Healthcare Cyber-Physical System - Pandemic Era Perspectives

Invite Talk – Conference on Social Connections to Promote Individual and Community Resilience in Post-COVID-19 Society

Hilton Arlington

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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 – COVID-19 Perspectives
- Conclusions and Future Directions

Healthcare
to
Smart Healthcare

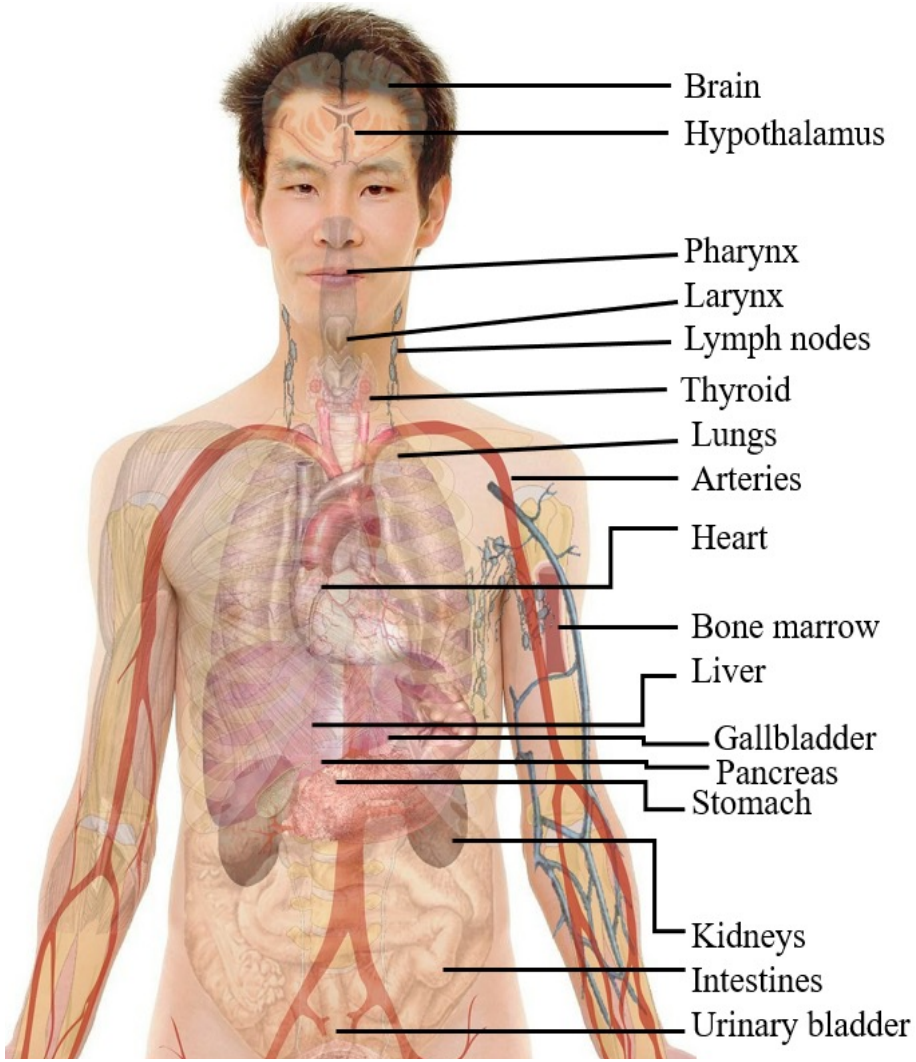
Human Body and Health

Human Body

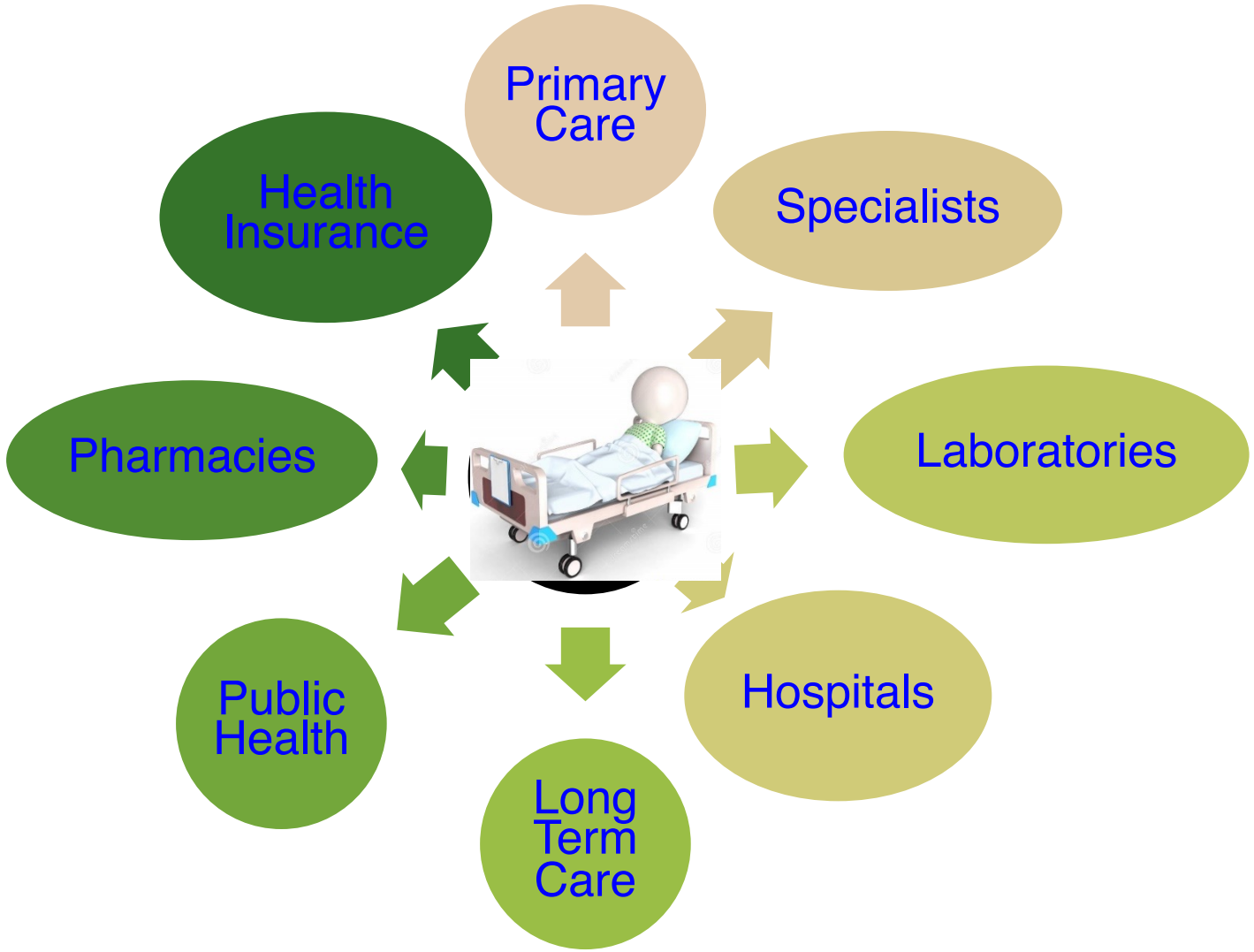
- From an engineering perspective - Human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical …).

Health

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



Traditional Healthcare

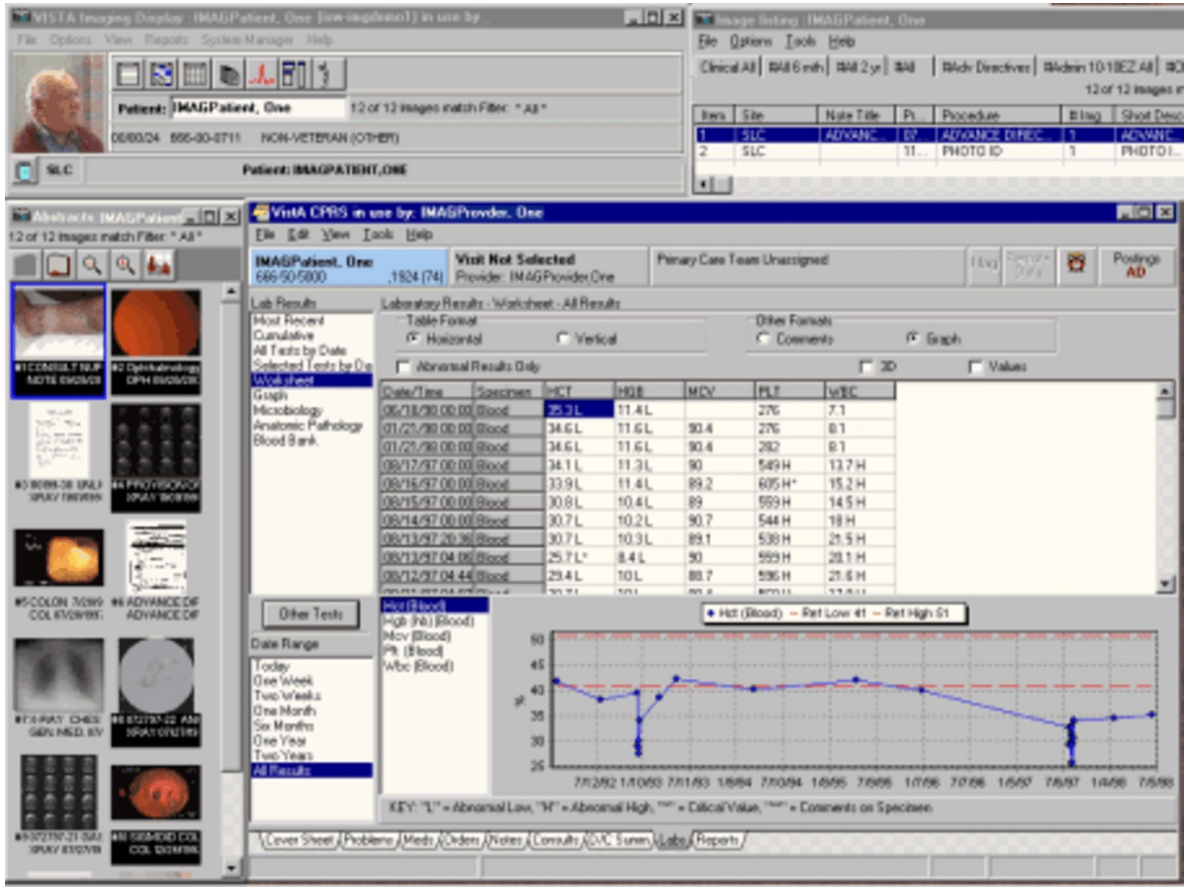


- Physical presence needed
- Deals with many stakeholders
- Stakeholders may not interact
- May not be personalized
- Not much active feedback
- Less effective follow-up from physicians

