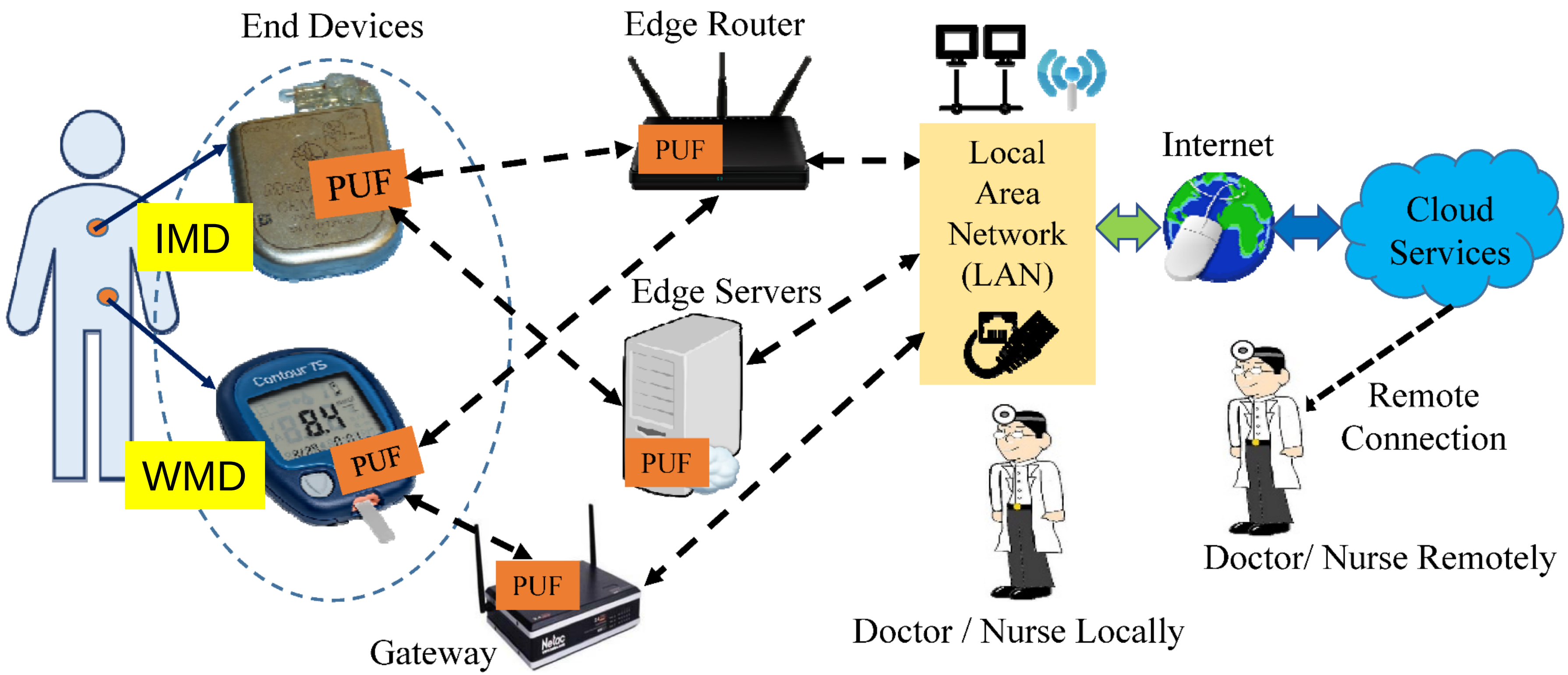

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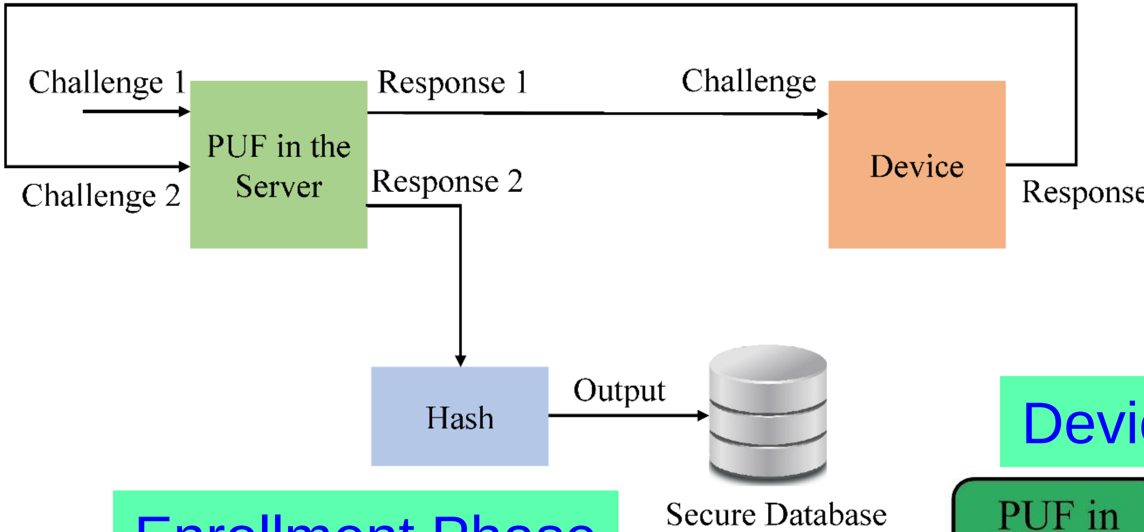
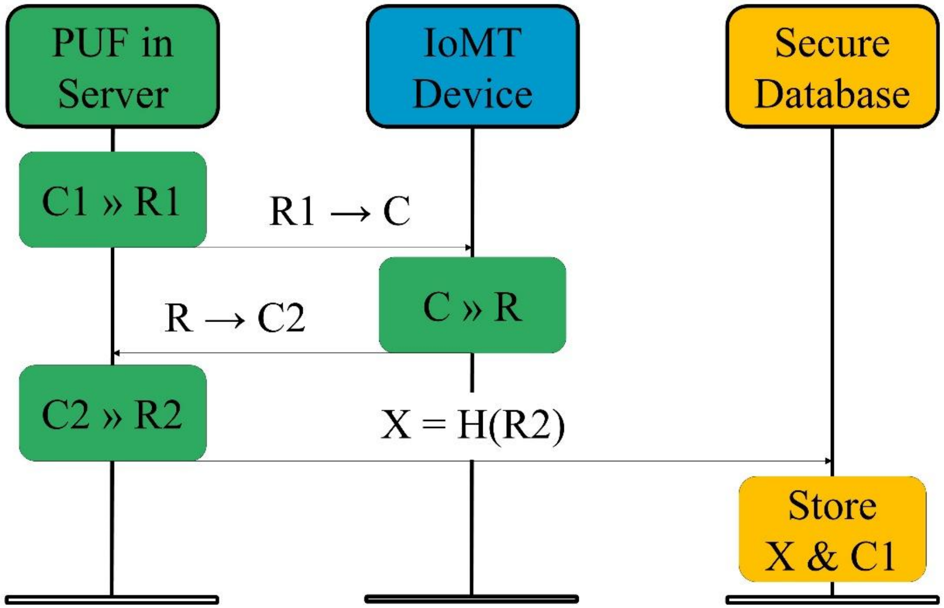
IoMT Security – Our Proposed PMsec



Enrollment Phase

Device Registration Procedure



PUF Security Full Proof:

- Only server PUF Challenges are stored, not Responses
- Impossible to generate Responses without PUF

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.

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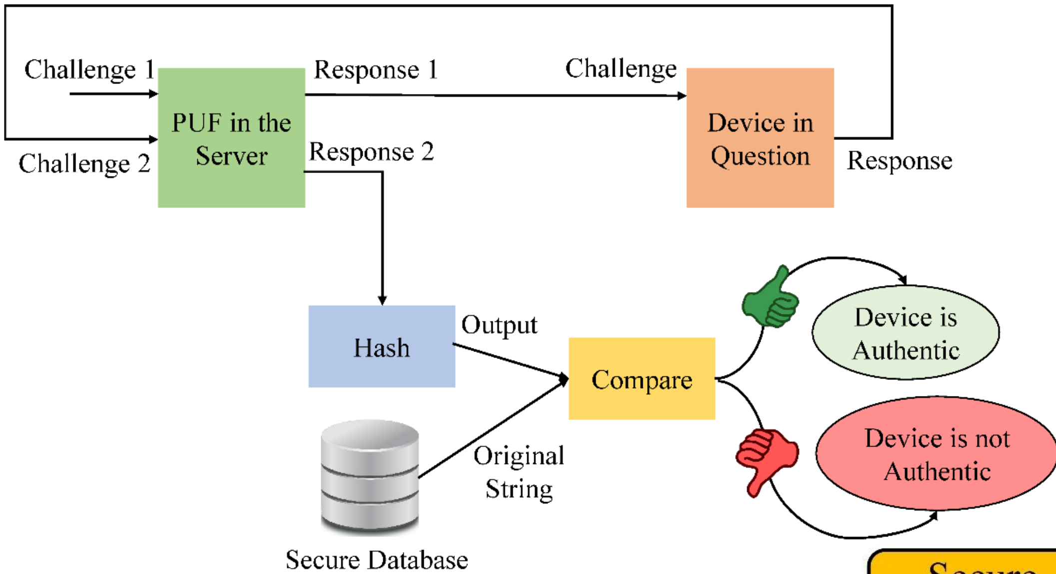
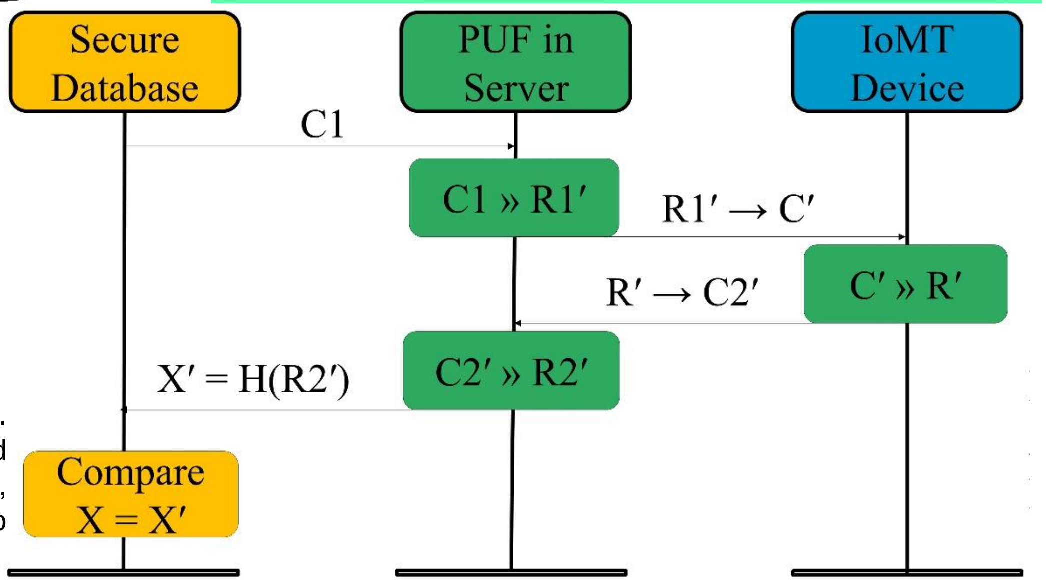


Authentication Phase

Device Authentication Procedure



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IoMT Security – Our PMsec in Action

```
------------Enrollment Phase------------
Generating the Keys
Sending the keys to the Client
Receiving the Keys from the client
Saving the database
>>>
```

Output from Server during Enrollment

```
COM4
Send

Hello
Received Key from the Server
Generating PUF Key
PUF Key : 1011100001011100101111000101111000101101001101110010100101000011
Sending key for authentication
```

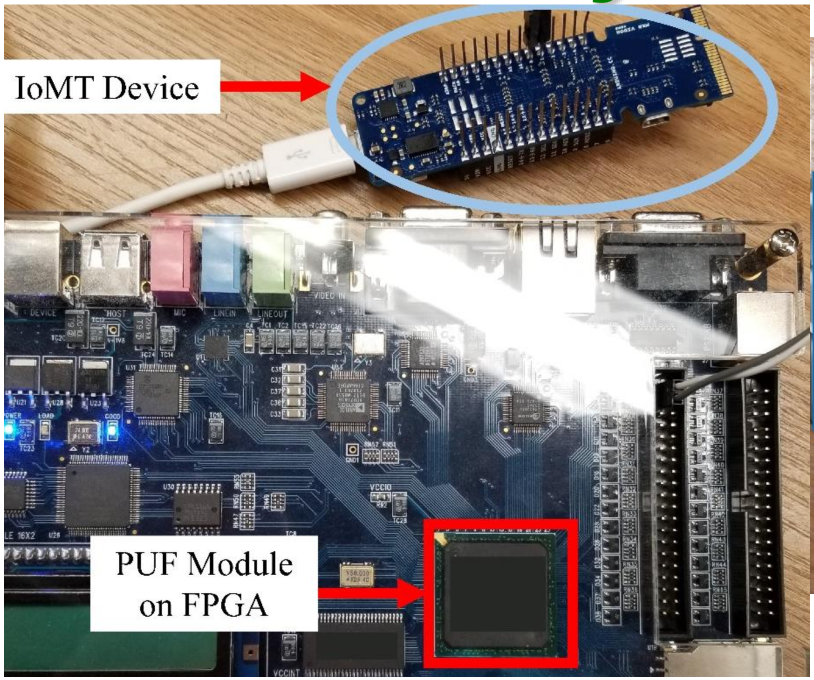
Output from IoMT Device

```
>>>
Hello
-----------Authentication Phase-----------
Input to the PUF at server : 01001101
Generating the PUF key
Sending the PUF key to the client
PUF Key from client is  1011100001011100101111000101111000101101001101110010100101000011
SHA256 of PUF Key is :  580cdc9339c940cdc60889c4d8a3bc1a3c1876750e88701cbd4f5223f6d23e76
Authentication Successful
>>> |
```

Output from Server during Authentication

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

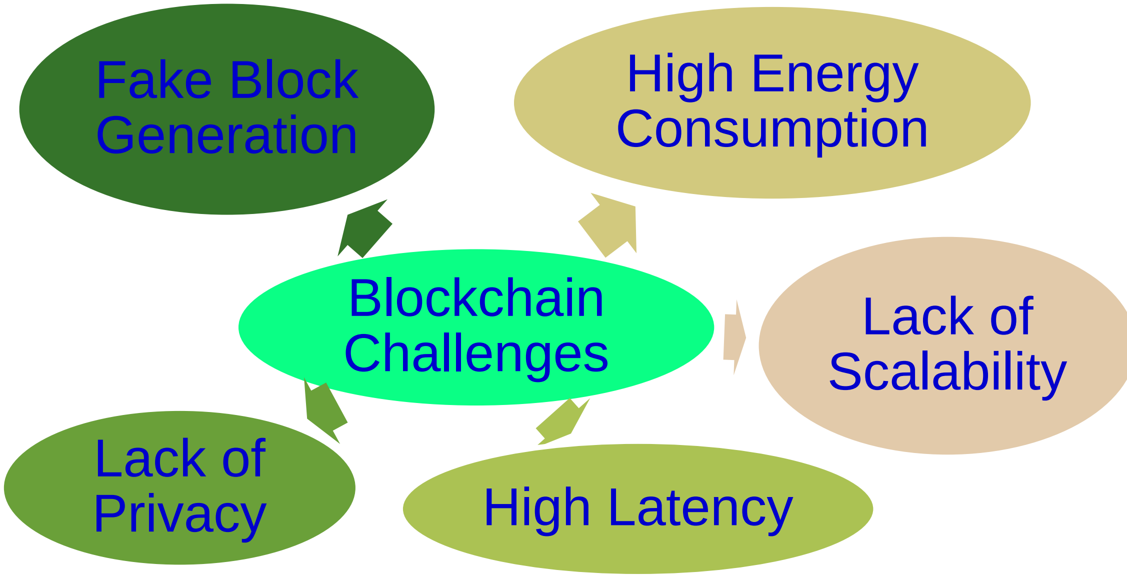


Average Power Overhead – ~ 200 μW

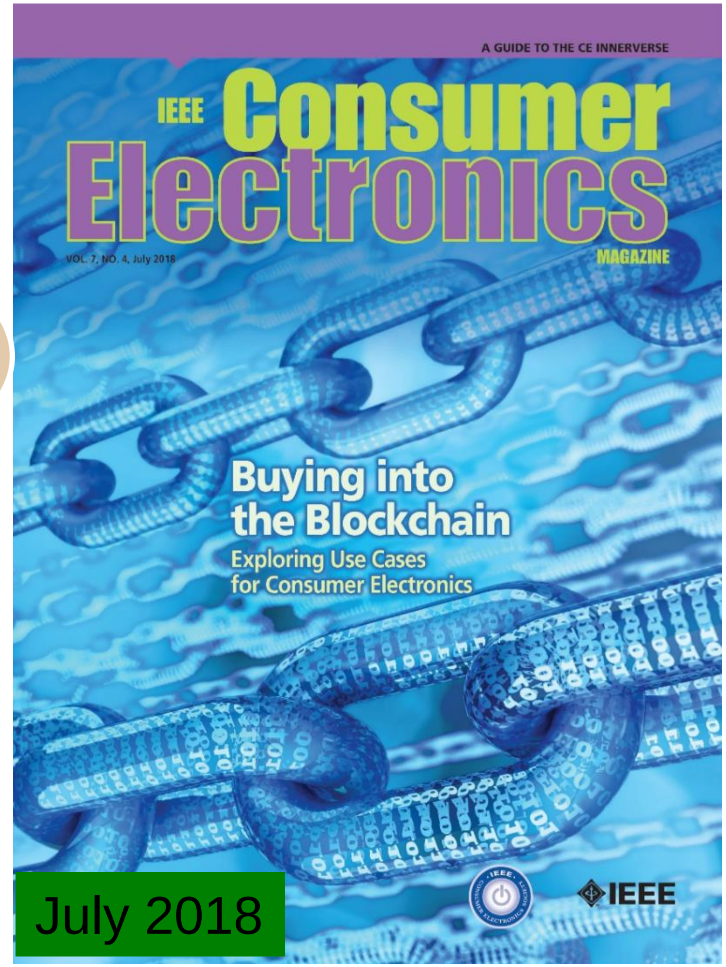
Proposed Approach Characteristics	Value (in a FPGA / Raspberry Pi Platform)
Time to Generate the Key at Server	800 ms
Time to Generate the Key at IoMT Device	800 ms
Time to Authenticate the Device	1.2 sec - 1.5 sec

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 for Smart Healthcare?



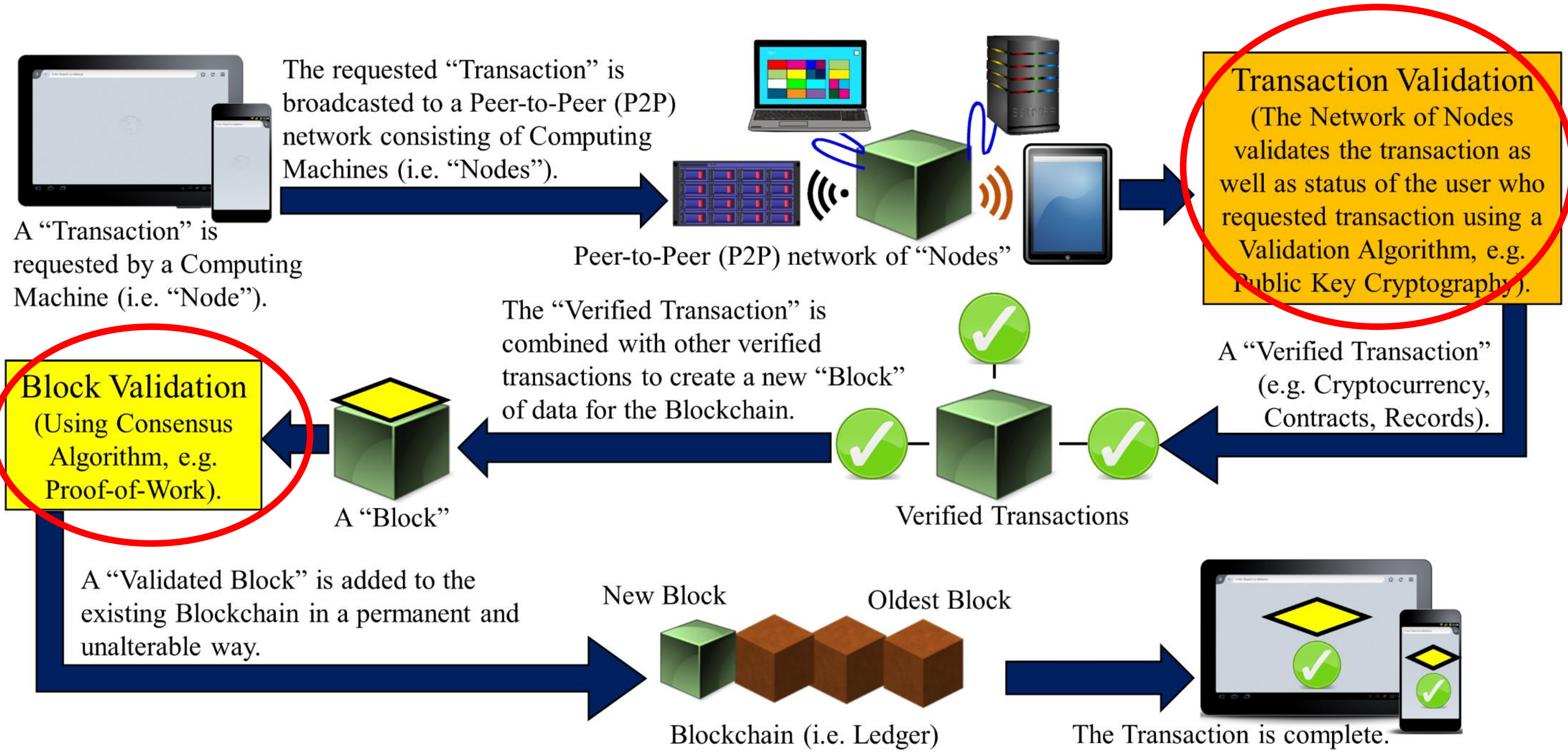
- ➢ Energy for mining of 1 bitcoin → 2 years consumption of a US household.
- ➢ Energy consumption for each bitcoin transaction → 80,000X of energy consumption of a credit card processing.



July 2018

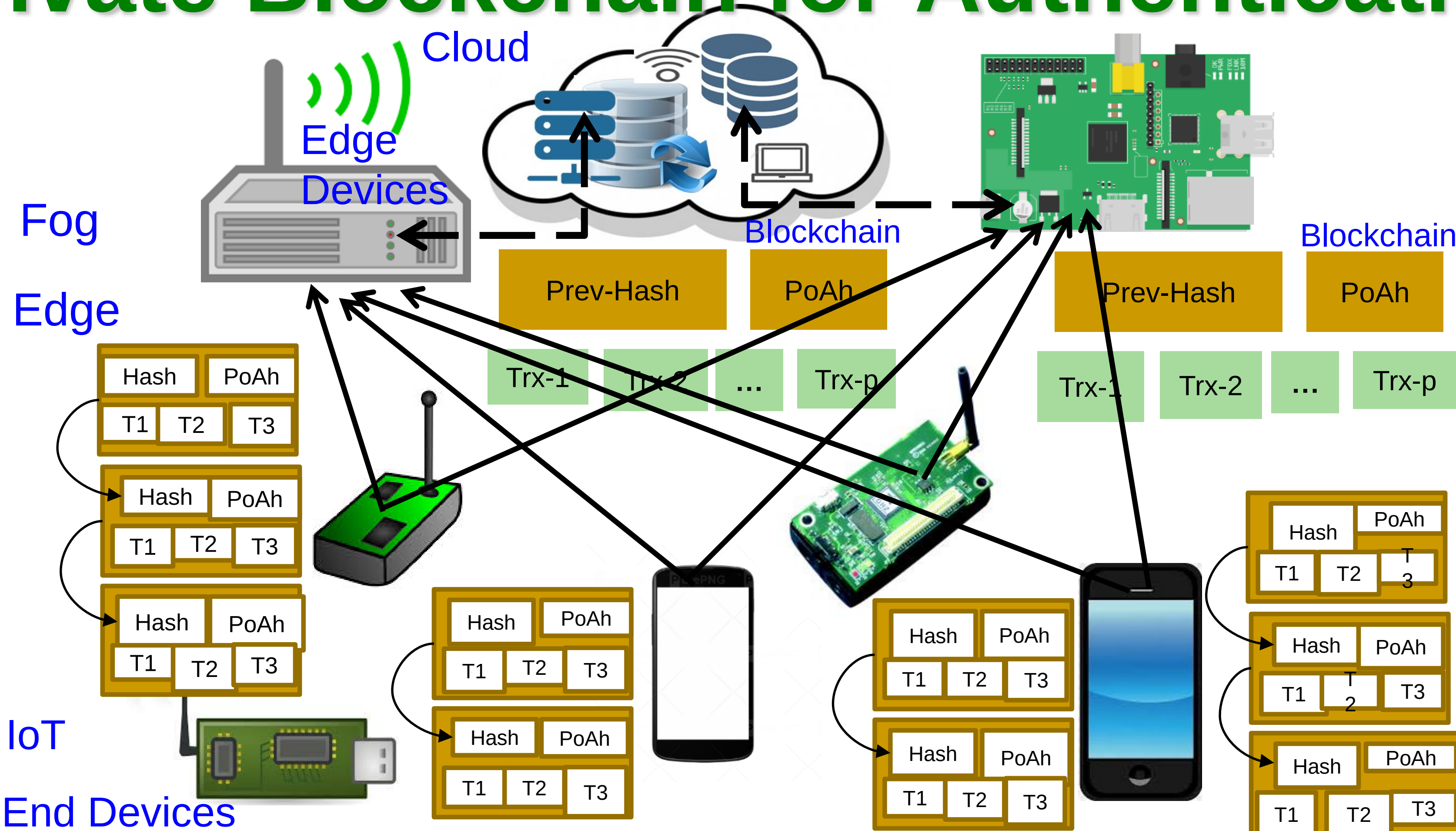
Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

Blockchain Challenges - Energy



Source: D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos, and G. Das, "Everything you Wanted to Know about the Blockchain", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 4, July 2018, pp. 06--14.

Our PoAh-Chain: The IoT Friendly Private Blockchain for Authentication



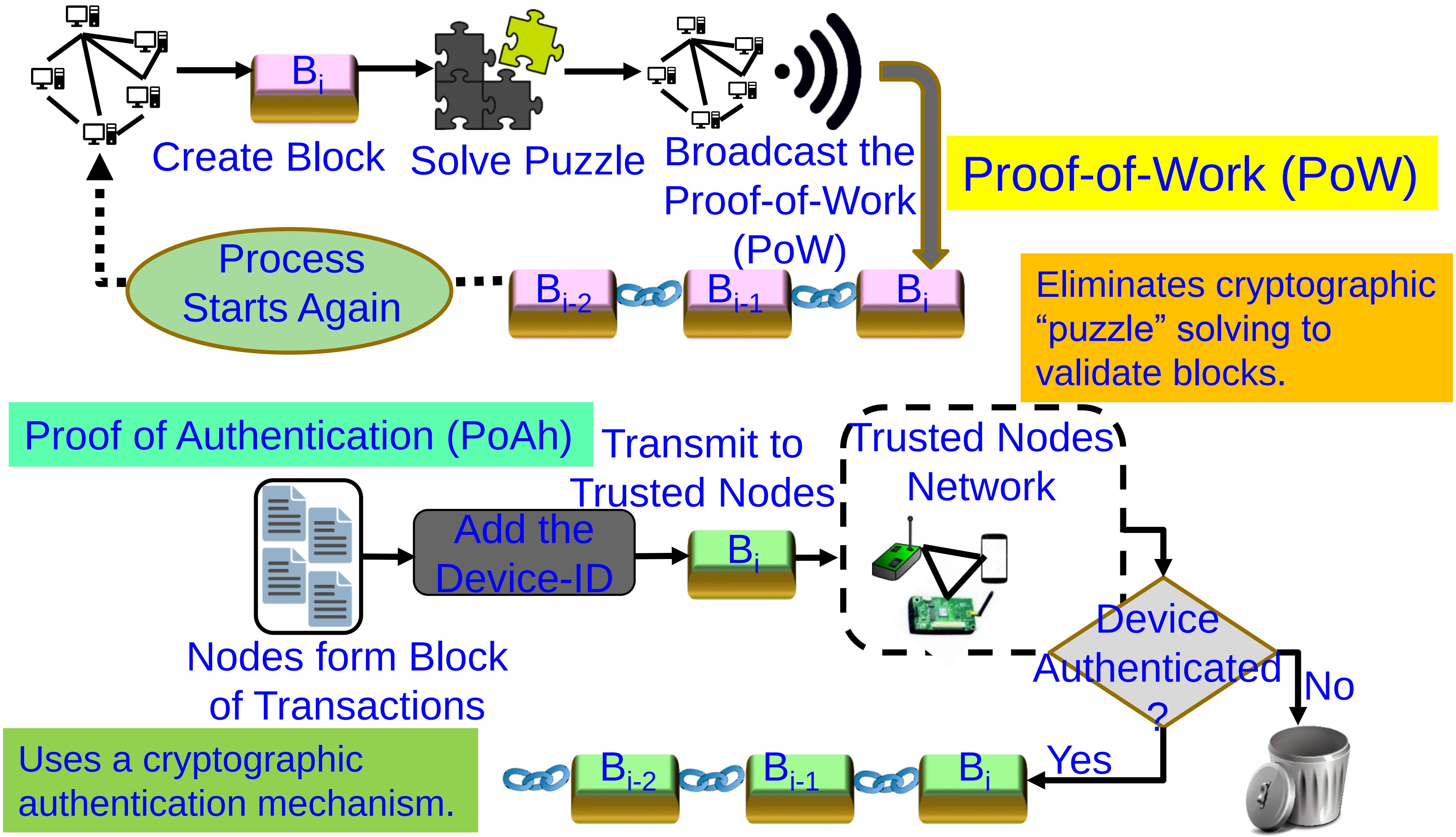
Source: D. Puthal and S. P. Mohanty, "Proof of Authentication: IoT-Friendly Blockchains", *IEEE Potentials Magazine*, Volume 38, Issue 1, January 2019, pp. 26--29.