Telemedicine

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

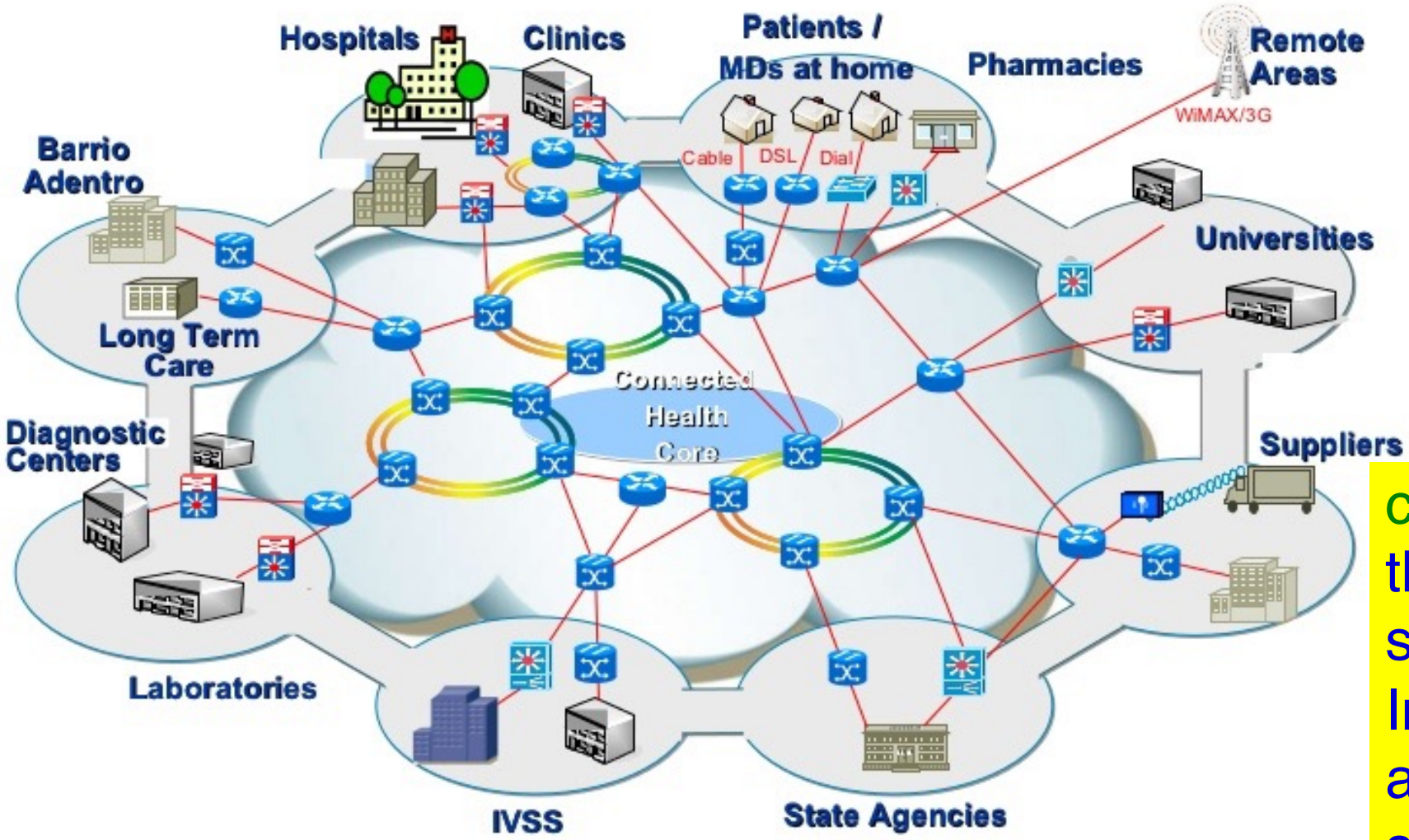
Electronic Health (eHealth)



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

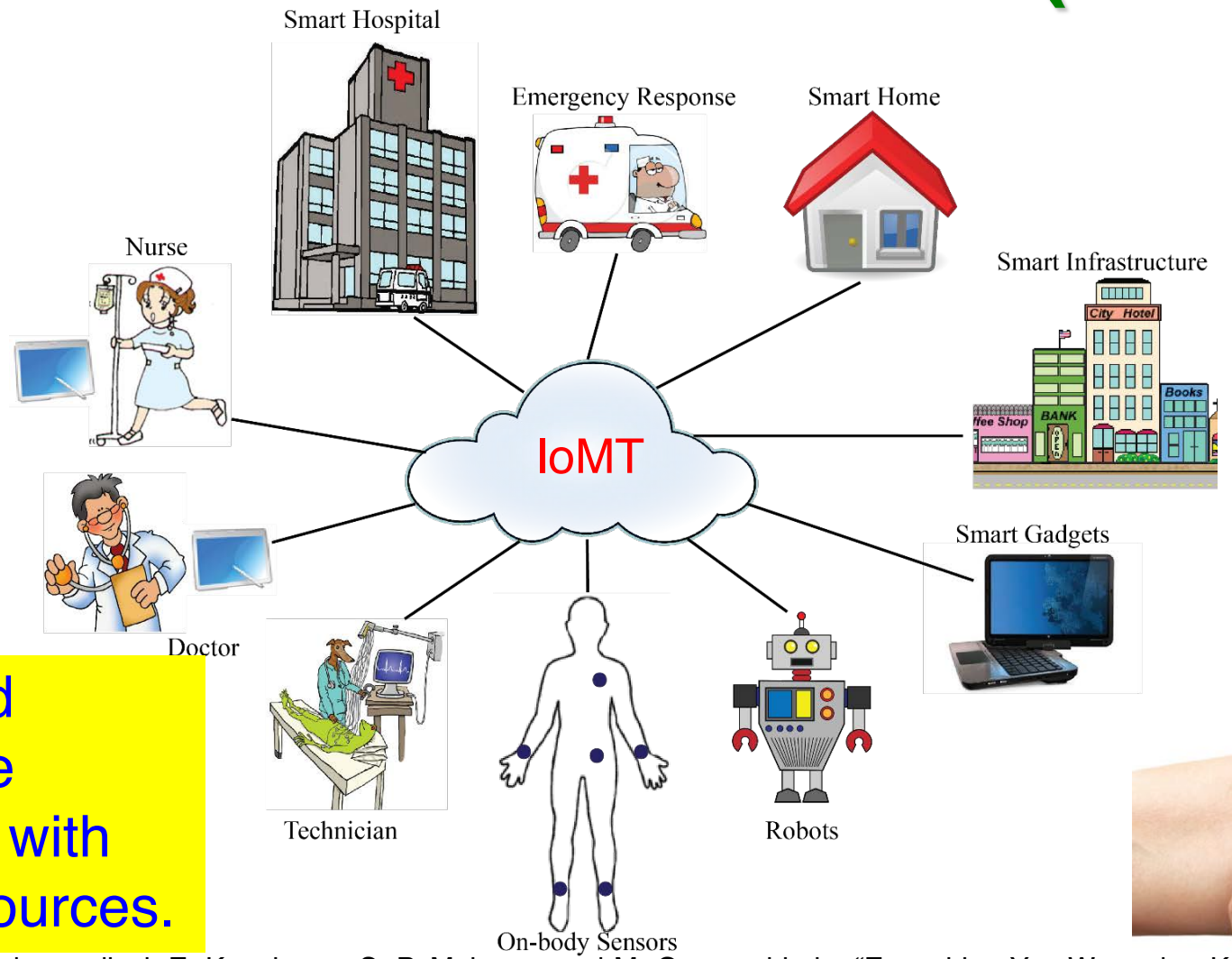
cHealth: Connections of the various healthcare stake holders through Internet to share appropriate data to better serve the patients.

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.

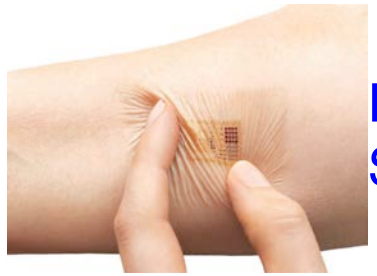
Smart Healthcare (sHealth)



Fitness Trackers

Headband with Embedded Neurosensors

Quality and sustainable healthcare with limited resources.



Embedded Skin Patches

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

Smart Healthcare - Characteristics

What is Smart Healthcare?

Smart Healthcare

←

Conventional Healthcare

+ Body sensors

+ Information & Communication Technology (ICT)

+ AI/ML

+ Smart Technology (BCI, VR, etc.)

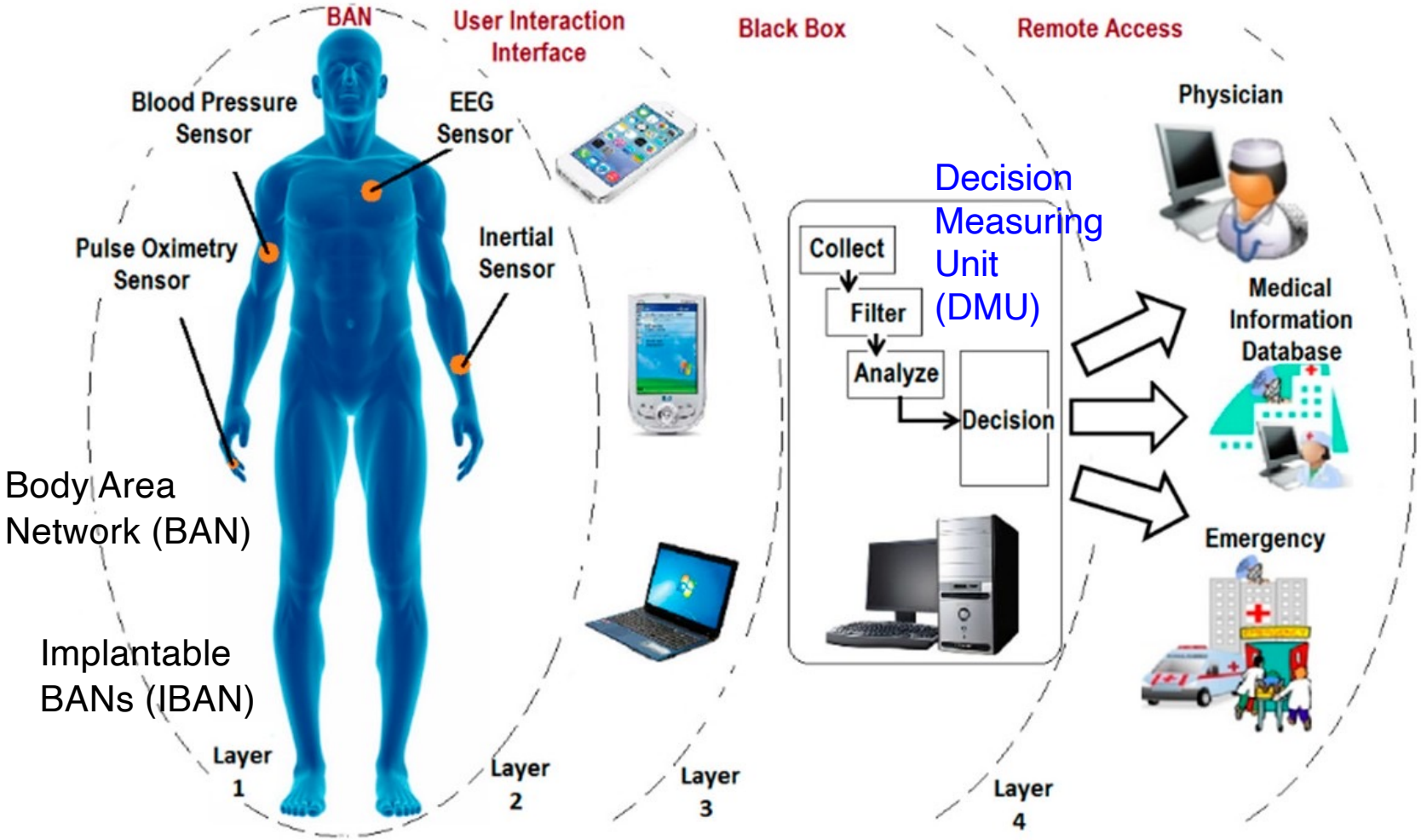
Internet of Medical Things (IoMT)

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.