Blockchain Consensus Types

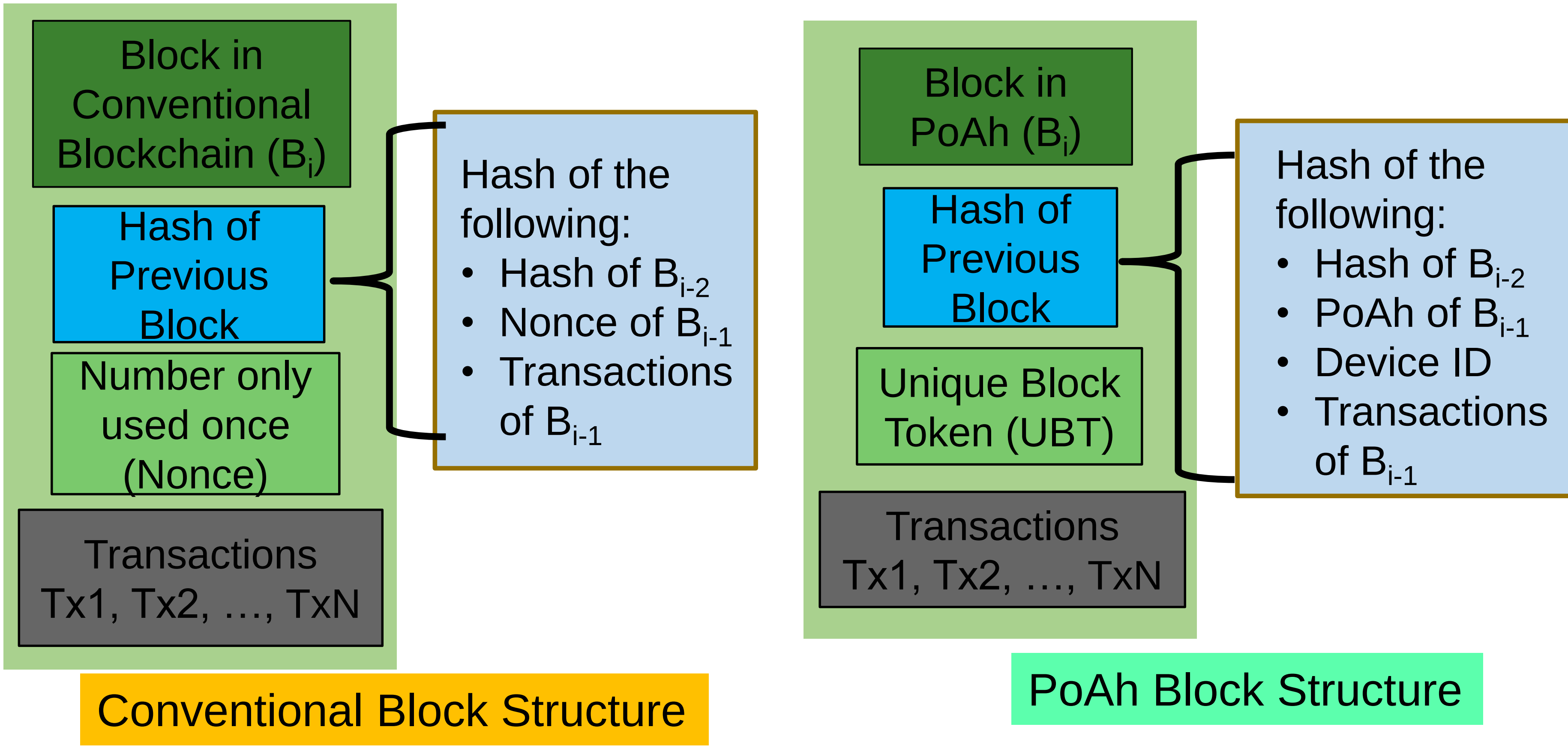
Blockchain Consensus Algorithm

- Validation Based
  - Proof of Work (PoW)
  - Proof of Stack (PoS)
  - Proof of Activity (PoA)
  - Proof of Relevance (PoR)
  - Proof of Elapsed Time
- Voting Based
  - Ripple
  - Proof of Vote
  - Proof of Trust
- Authentication Based
  - Proof of Authentication (PoAh)
  - Proof of PUF-Enabled Authentication (PoP) (**Current Paper**)

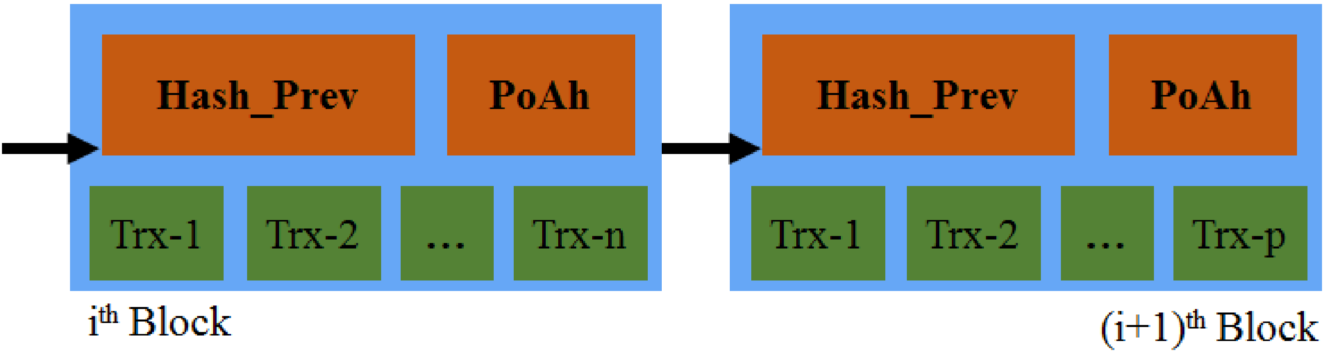
Our Proof-of-Authentication (PoAh)



Our PoAh-Chain: Proposed New Block Structure



Our PoAh is 200X Faster than PoW



Eliminates cryptographic "puzzle" solving to validate blocks.

	Proof-of-Work (PoW)	Proof-of-Stake (PoS)	Proof-of-Activity (PoA)	Proof-of-Authentication (PoAh)
Energy consumption	High	High	High	Low
Computation requirements	High	High	High	Low
Latency	High	High	High	Low
Search space	High	Low	NA	NA

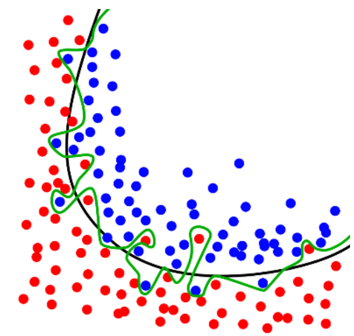
PoW - 10 min in cloud	PoAh - 3 sec in Rasperry Pi	PoAh - 200X faster than PoW

Source: D. Puthal, S. P. Mohanty, P. Nanda, E. Kougianos, and G. Das, "Proof-of-Authentication for Scalable Blockchain in Resource-Constrained Distributed Systems", in *Proc. 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

Machine Learning Challenges

Machine Learning Issues

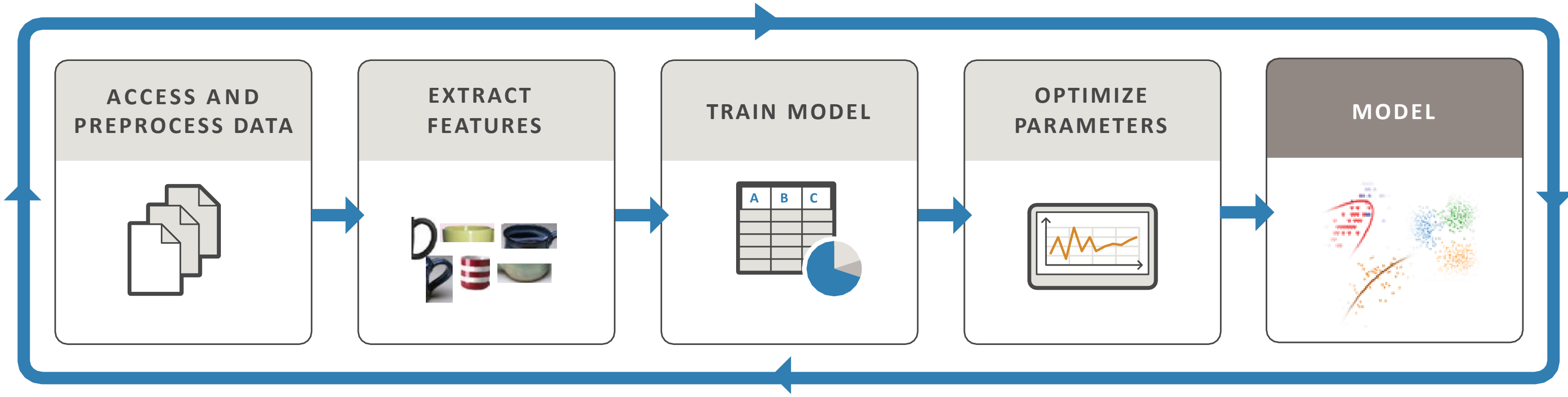
- High Energy Requirements
- High Computational Resource Requirements
- Large Amount of Data Requirements
- Underfitting/Overfitting Issue
- Class Imbalance Issue
- Fake Data Issue



Source: Mohanty ISCT Keynote 2019

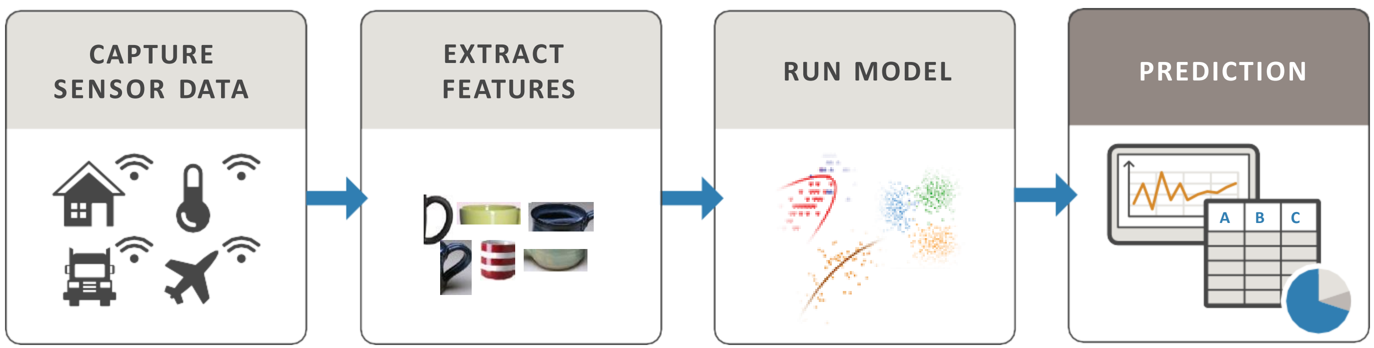
Deep Neural Network (DNN) - Resource and Energy Costs

TRAIN: Iterate until you achieve satisfactory performance.



Needs Significant:
- ➢ Resource
- ➢ Energy

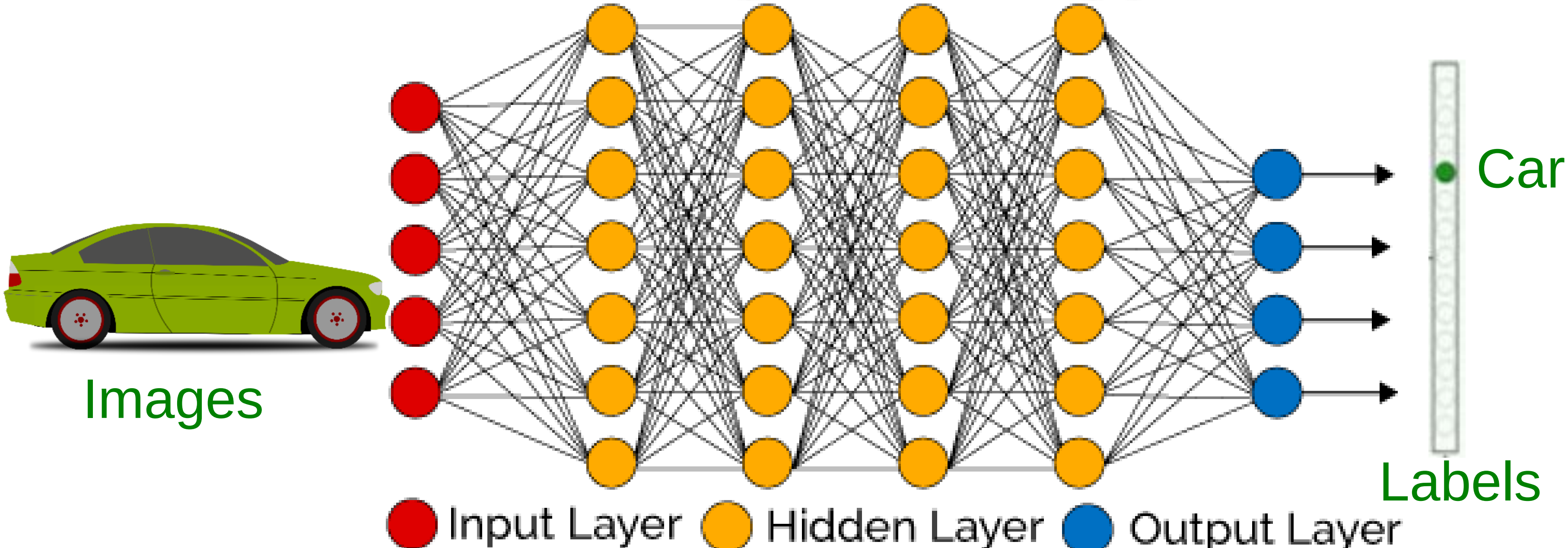
PREDICT: Integrate trained models into applications.



Needs:
- ➢ Resource
- ➢ Energy

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

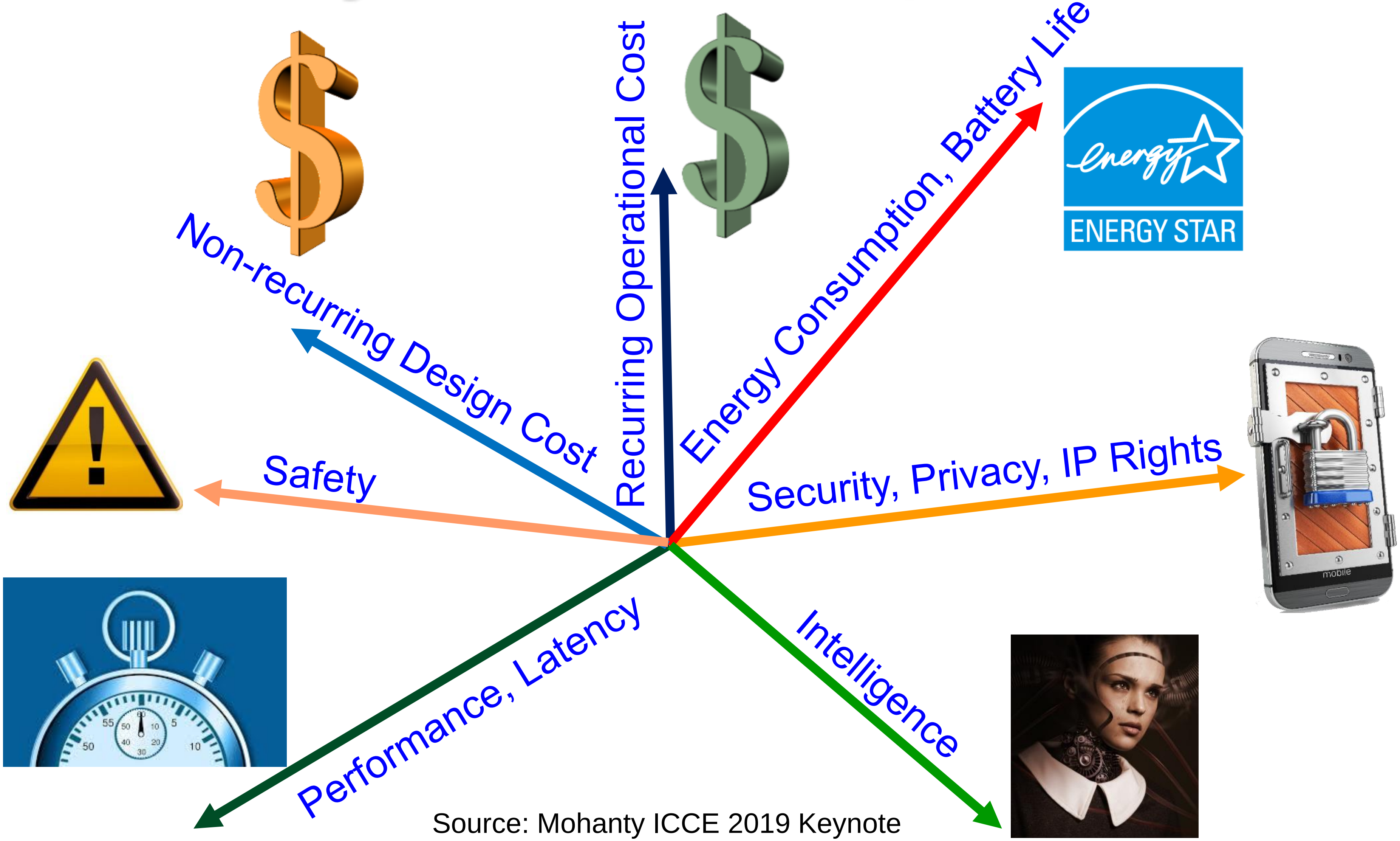
DNN Training - Energy Issue



- 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.

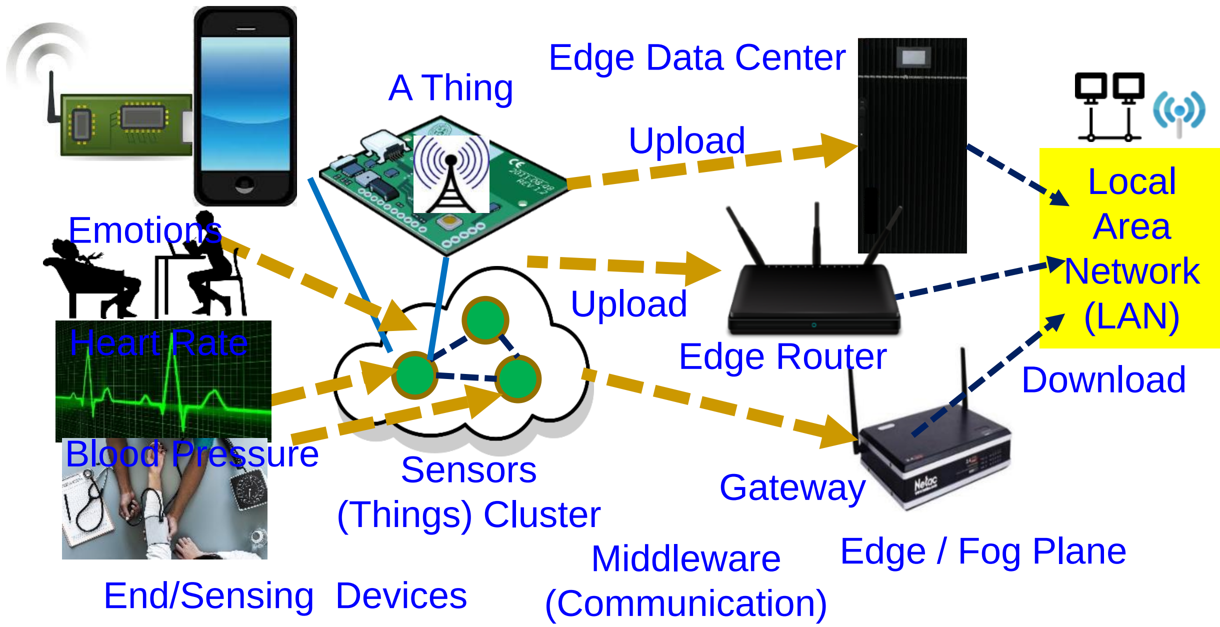
Source: Mohanty iSES 2018 Keynote

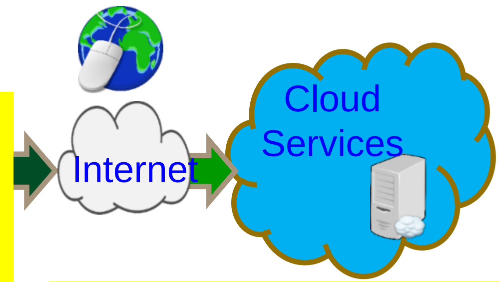
CE/IoT System - Multi-Objective Tradeoffs



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

End Security/Intelligence

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

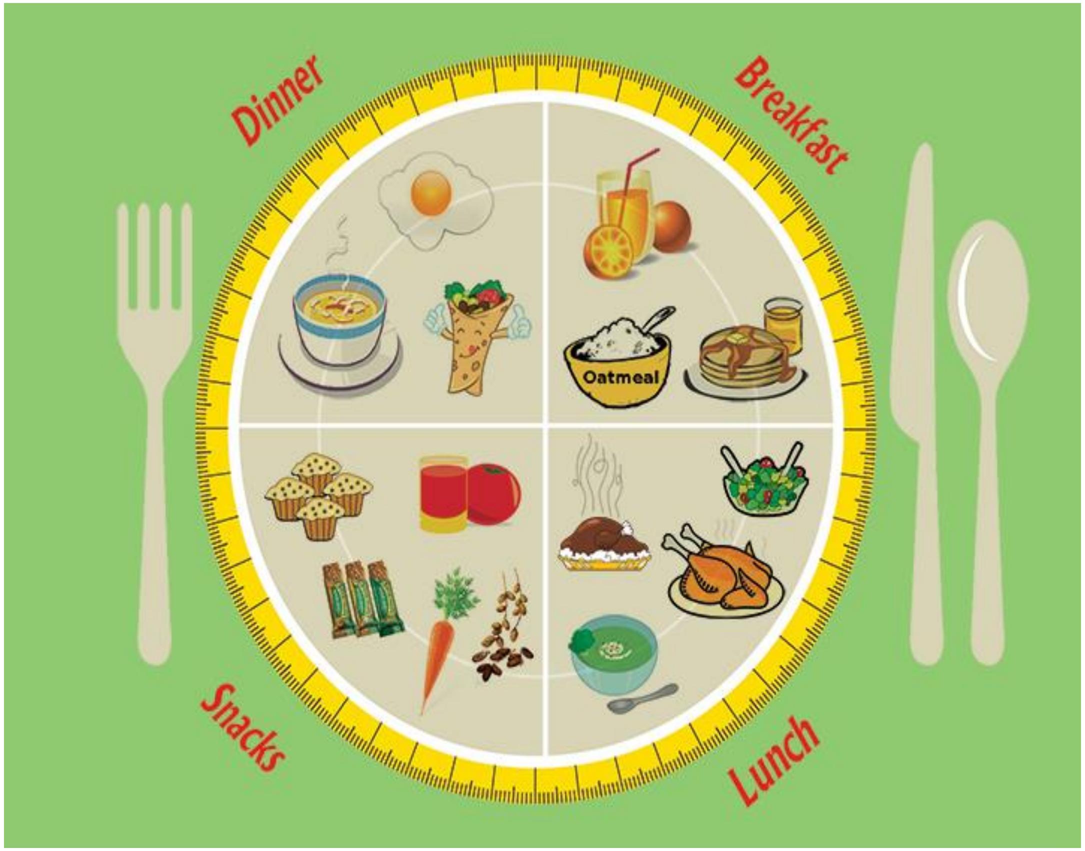
Edge Security/Intelligence

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

Source: Our IFIP IoT 2019 Talk (Good-Eye: A Combined Computer-Vision and Physiological-Sensor based Edge Device for Full-Proof Prediction and Detection of Fall of Adults)

Smart Healthcare – Specific Examples

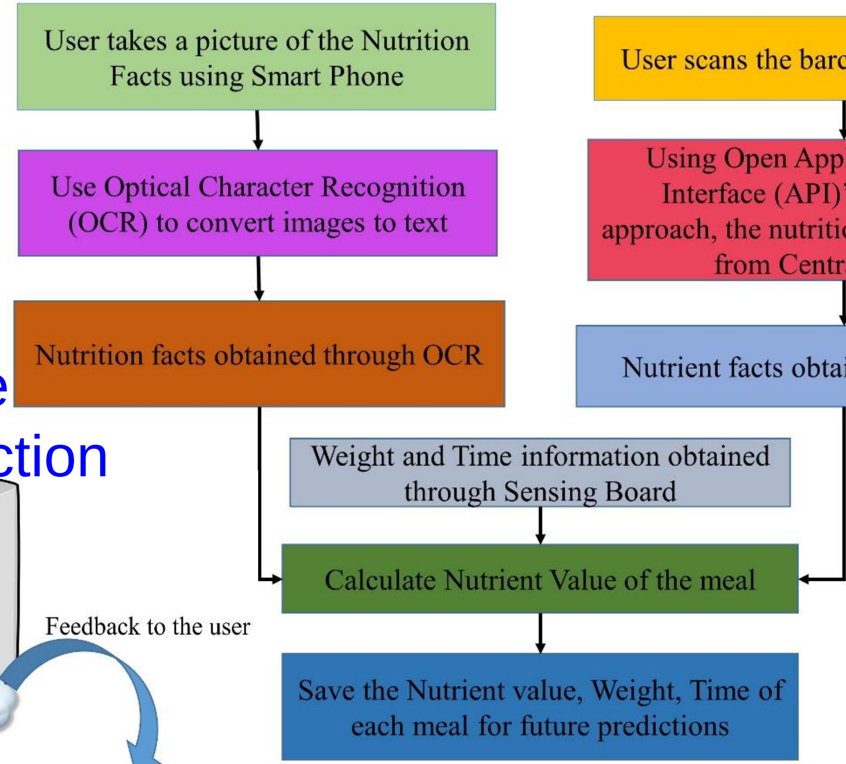
Food Intake Monitoring and Diet Management is Important



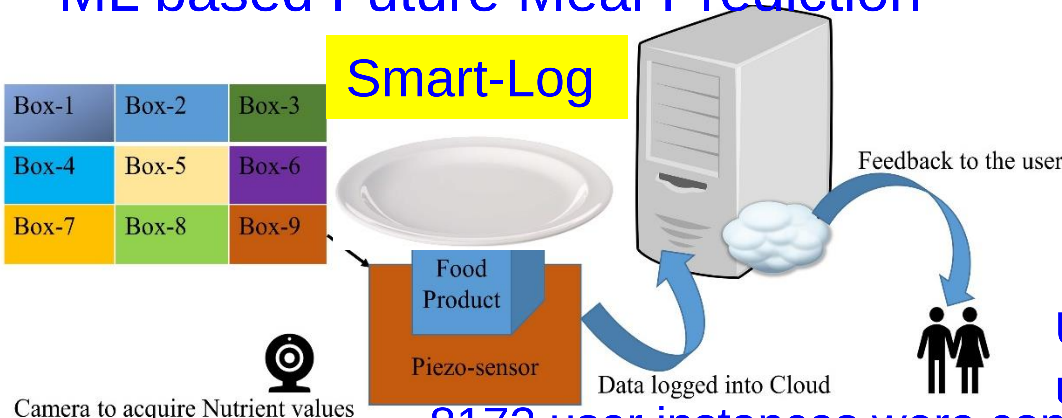
Smart Healthcare – Diet Monitoring

Automated Food intake Monitoring and Diet Prediction System

- Smart plate
- Data acquisition using mobile
- ML based Future Meal Prediction



Smart-Log



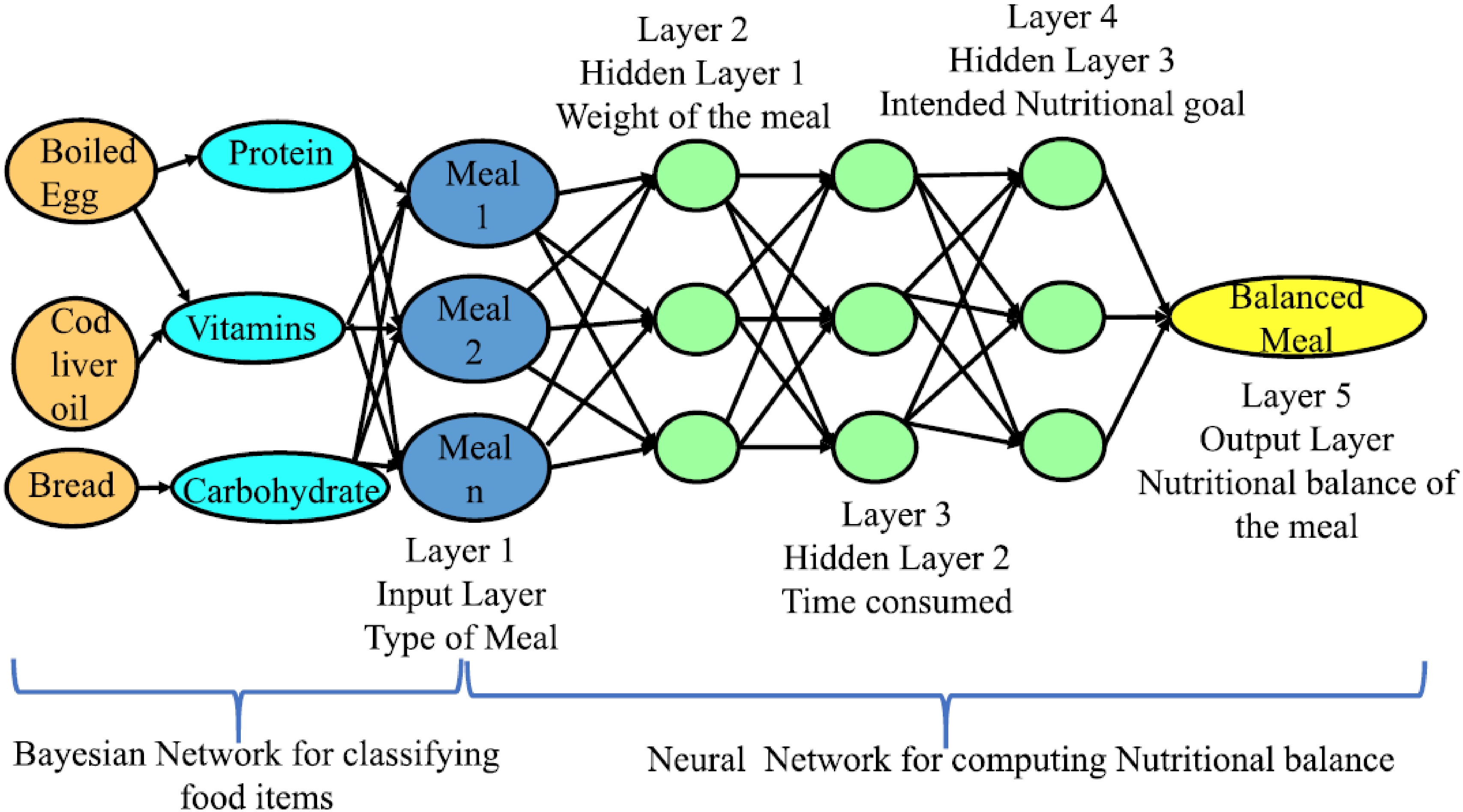
USDA National Nutrient Database used for nutrient values of 8791 items.