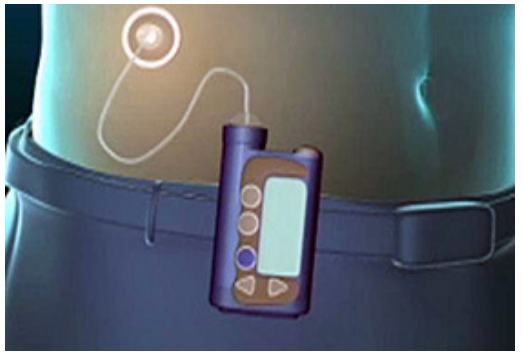
Wearable Medical Devices (WMDs)

Fitness Trackers

Headband with Embedded Neurosensors

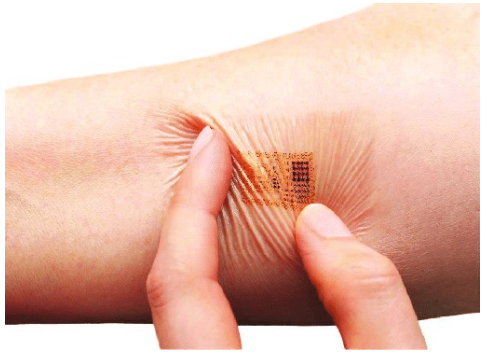
Source: https://www.empatica.com/embrace2/

Medical grade smart watch to detect seizure



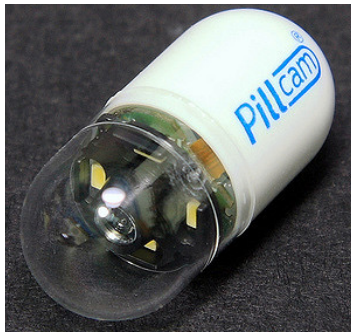
Source: https://www.webmd.com

Insulin Pump

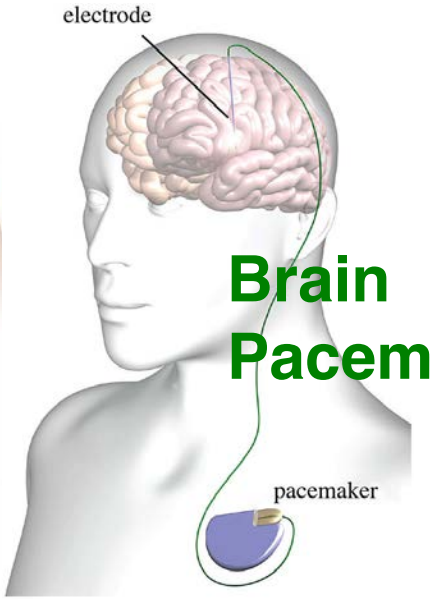


Embedded Skin Patches

Implantable Medical Devices (IMDs)



Pill Camera



Brain Pacemaker

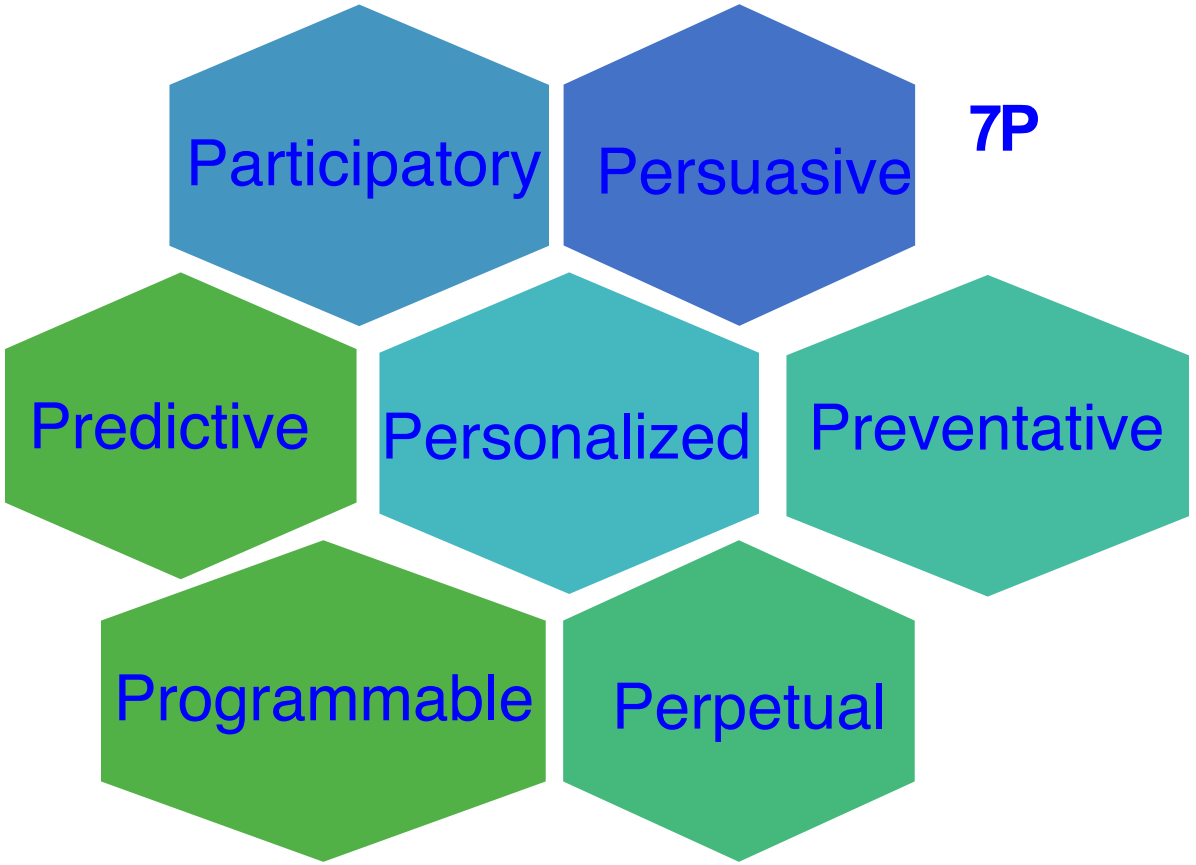
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "*Everything You Wanted to Know about Smart Health Care*", IEEE Consumer Electronics Magazine (MCE), Volume 7, Issue 1, January 2018, pp. 18-28.

Collectively:
Implantable and Wearable Medical Devices (IWMDs)

Implantable MEMS Device

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

Smart Healthcare – 7Ps



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.

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

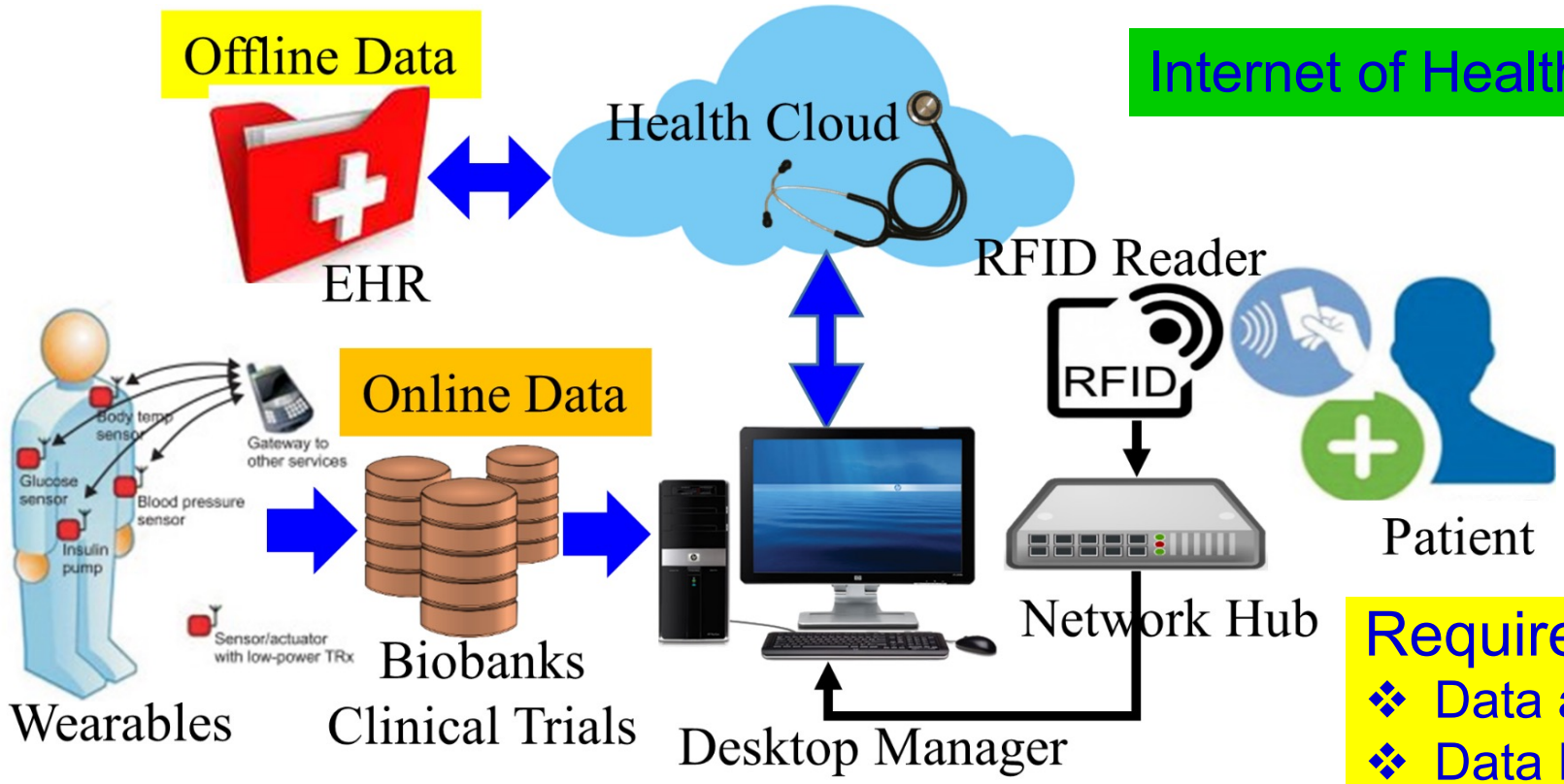
Market Challenges

- 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)



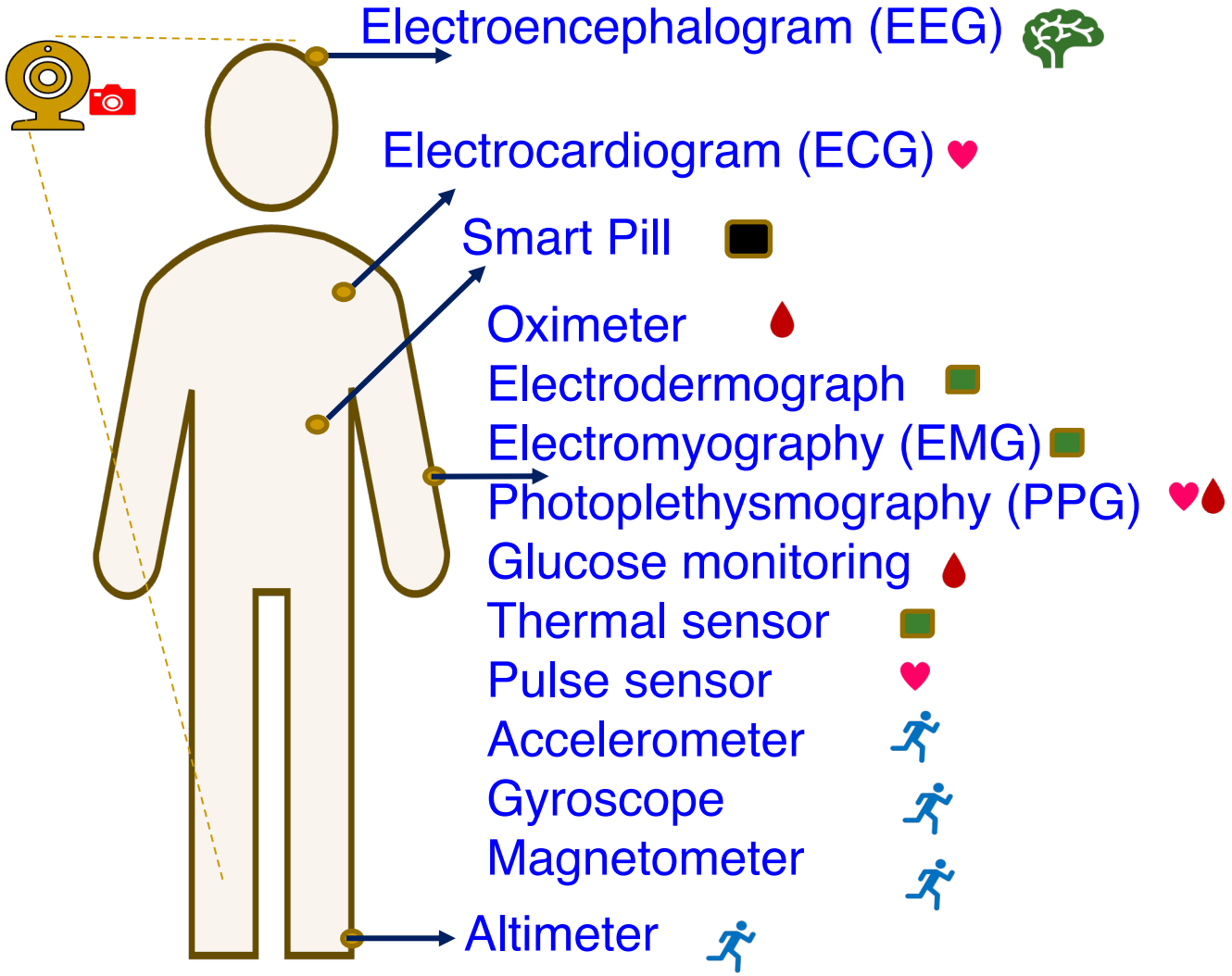
Requires:

- 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

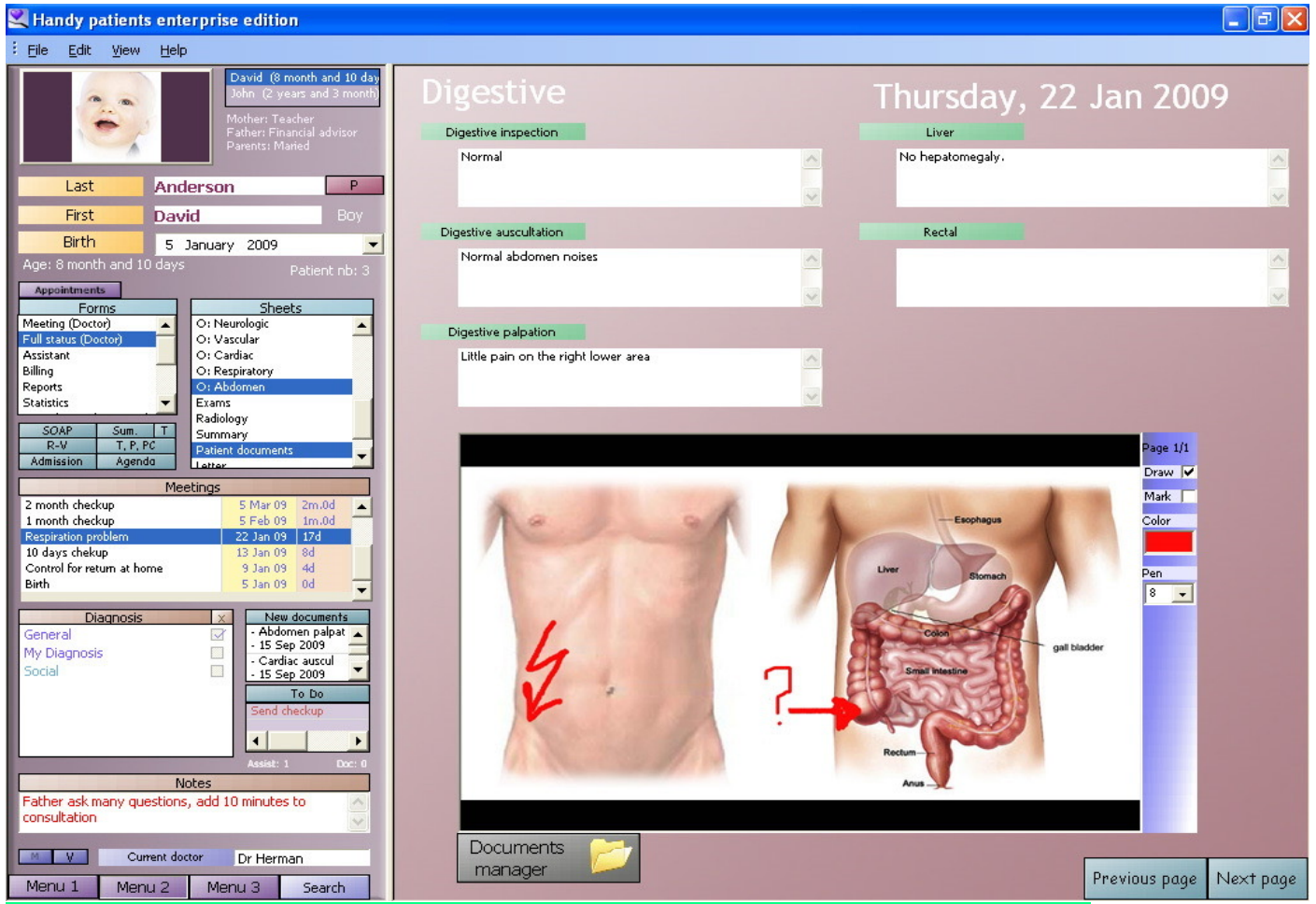
Smart Healthcare Communication

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 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

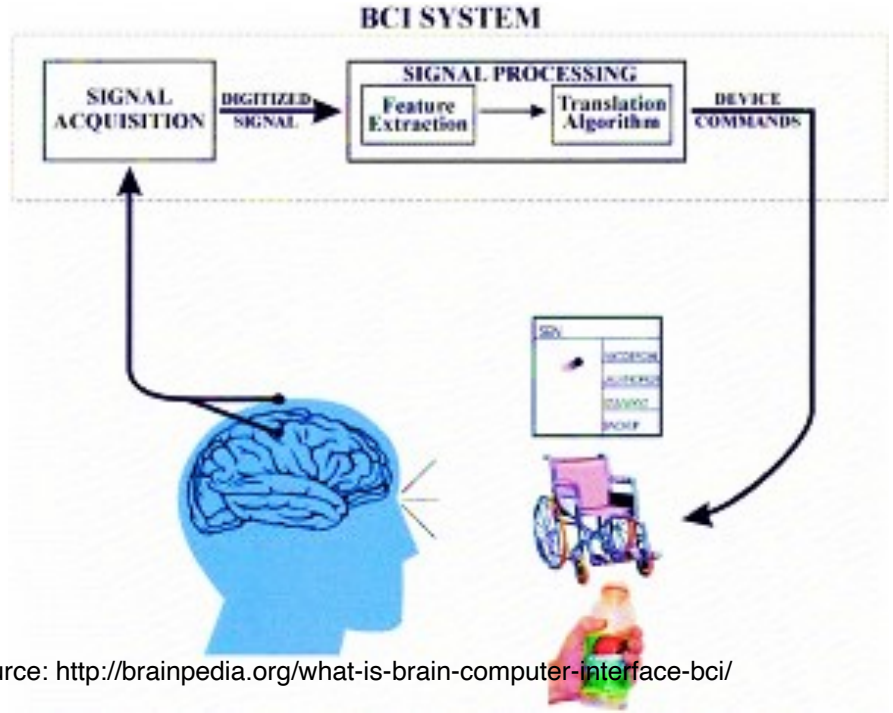
Systems & Analytics
- Clinical Decision Support Systems (CDSSs)
- Electronic Health Records (EHRs)

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

Brain Computer Interface (BCI)