8172 user instances were considered

Research Works	Food Recognition Method	Efficiency (%)
This Work	Mapping nutrition facts to a database	98.4

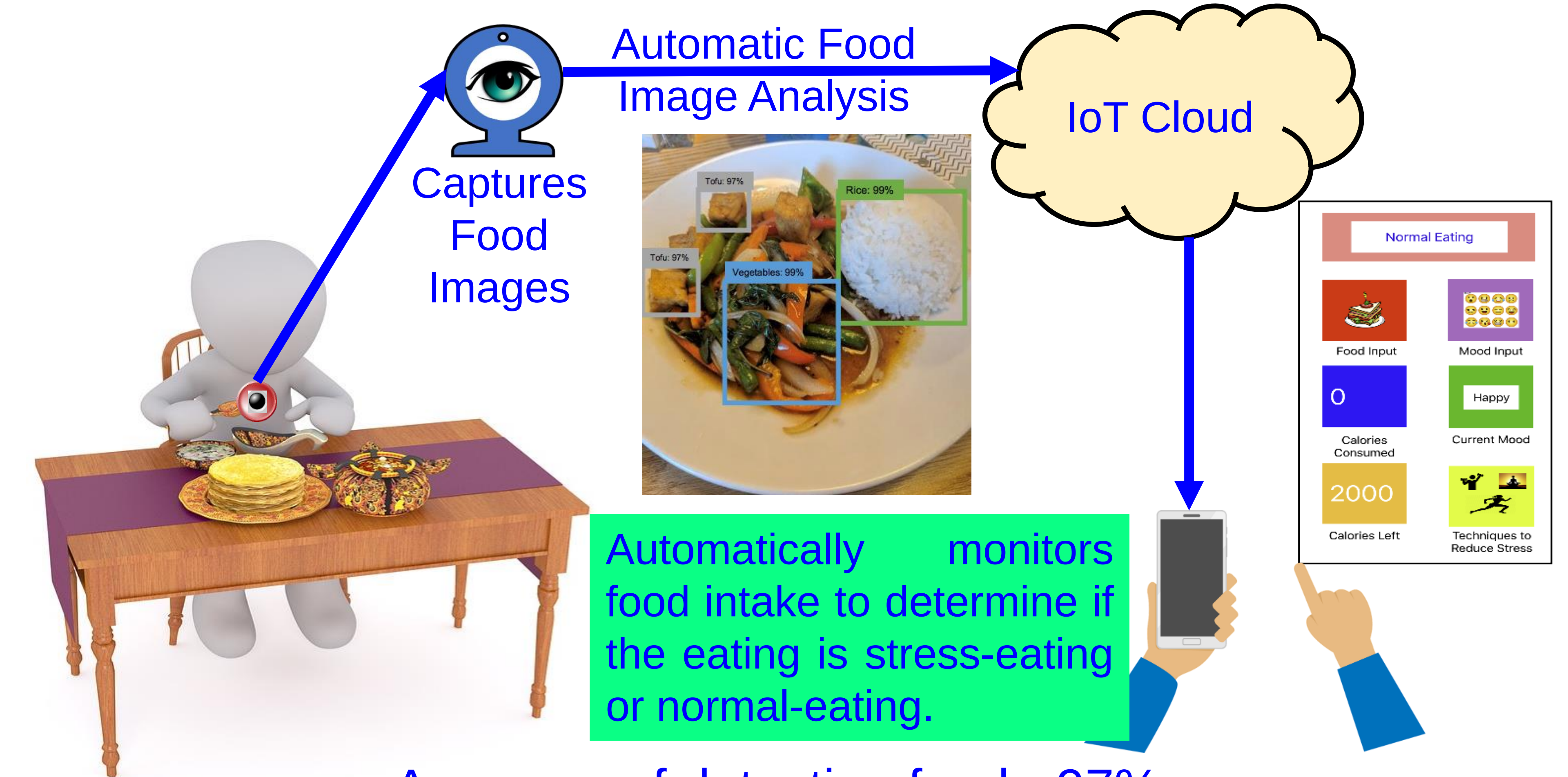
Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, S. P. Mohanty, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", *IEEE Trans. on Consumer Electronics*, Vol 64, No 3, Aug 2018, pp. 390-398.

Smart-Log Diet Monitoring and Prediction: DNN Model



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 Trans. on Consumer Electronics*, Vol 64, No 3, Aug 2018, pp. 390-398.

Smart Healthcare - Vision-Based Approach



Accuracy of detecting food - 97%

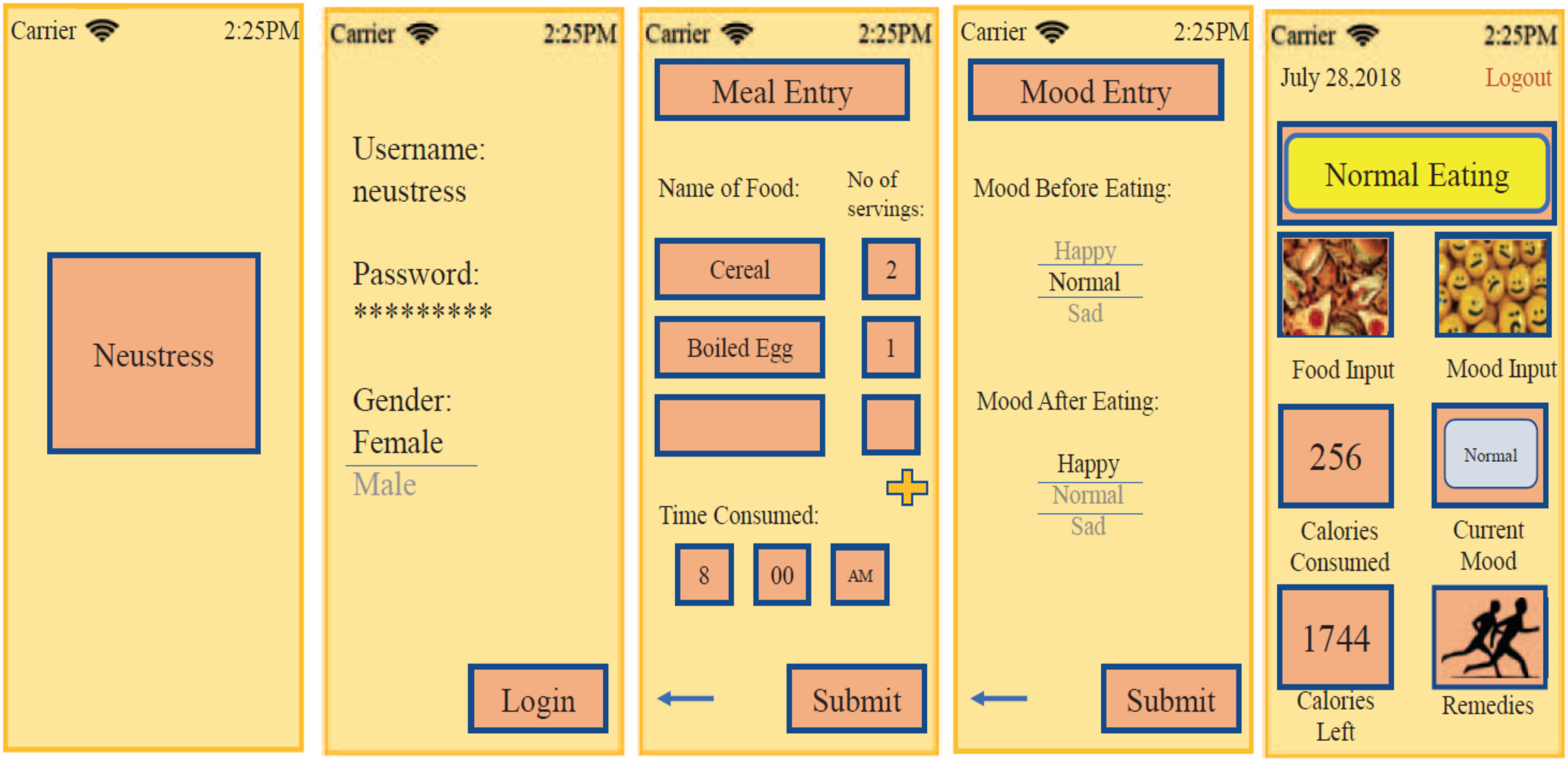
Source: Mohanty ICCE 2019: "Stress-Log: An IoT-based Smart System to Monitor Stress-Eating", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

Stress-Log: Implementation

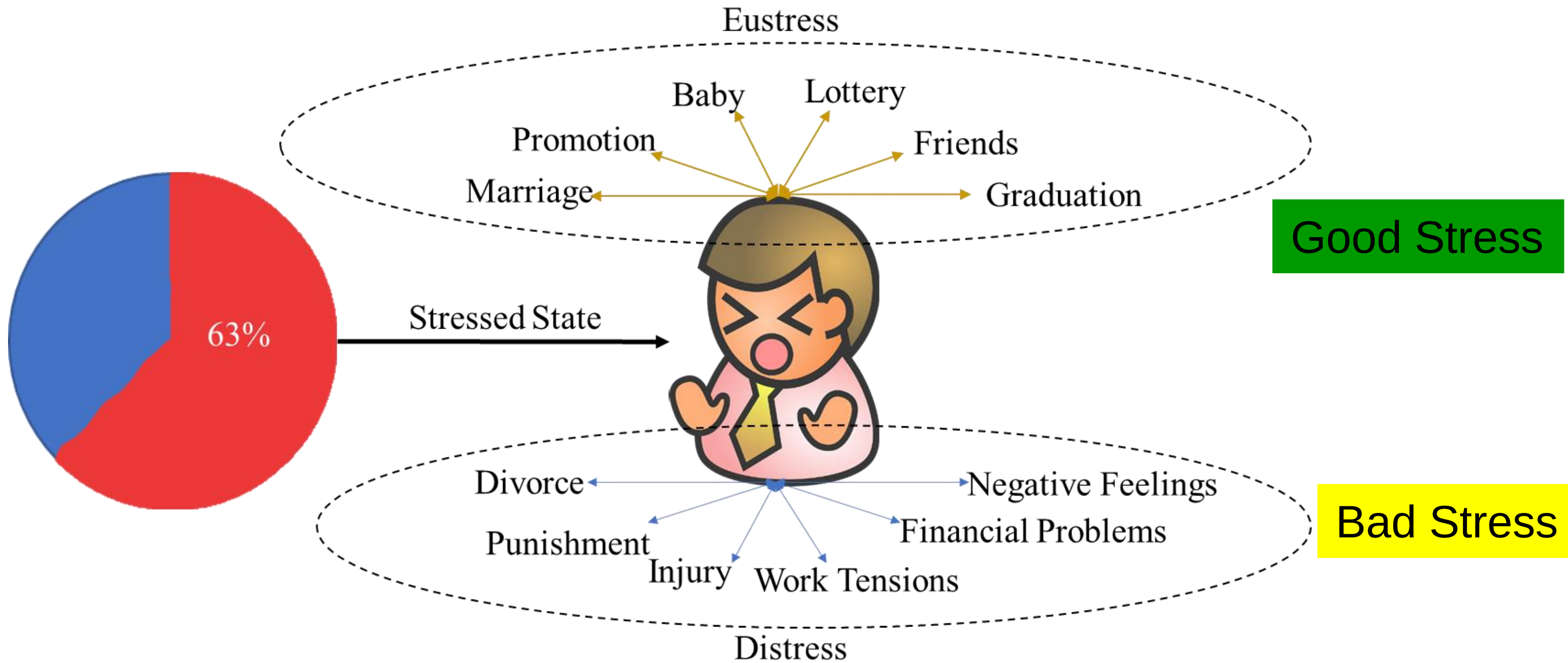
The data collected is sent to the Firebase Database in which the calorie count is generated by using a dataset with calories and sugars count of individual items from data.gov.

Source: Mohanty ICCE 2019: "Stress-Log: An IoT-based Smart System to Monitor Stress-Eating", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

Stress-Log: GUI

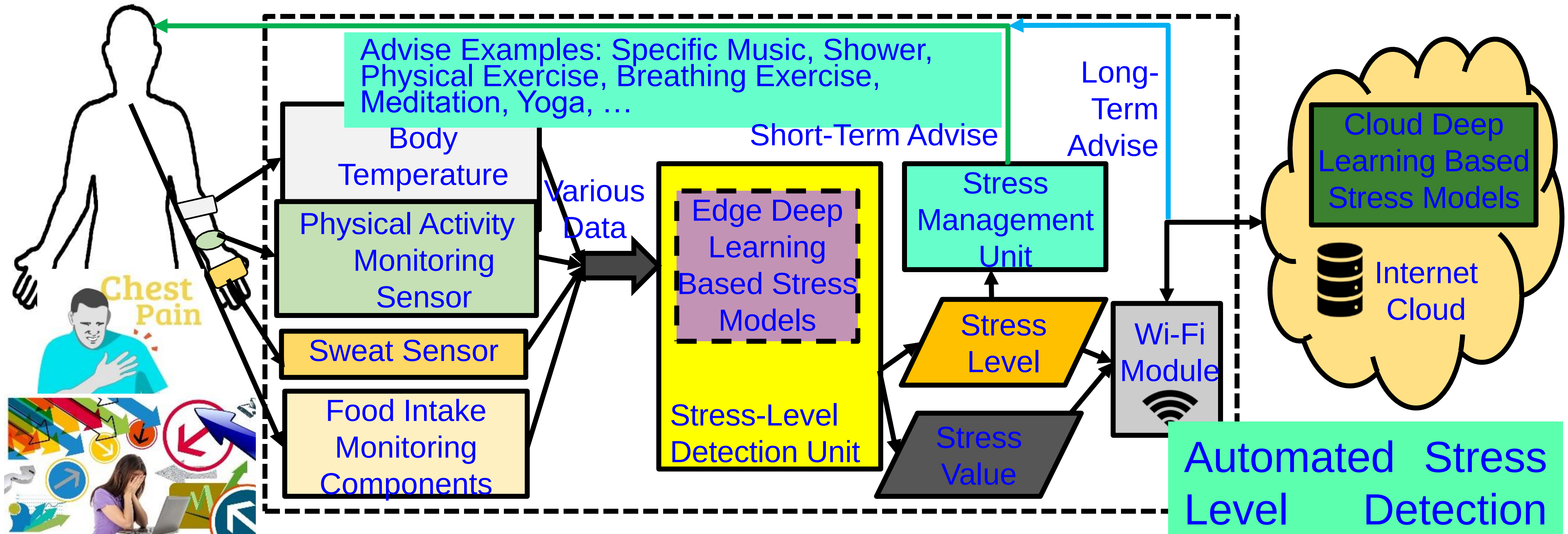


Stress is a Major Health Issue



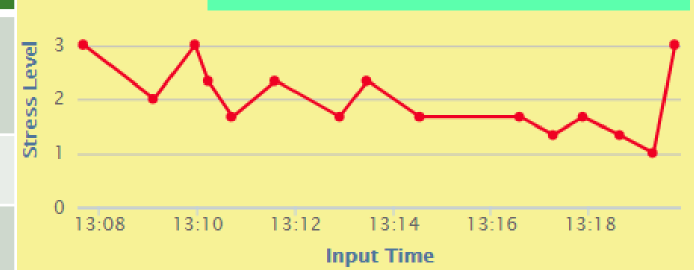
- Stress is the relationship between a person and a situation, which adversely impacts the happiness and health of the sufferer or physiological reactions.
- Stress can be divided into two parts: stressor and reaction.
- Stressor is the activity or effect that triggers a change in the physiological parameter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

Smart Healthcare - Stress Monitoring & Control



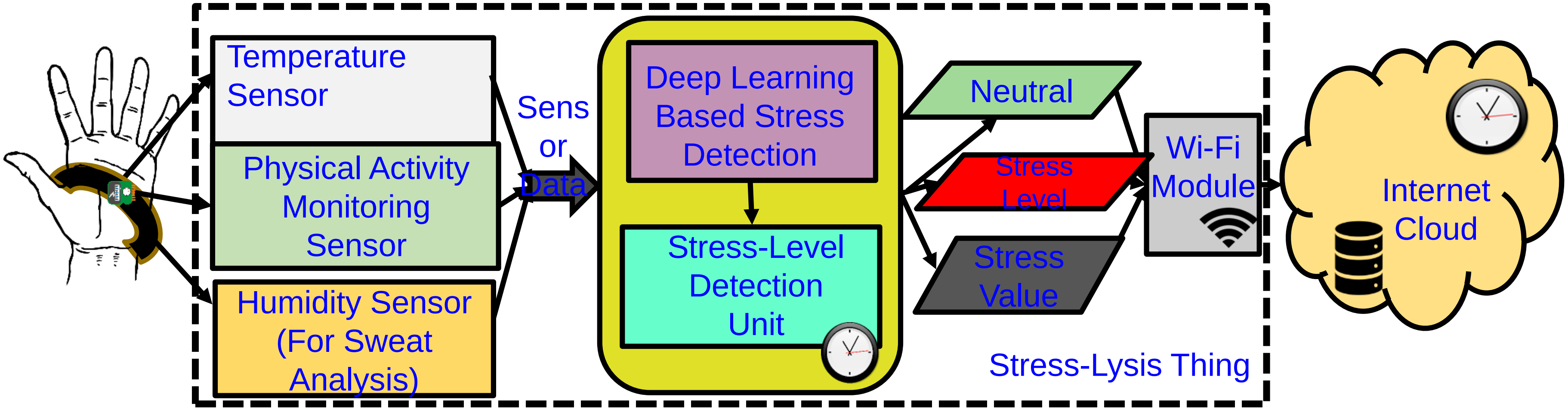
Automated Stress Level Detection and Management

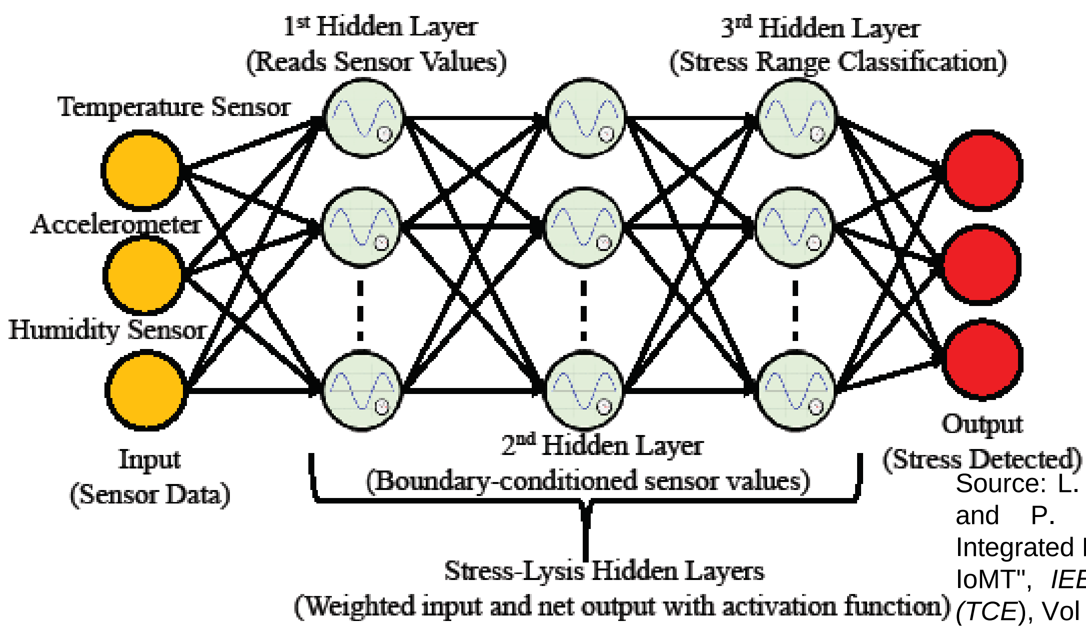
Sensor	Low Stress	Normal Stress	High Stress
Accelerometer (steps/min)	0-75	75-100	101-200
Humidity (RH%)	27-65	66-91	91-120
Temperature ℉	98-100	90-97	80-90



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.

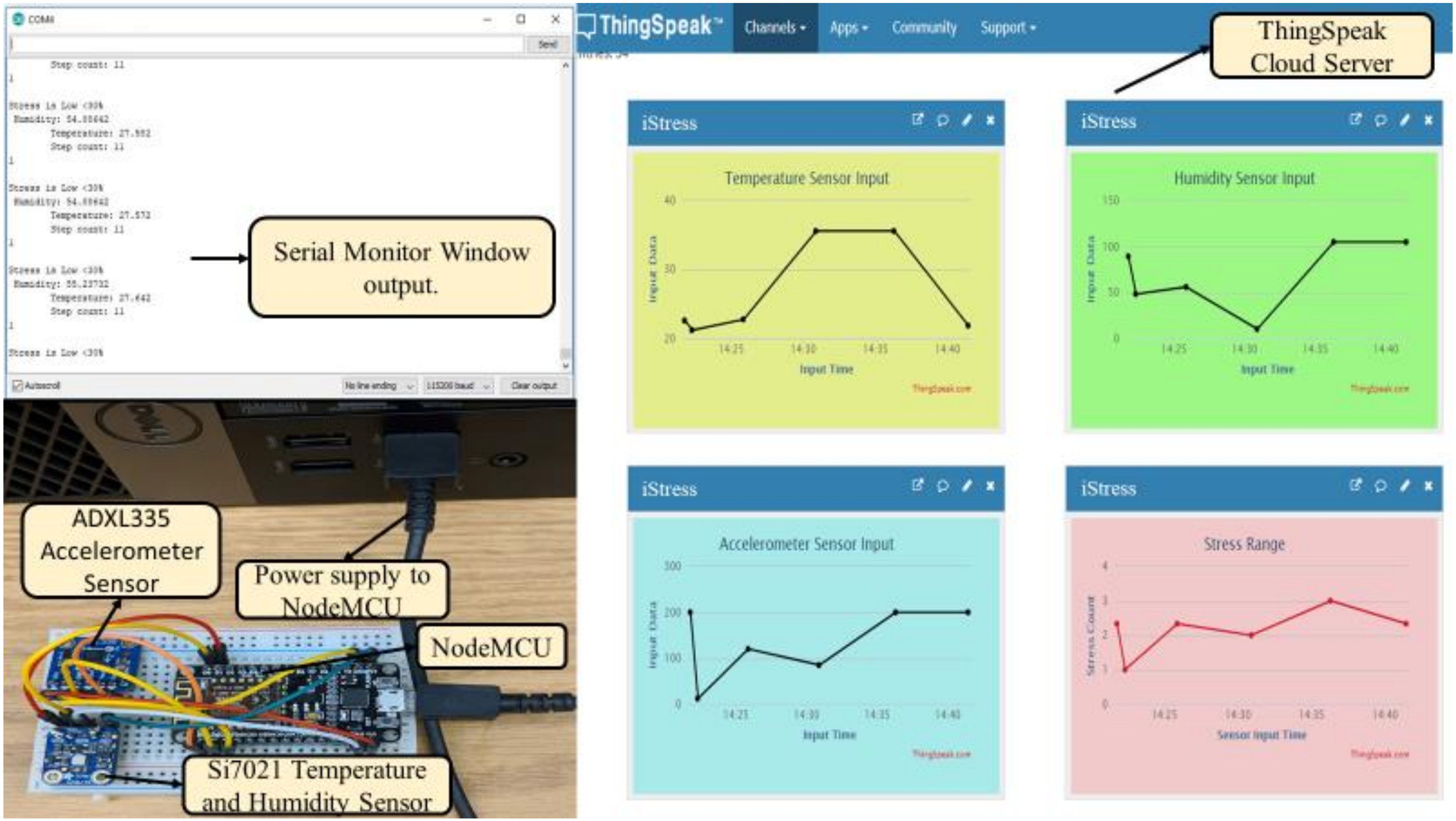
Stress-Lysis: From Physiological Signals





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.

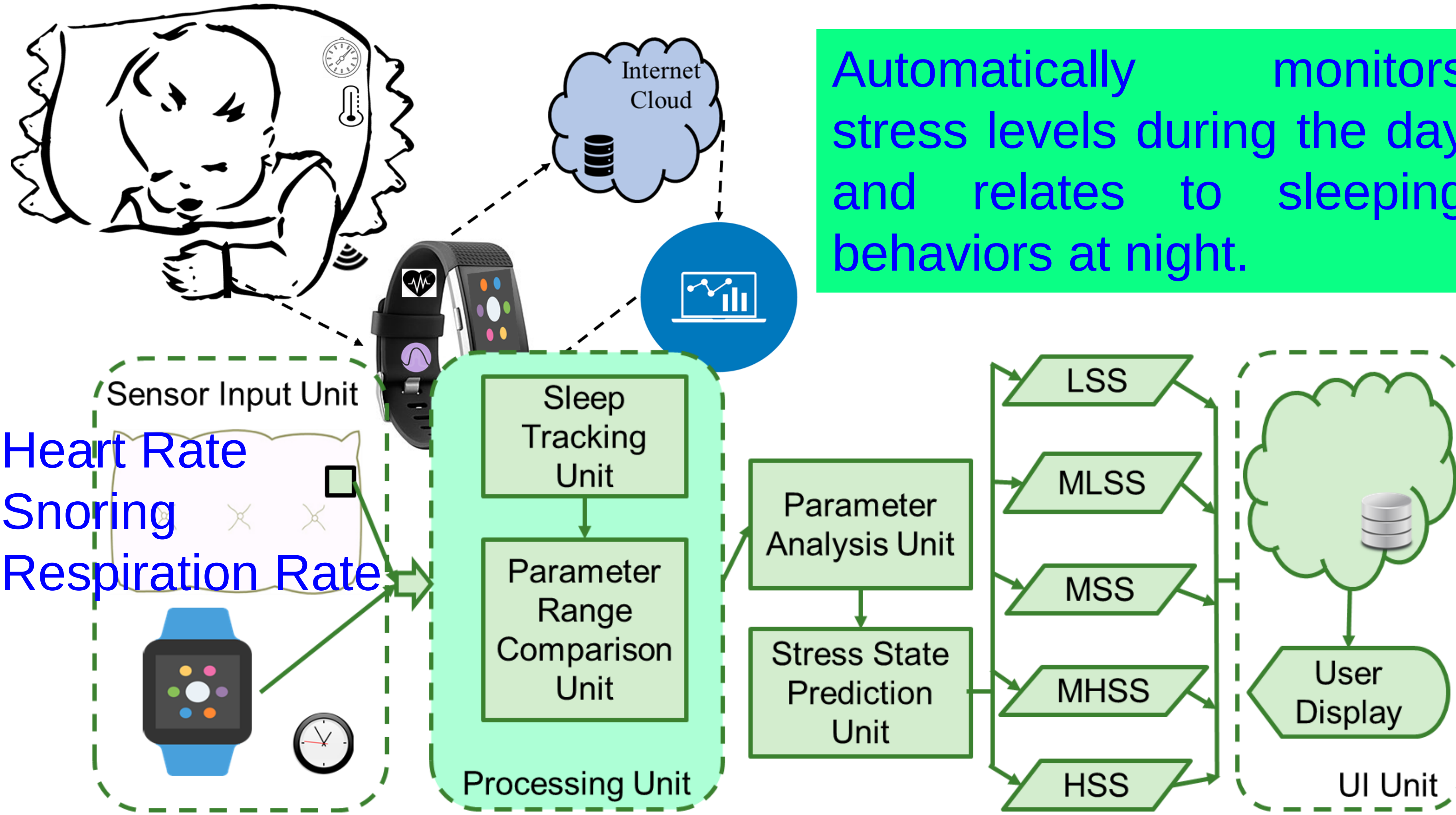
Stress-Lysis: Experiments



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.

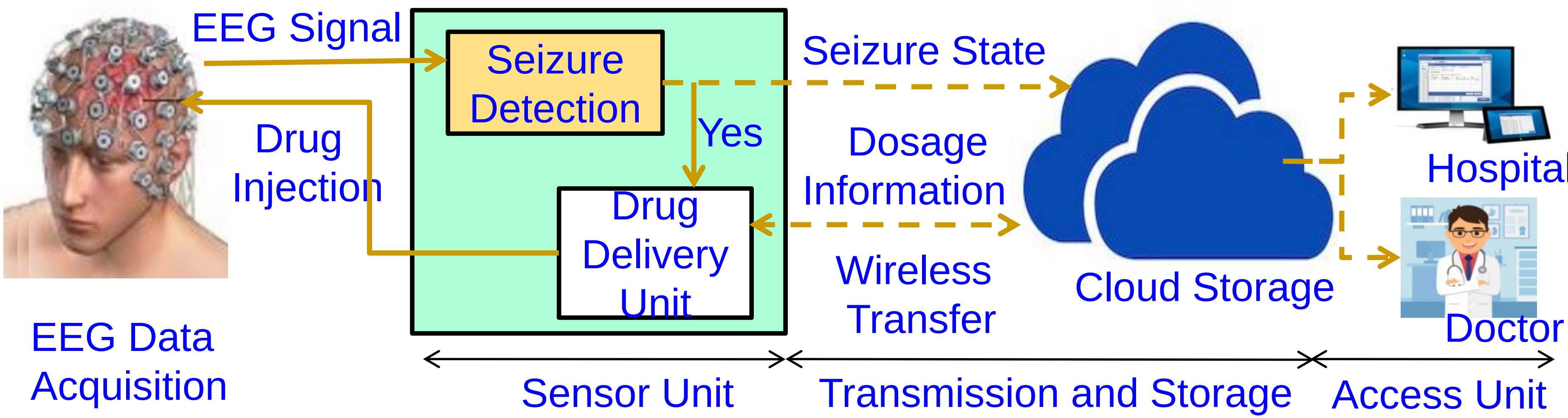
Smart Healthcare – Smart-Pillow

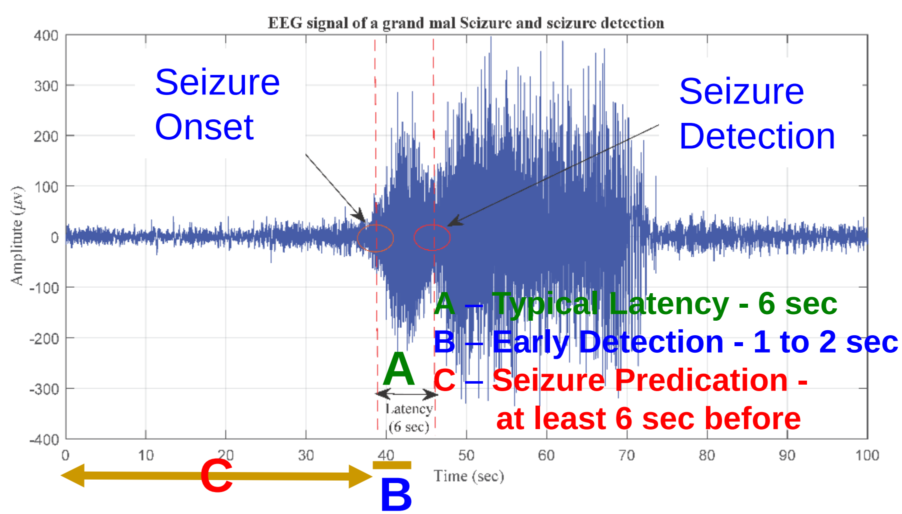
Automatically monitors stress levels during the day and relates to sleeping behaviors at night.