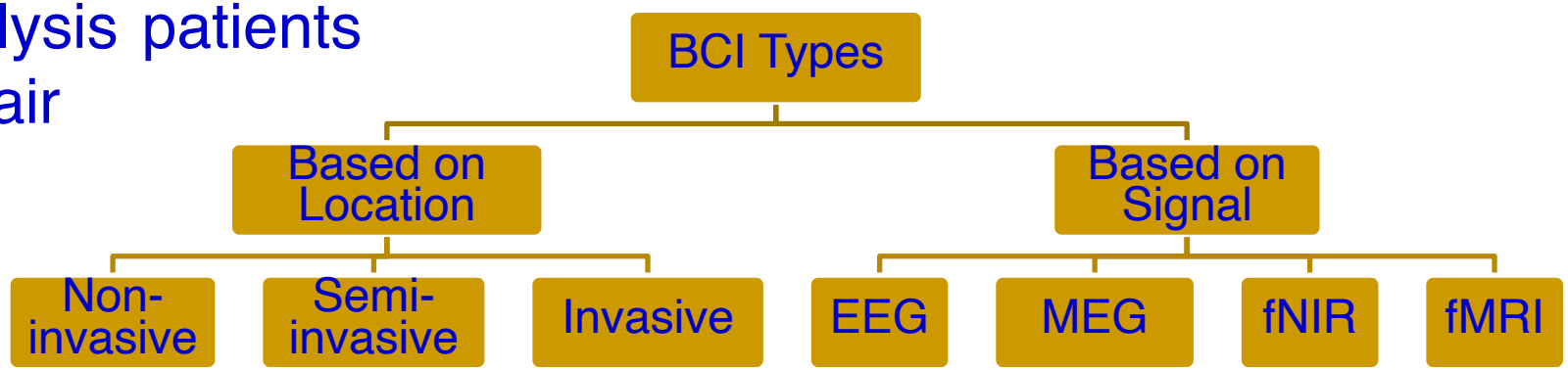


Source: http://brainpedia.org/what-is-brain-computer-interface-bci/

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

For Therapy

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

In Surgery

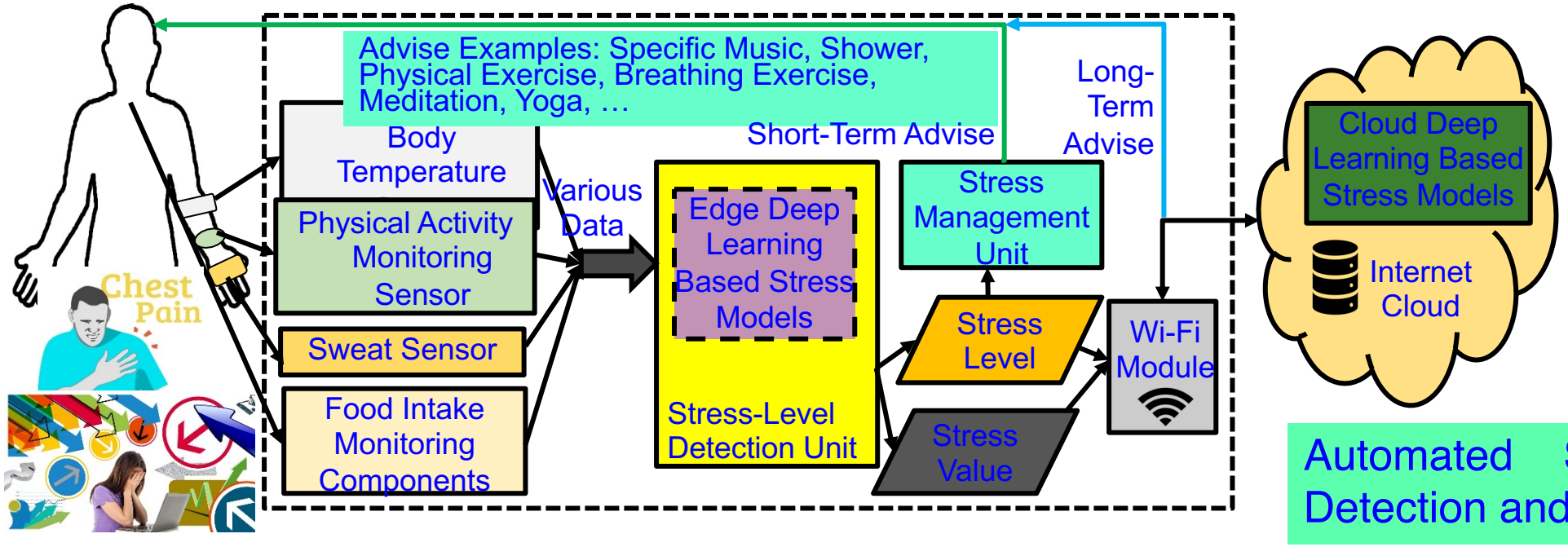
Smart Healthcare – Specific Examples

Stress is a Global Issue

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

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

Stress Monitoring & Control – Our Vision

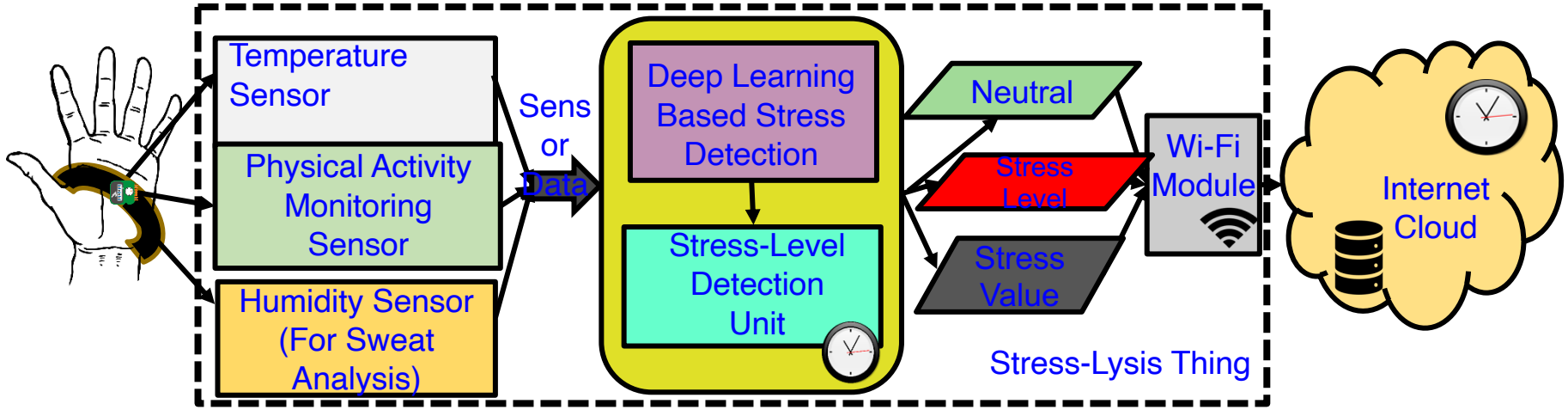


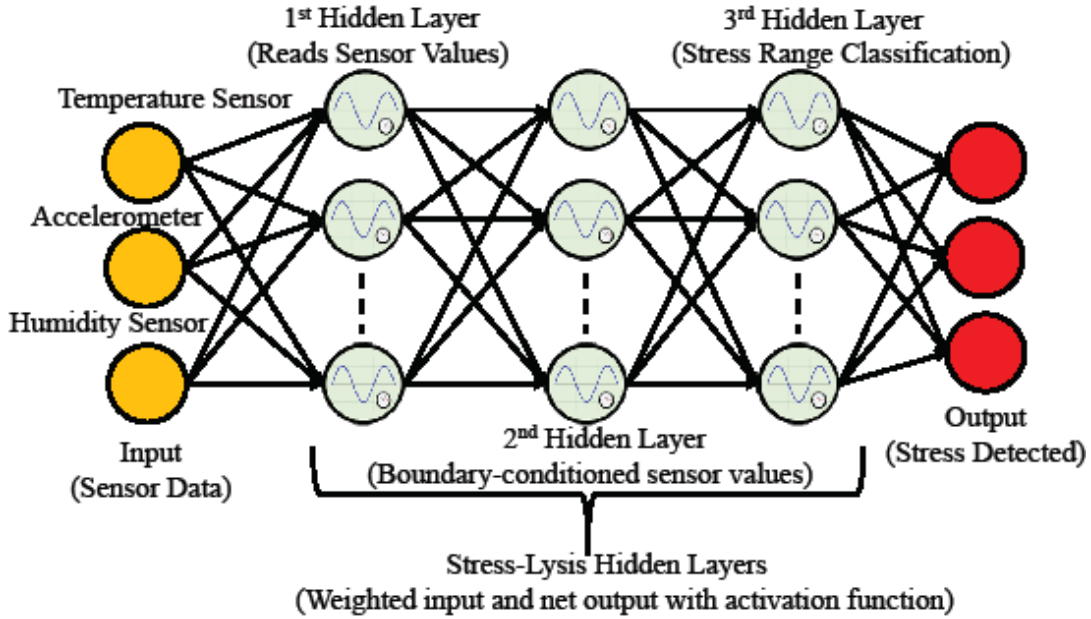
Automated Stress Level Detection and Management

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.

Stress-Lysis: From Physiological Signals

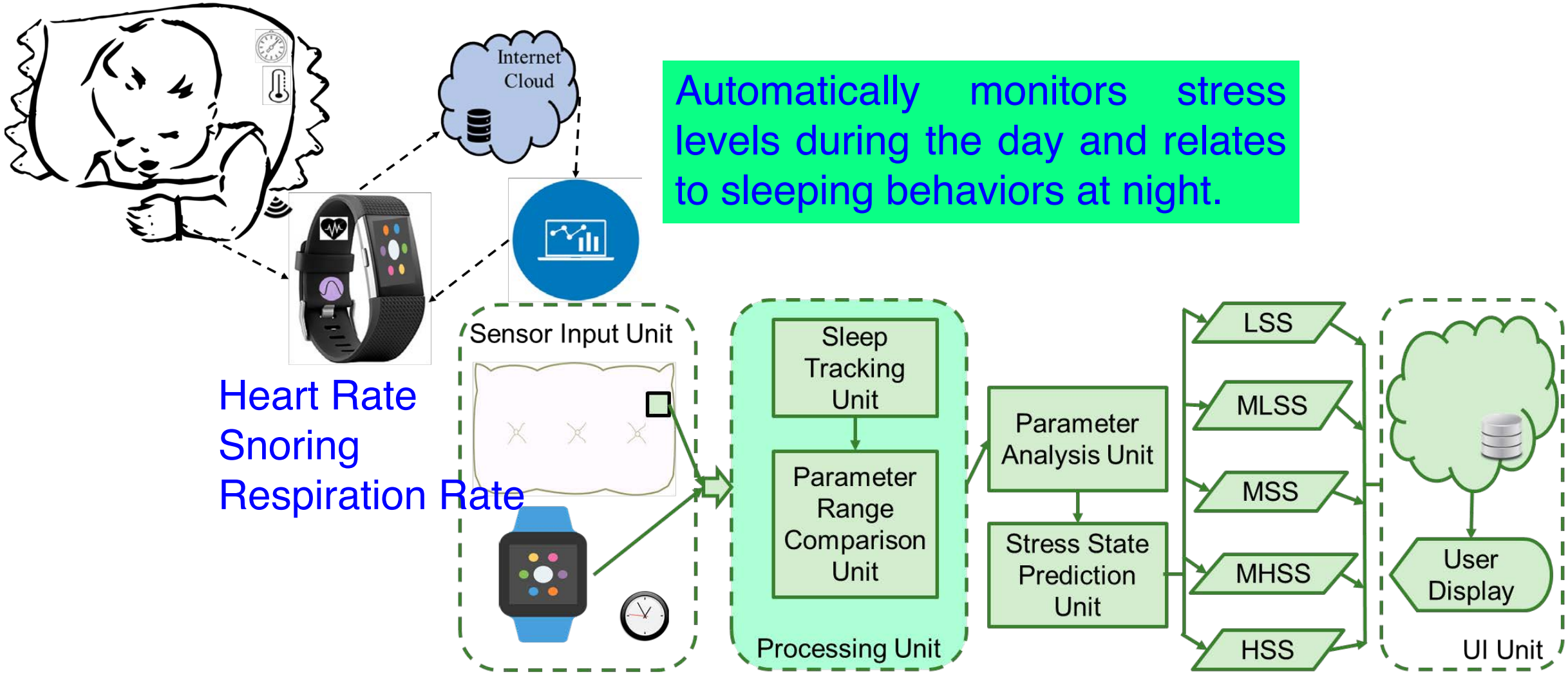




Stress-Lysis - DNN has been trained with a total of 26,000 samples per dataset and has accuracy upto 99.7%.

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.

Smart Healthcare – Smart-Pillow



Source: L. Rachakonda, S. P. Mohanty, E. Kougianos, K. Karunakaran, and M. Ganapathiraju, "Smart-Pillow: An IoT based Device for Stress Detection Considering Sleeping Habits", in *Proceedings of the 4th IEEE International Symposium on Smart Electronic Systems (iSES)*, 2018, pp. 161--166.

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

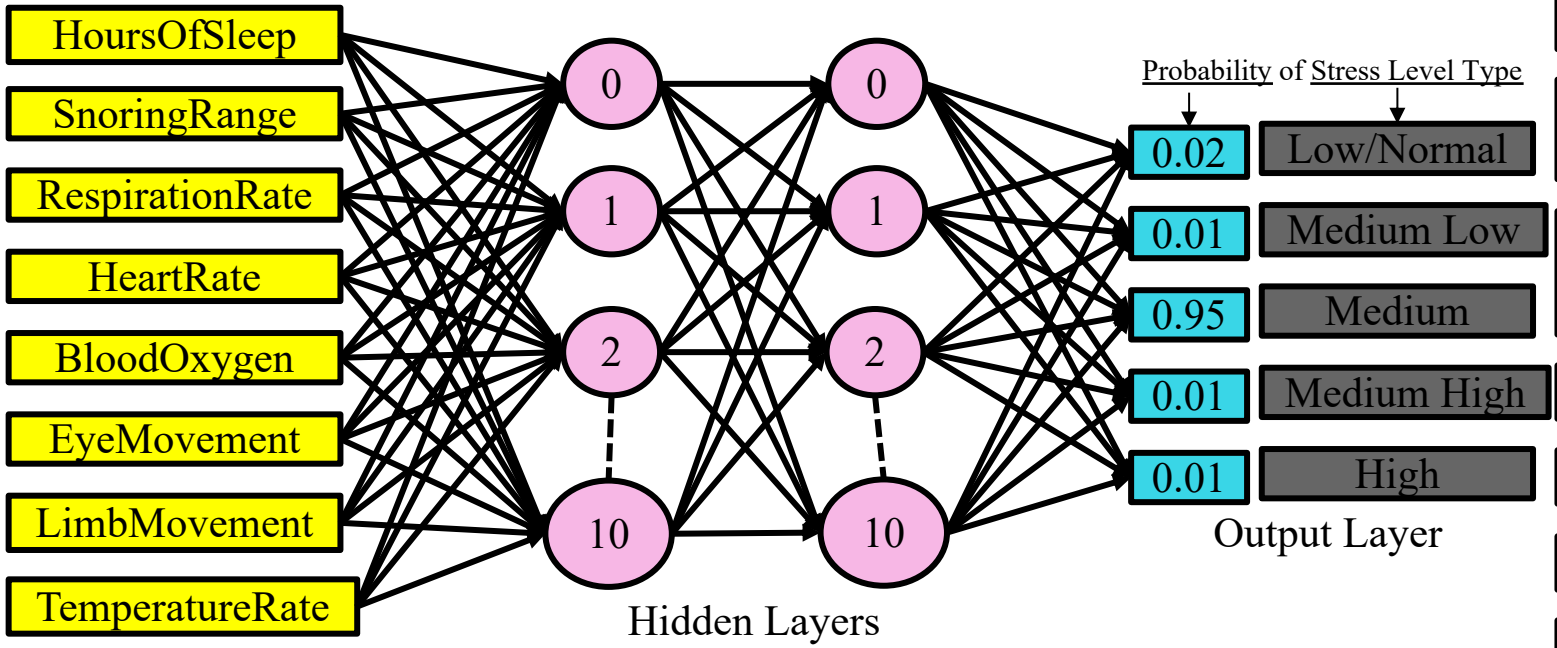
Secure Data Storage

Secure Data Access

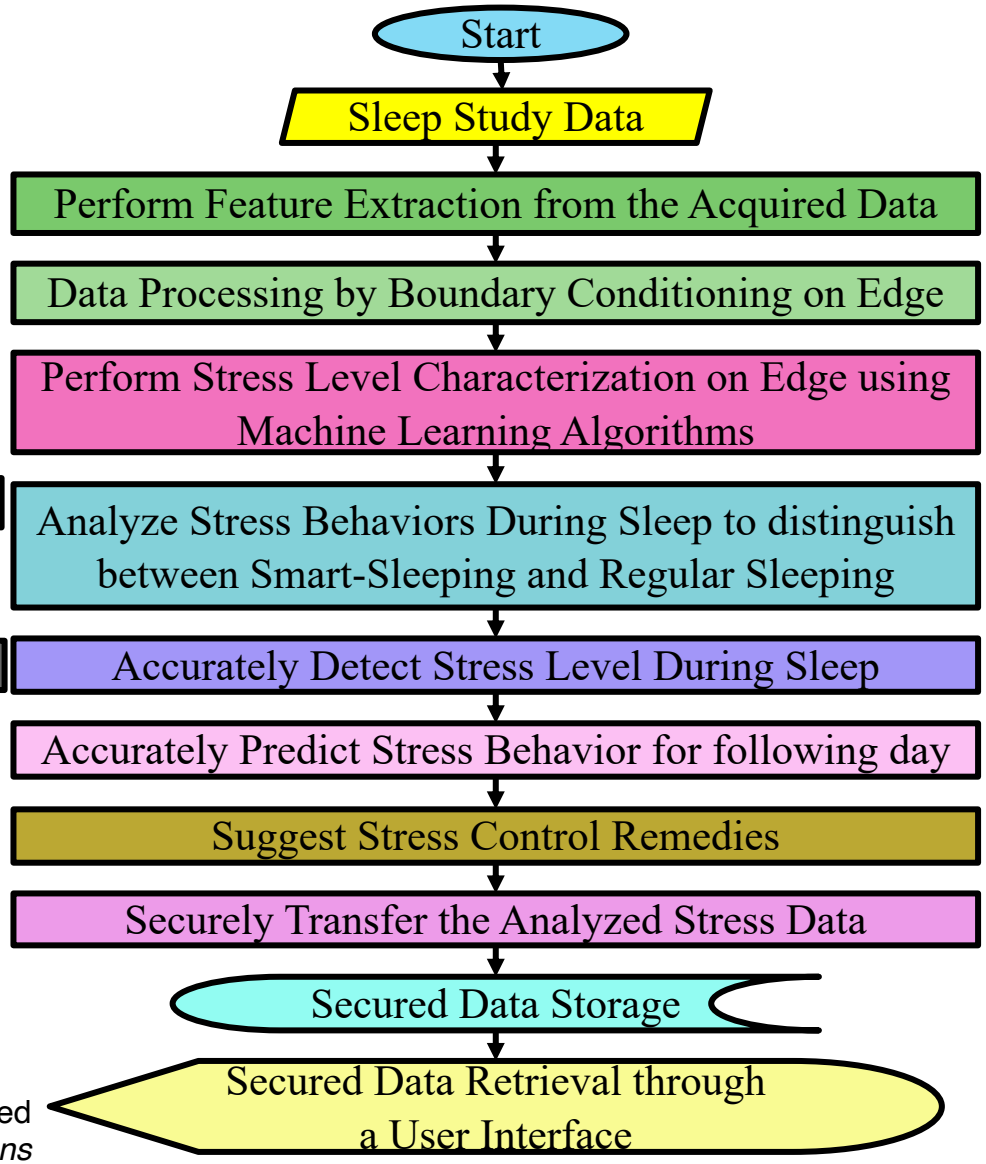
User Applications

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

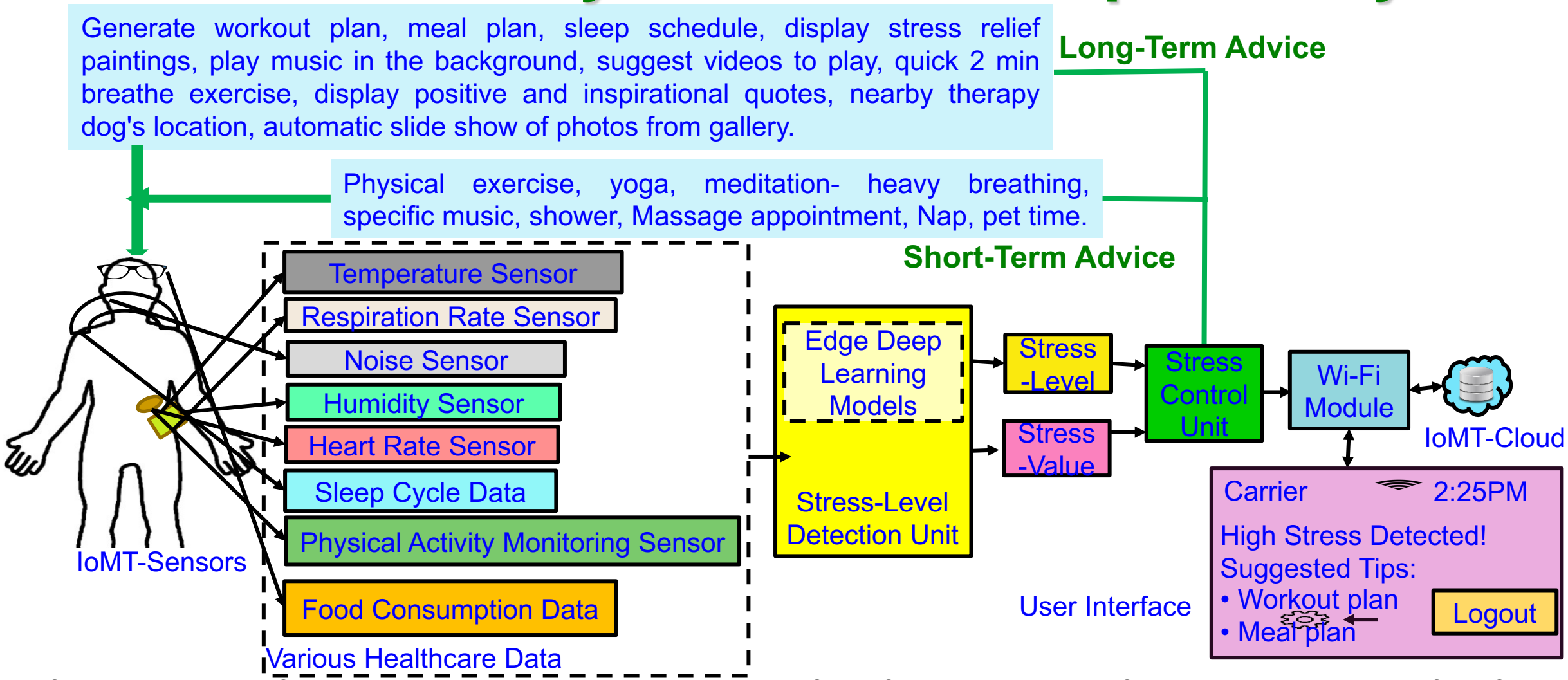


SaYoPillow – Uses deep learning for 96% accuracy with blockchain based security features



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.