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.

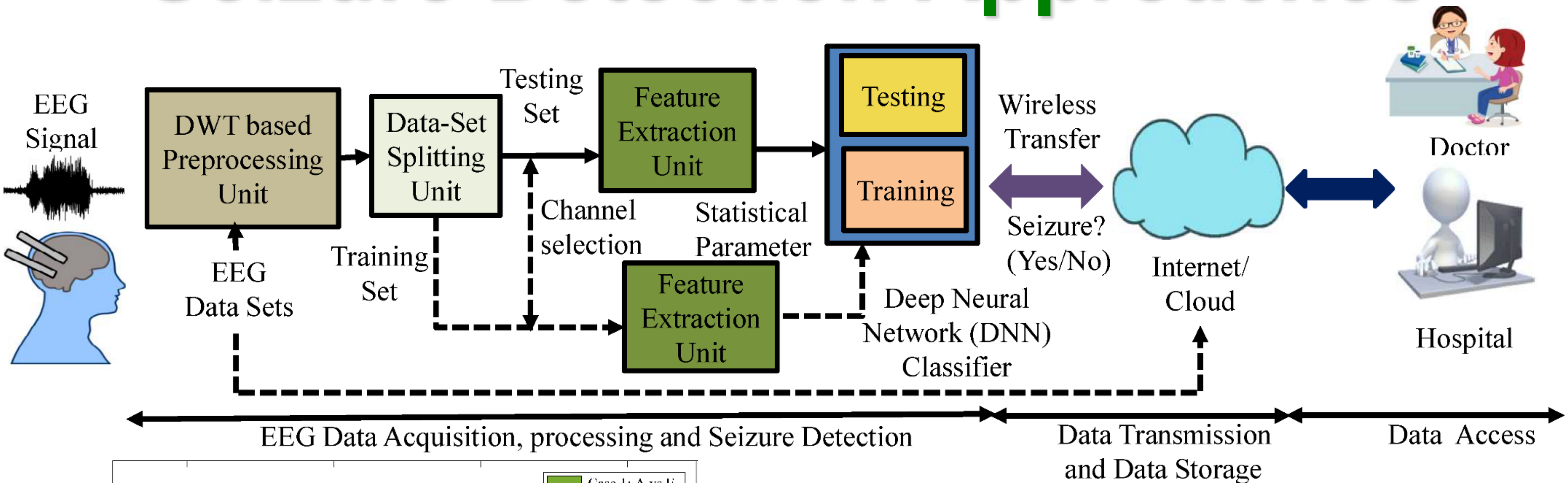
Smart Healthcare - Seizure Detection & Control

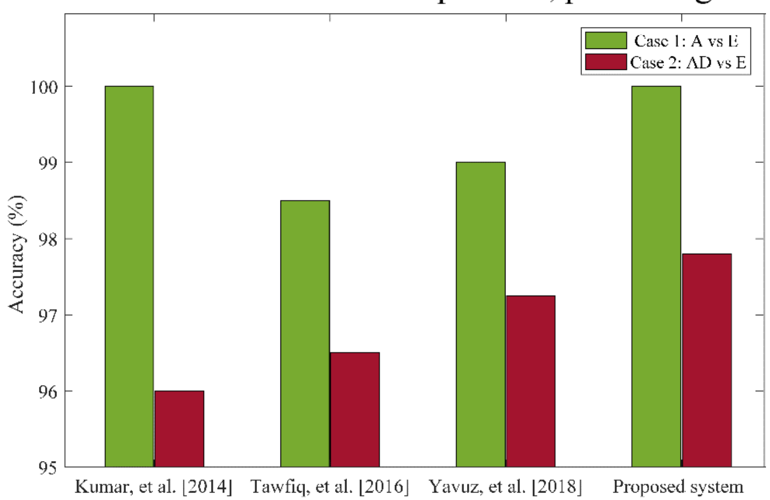




Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "eSeiz: An Edge-Device for Accurate Seizure Detection for Smart Healthcare", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 379--387.

Seizure Detection Approaches



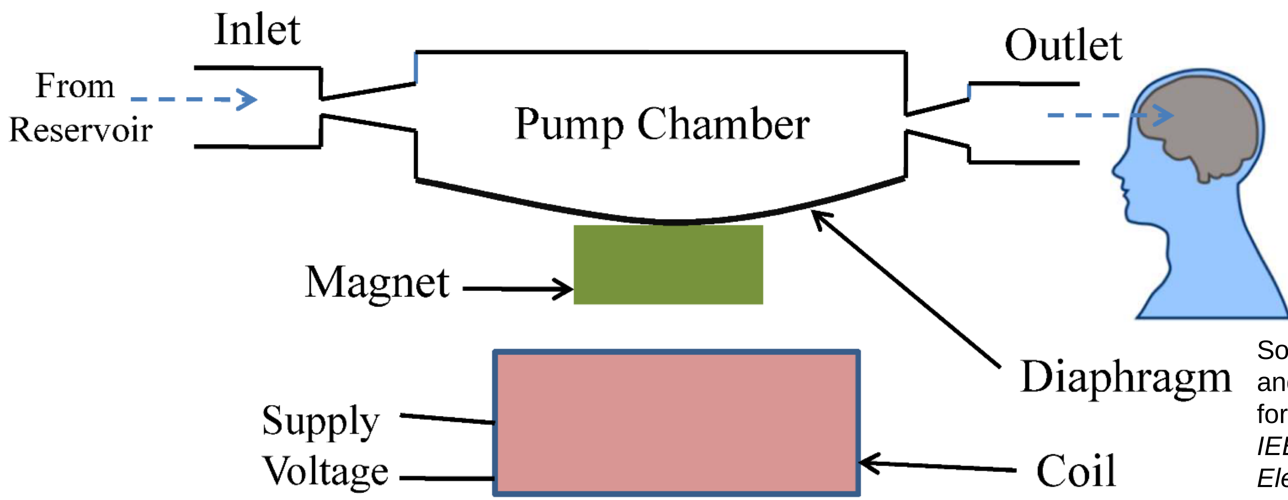


Cloud Vs Edge Computing

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

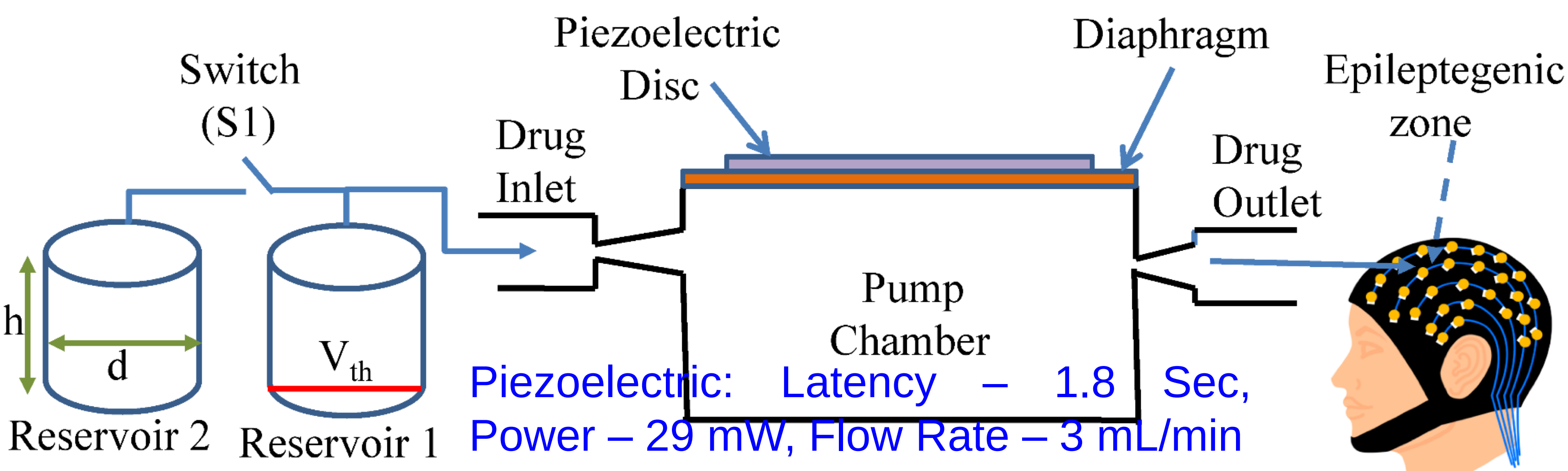
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, “Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT”, *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 3, Aug 2019, pp. 359--368.

Seizure Control Methods



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

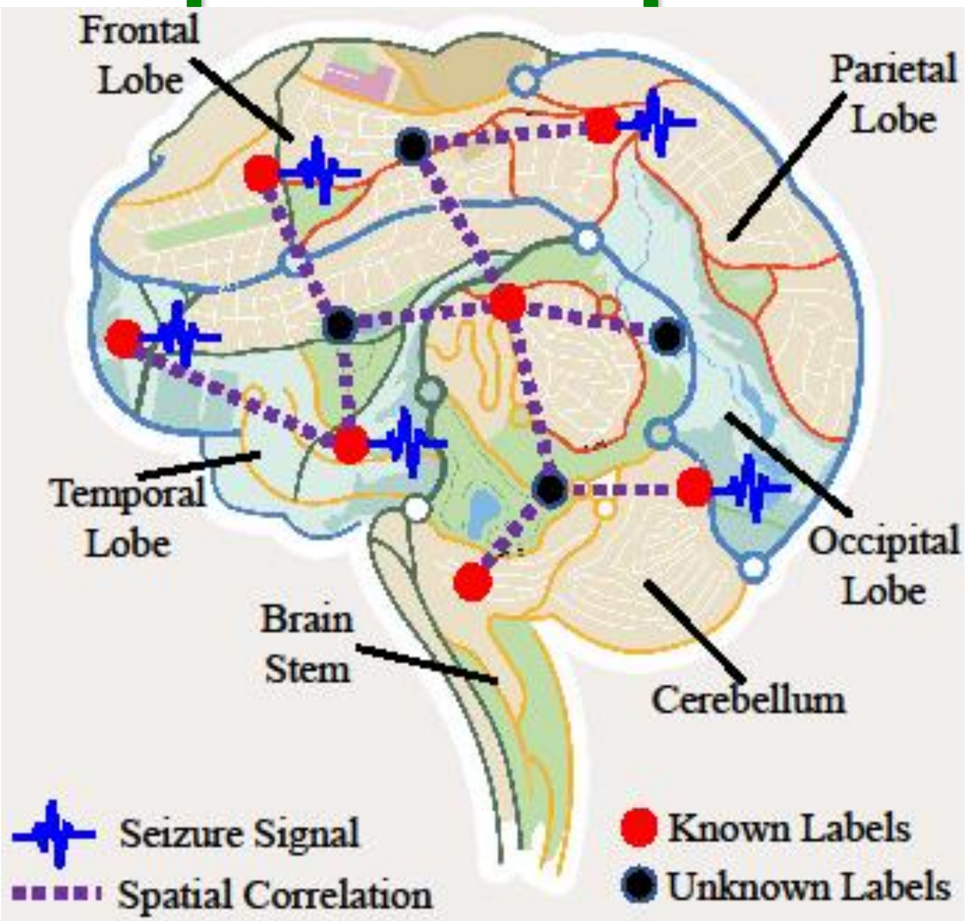
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "An IoT-based Drug Delivery System for Refractory Epilepsy", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

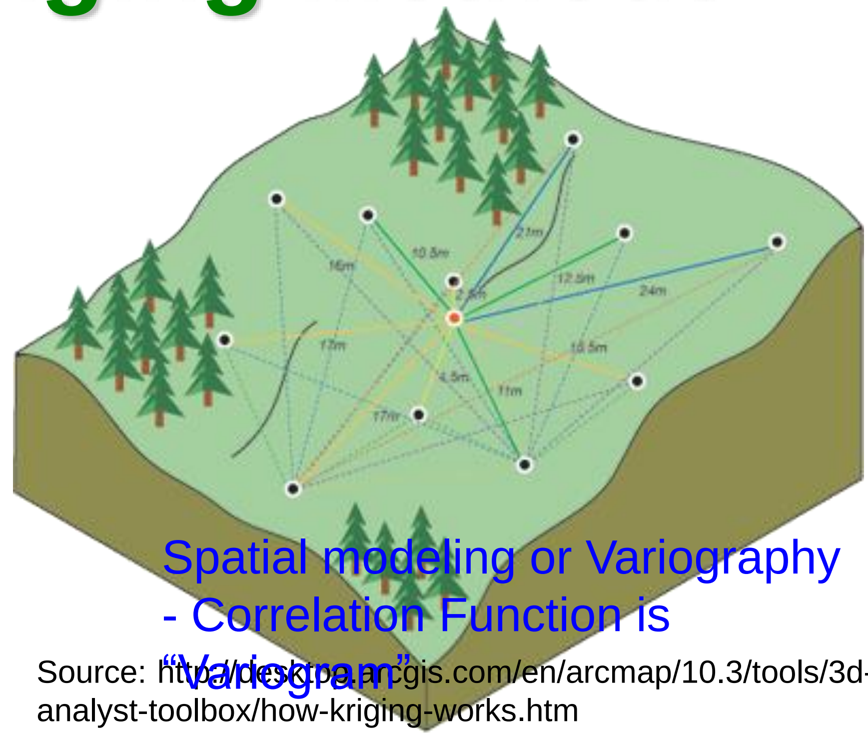


Piezoelectric: Latency – 1.8 Sec, Power – 29 mW, Flow Rate – 3 mL/min

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.