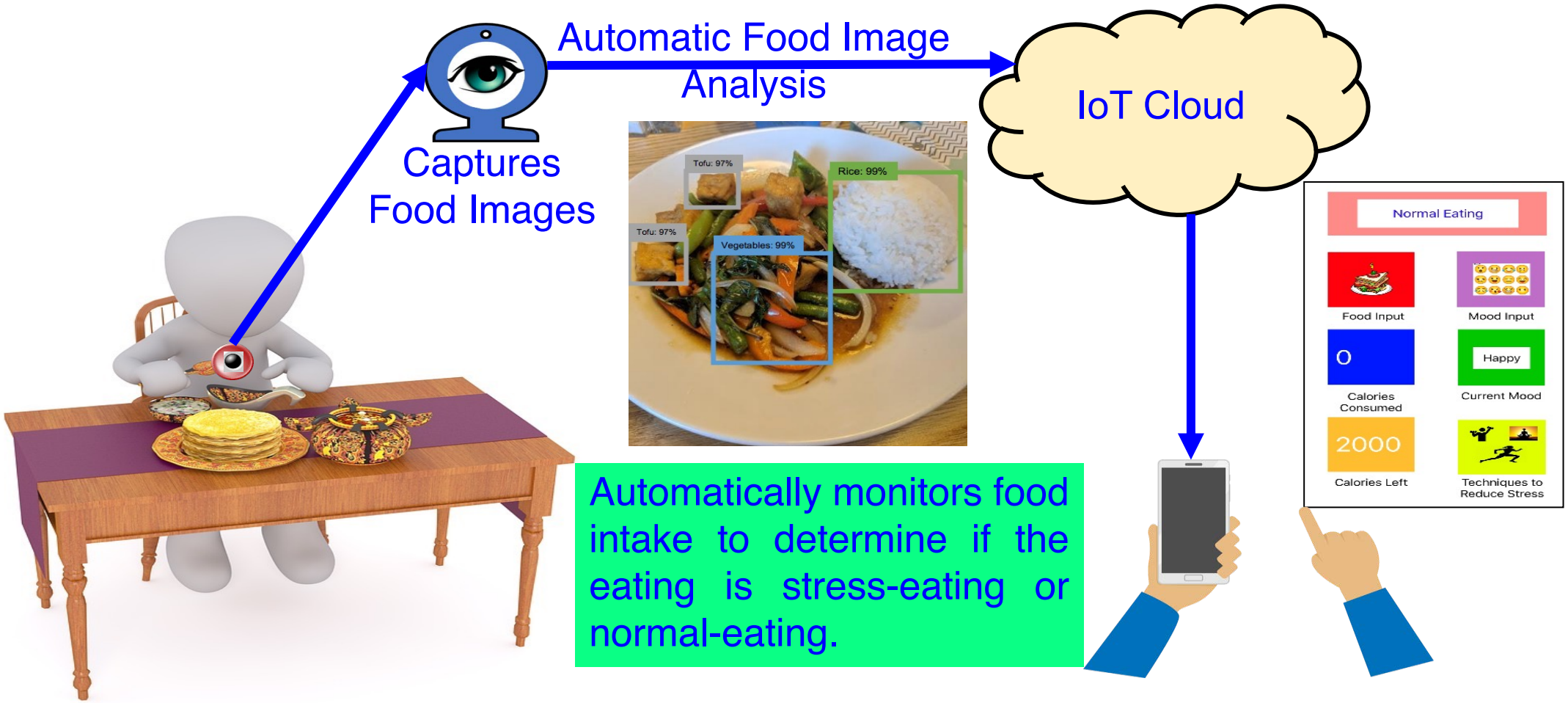
Imbalance Diet is a Global Issue

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

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

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

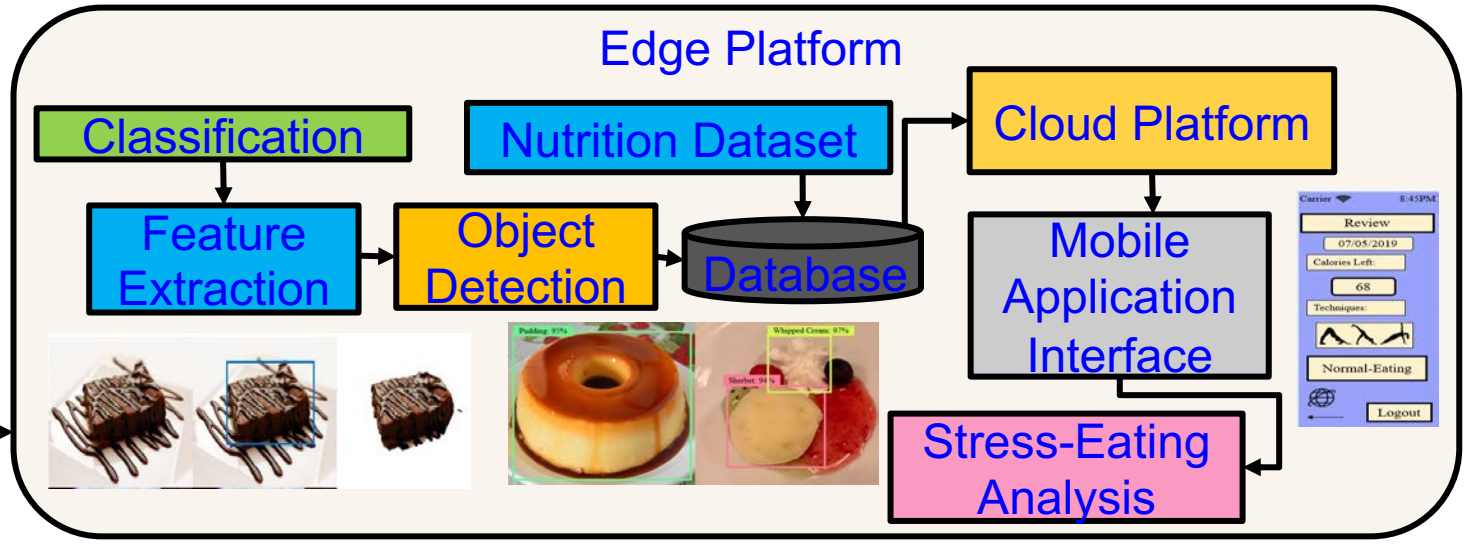
Automatic Diet Monitoring & Control - Our Vision



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.

Smart Healthcare – Diet Monitoring - iLog

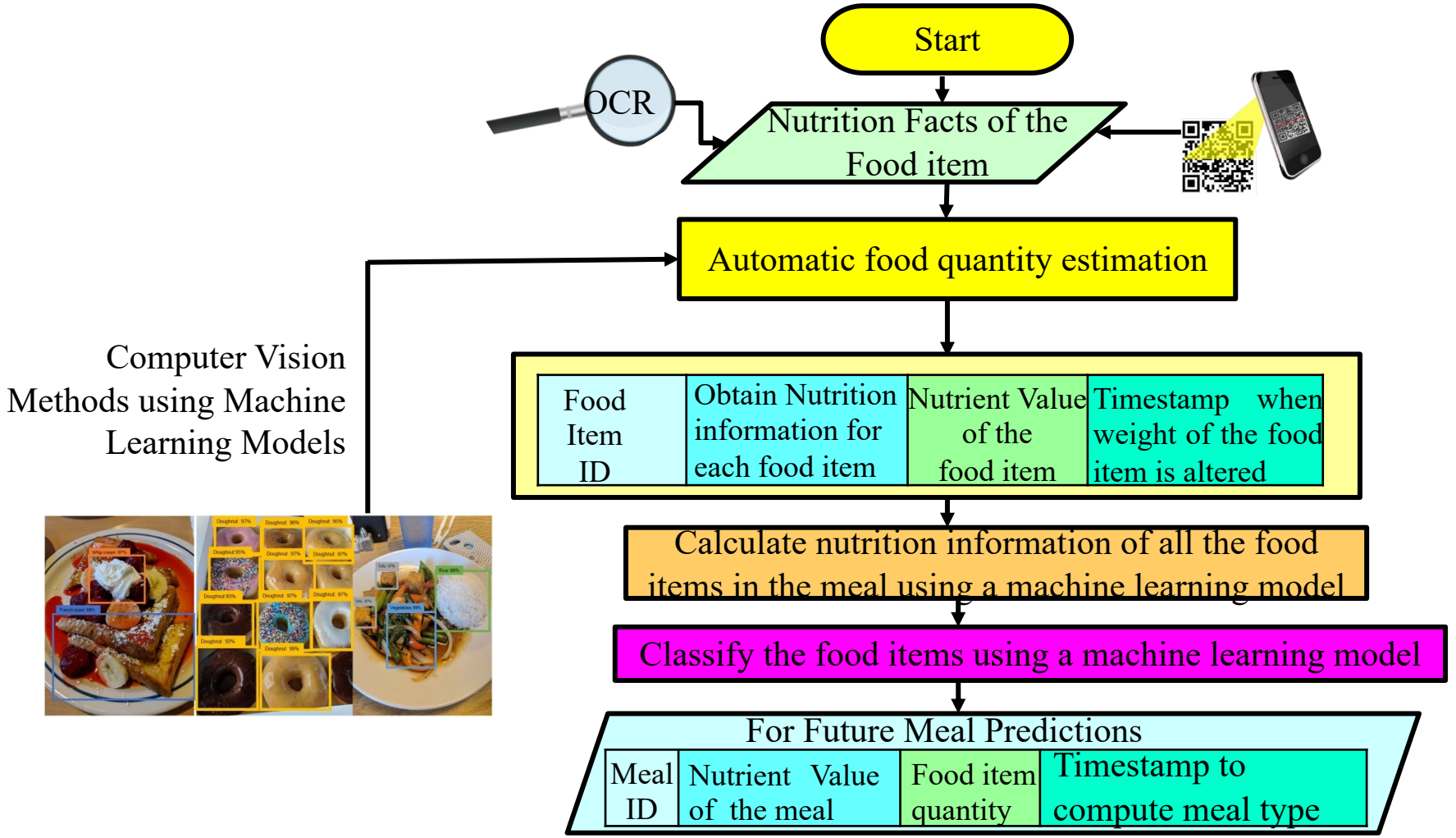
Reference Image



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.

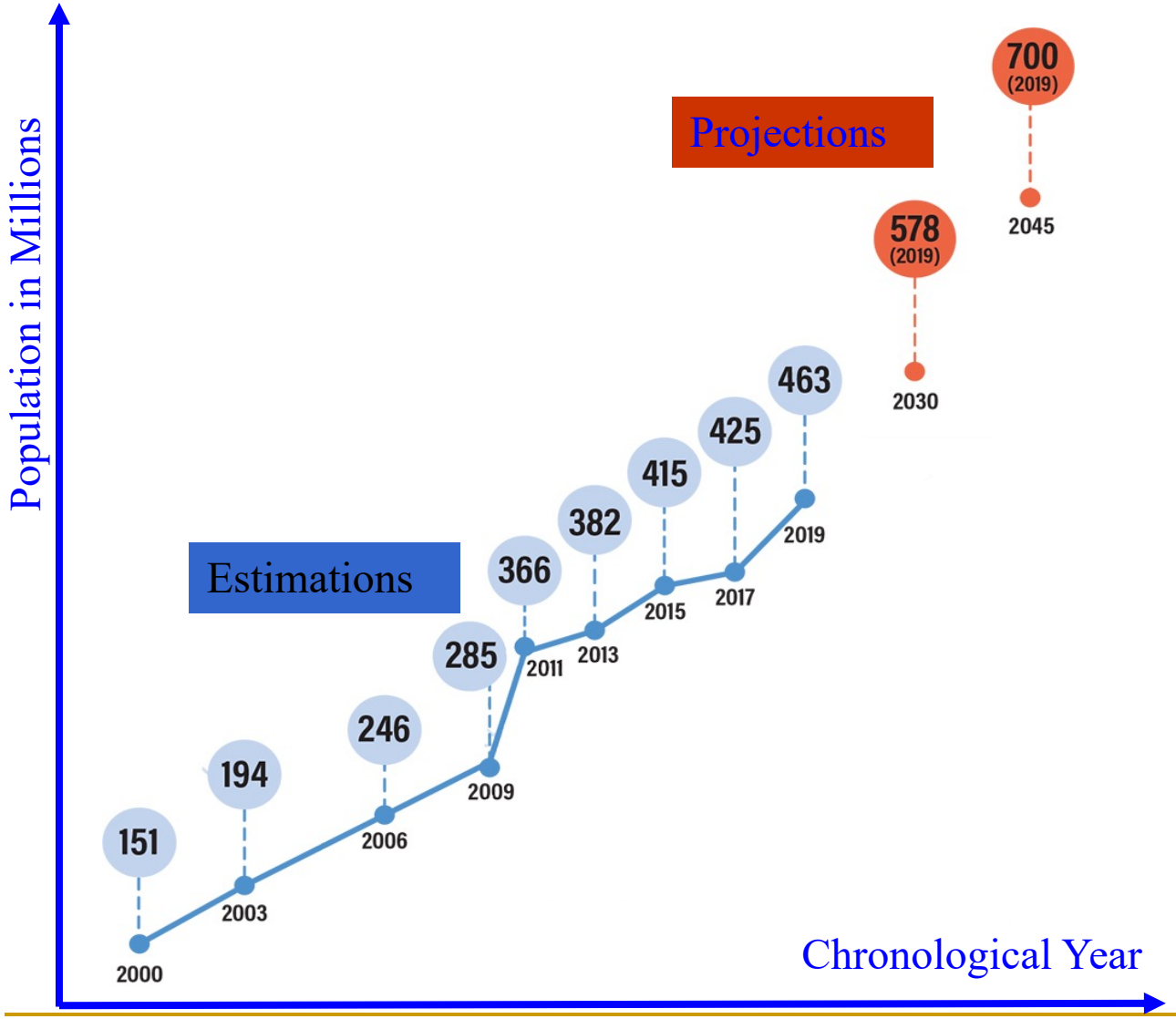
Smart Healthcare – Diet Prediction – Smart-Log



Smart-Log Prediction Accuracy - 98.6%

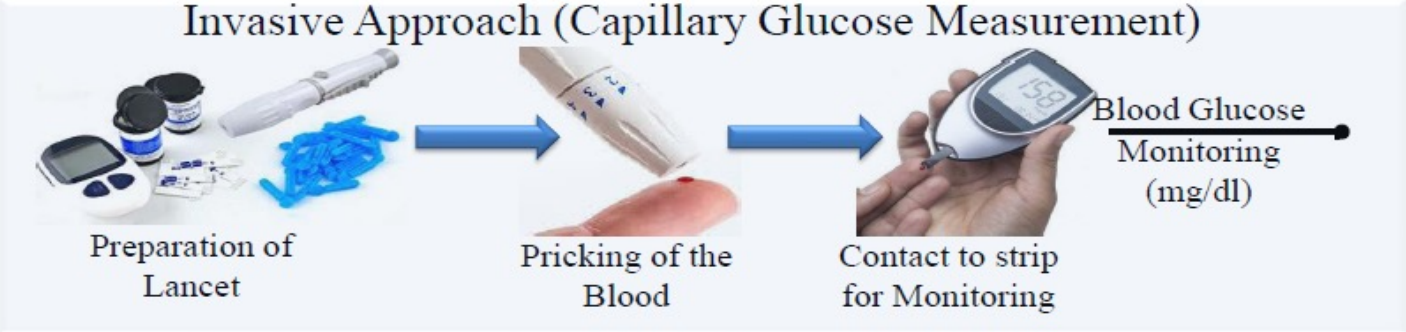
Source: P. Sundaravadivel, K. Kesavan, L. Kesavan, **S. P. Mohanty**, and E. Kougianos, "Smart-Log: A Deep-Learning based Automated Nutrition Monitoring System in the IoT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 64, Issue 3, Aug 2018, pp. 390-398.