Smart Healthcare – Brain as a Spatial Map → Kriging Methods





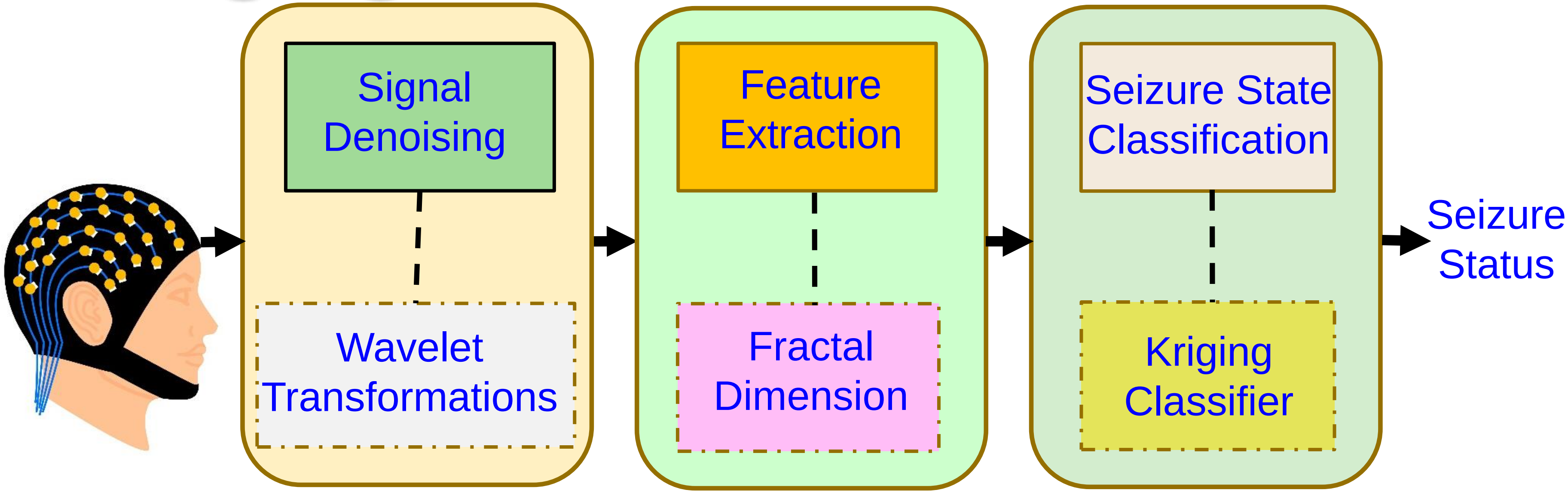
Spatial modeling or Variography - Correlation Function is "Variogram"

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

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.

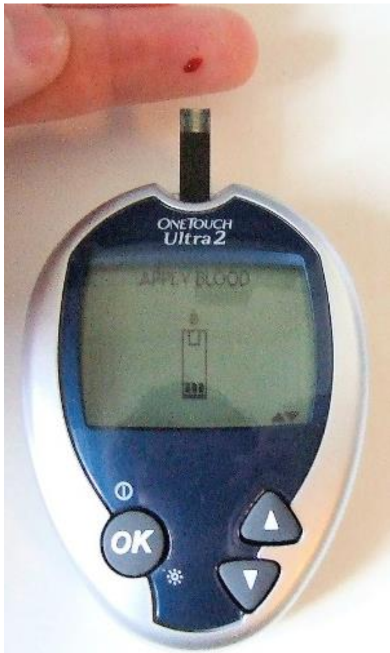
Kriging based Seizure Detection



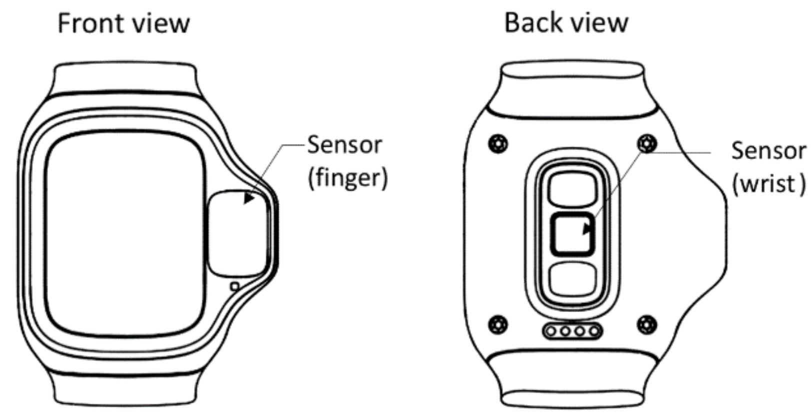
Works	Extracted Features	Classification Algorithm	Sensitivity	Latency
Zandi, et al. 2012 [23]	Regularity, energy & combined seizure indices	Cumulative Sum thresholding	91.00%	9 sec.
Altaf,etal. 2015 [24]	Digital hysteresis	Support Vector Machine	95.70%	1 sec
Vidyaratne, et al. 2017 [25]	Fractal dimension, 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.

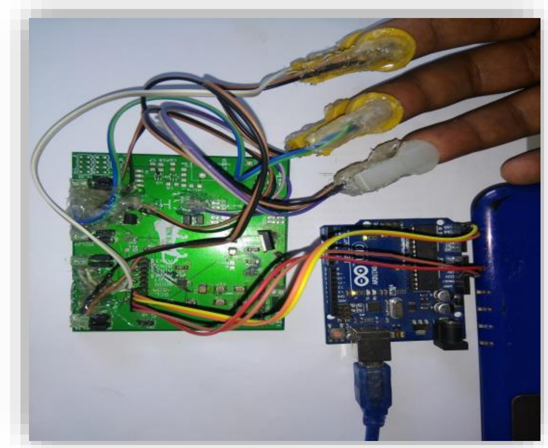
Blood Glucose Monitoring – Invasive Vs Noninvasive



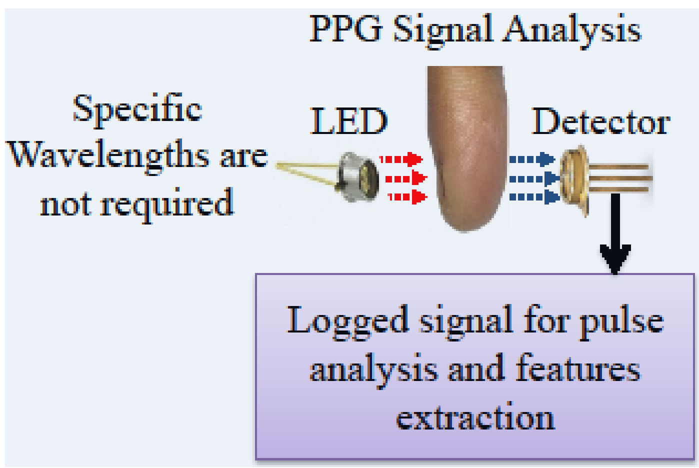
Traditional – Finger Pricking

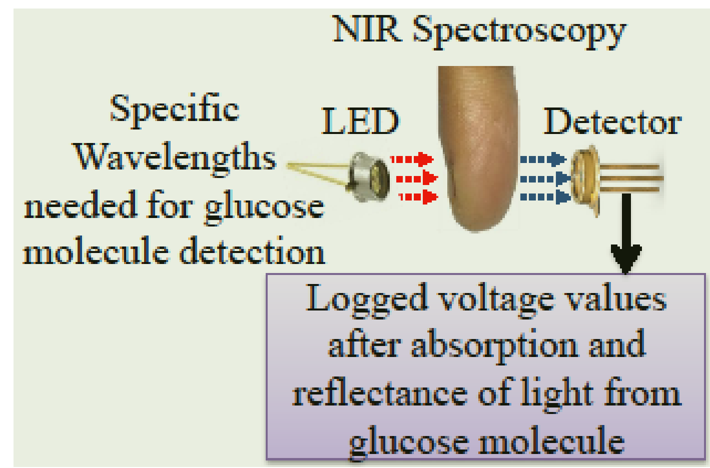


Photoplethysmogram (PPG)



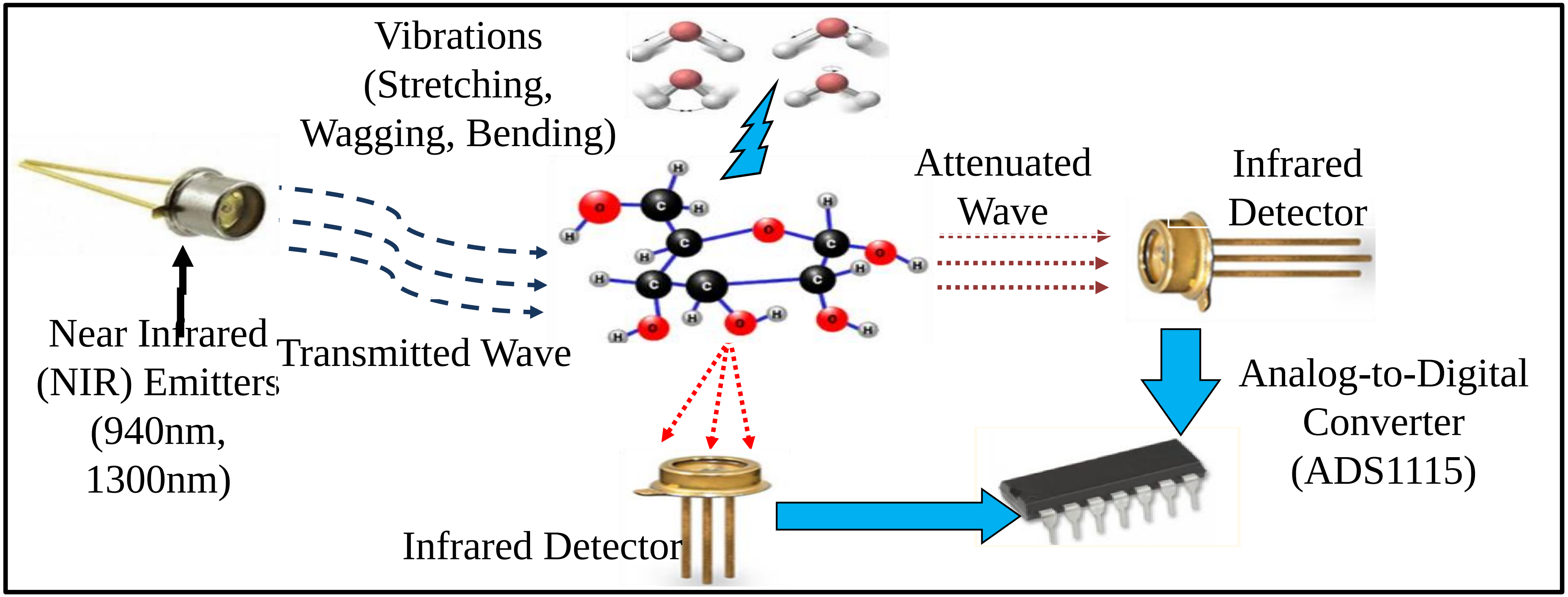
Near Infrared (NIR)





Smart Healthcare – iGLU –

Noninvasive, Accurate, Continuous Glucose Monitoring

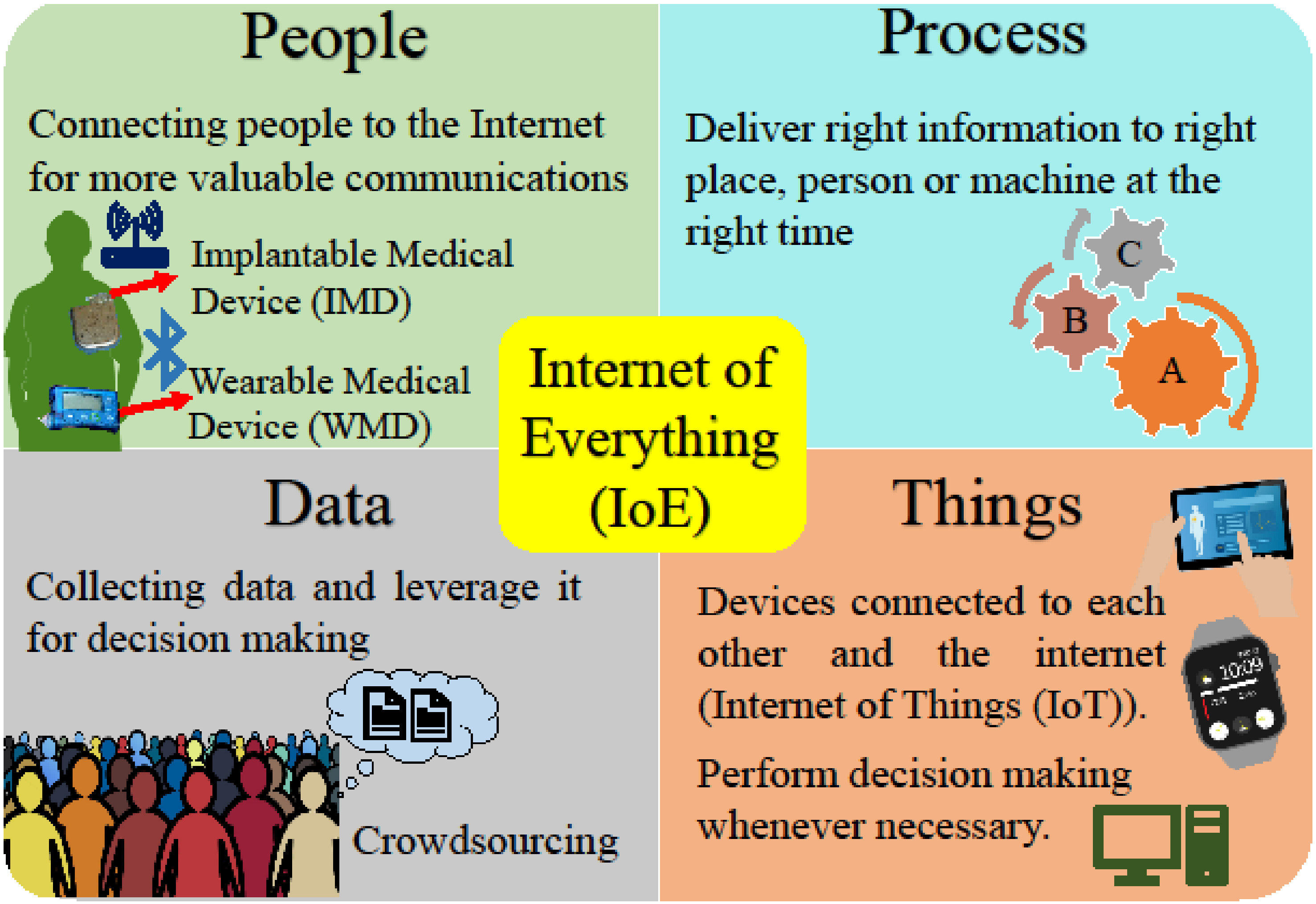


Clinically tested in an hospital.

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. To Appear.

Internet of Every Things (IoE)



Requires:
- Data, Device, and System Security
- Data, Location, and System Privacy

Source: S. P. Mohanty, V. P. Yanambaka, E. Kougianos, and D. Puthal, "PUFchain: Hardware-Assisted Blockchain for Sustainable Simultaneous Device and Data Security in the Internet of Everything (IoE)", arXiv Computer Science, arXiv:1909.06496, September 2019, 37-pages.

Conclusions and Future Research

Conclusions

- Healthcare has been evolving to Healthcare-Cyber-Physical-System (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, privacy, etc.

Future Research

- Internet-of-Everything (IoE) with Human as active part as crowdsourcing need research.
- IoE will need robust data, device, and 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.

Acknowledgement(s)

This material is based upon work supported by the National Science Foundation under Grant Nos. OAC-1924112. 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.