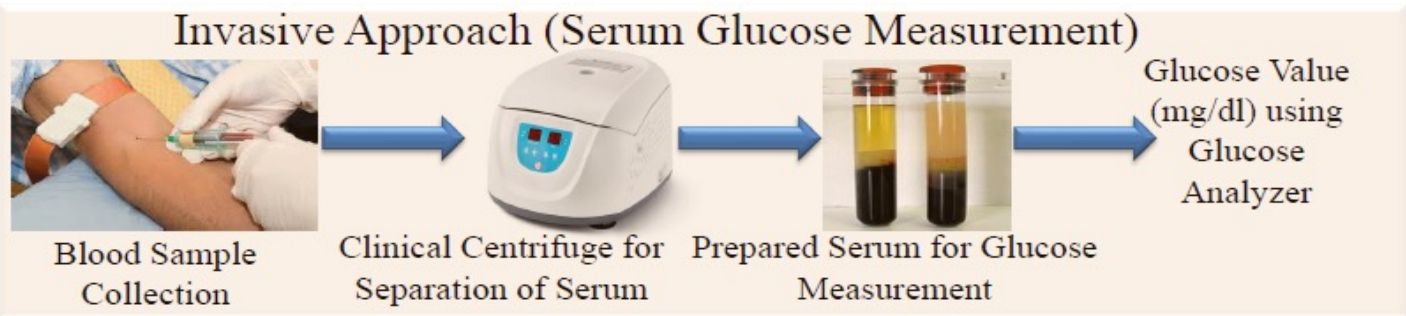
Diabetes is a Global Crisis

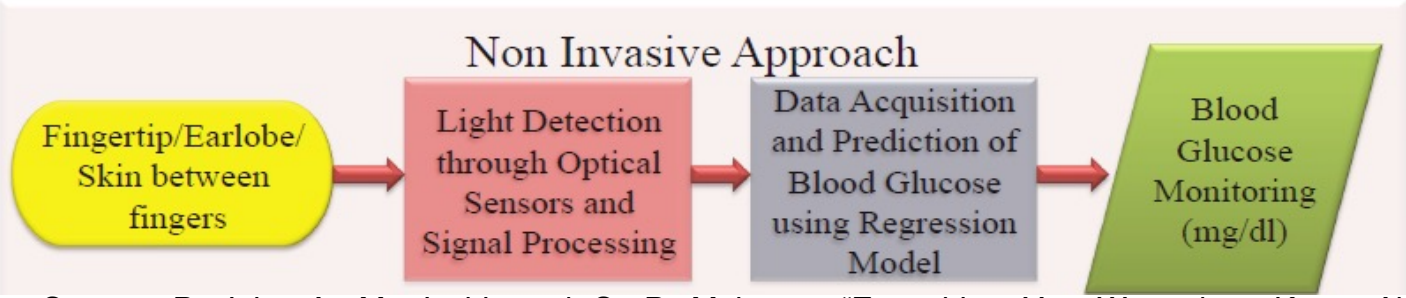


Source: A. M. Joshi, P. Jain and S. P. Mohanty, "Everything You Wanted to Know About Continuous Glucose Monitoring," *IEEE Consumer Electronics Magazine*, doi: 10.1109/MCE.2021.3073498.

Blood Glucose Monitoring – Invasive Vs Noninvasive







Traditional – Finger Pricking

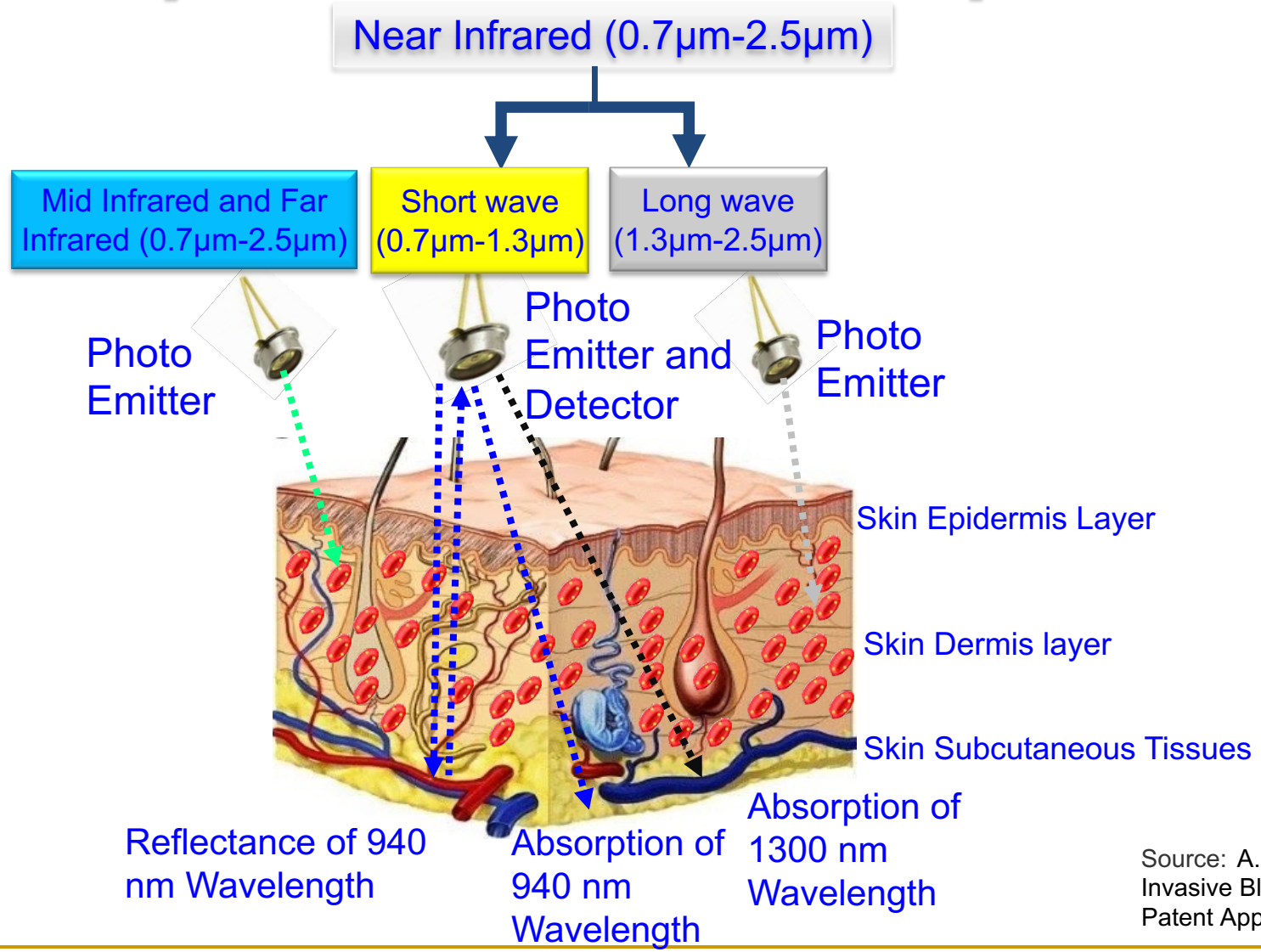
Invasive Approach – Processing Blood/Serum

Noninvasive – Wearable

Noninvasive Approach – Processing Light

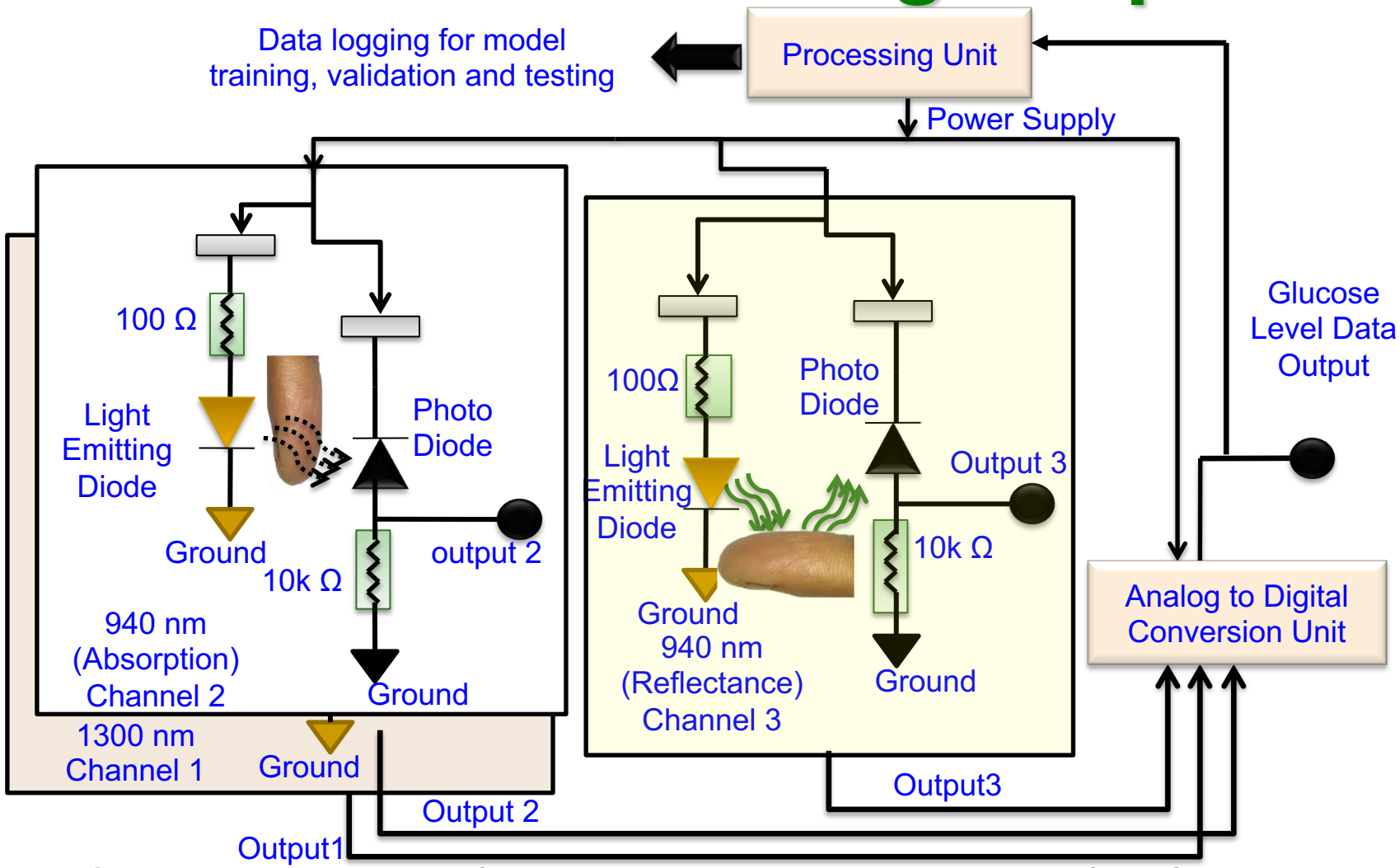
Source: P. Jain, A. M. Joshi, and S. P. Mohanty, "Everything You Wanted to Know About Noninvasive Glucose Measurement and Control", *arXiv Physics*, arXiv:2101.08996, January 2021, 51-pages.

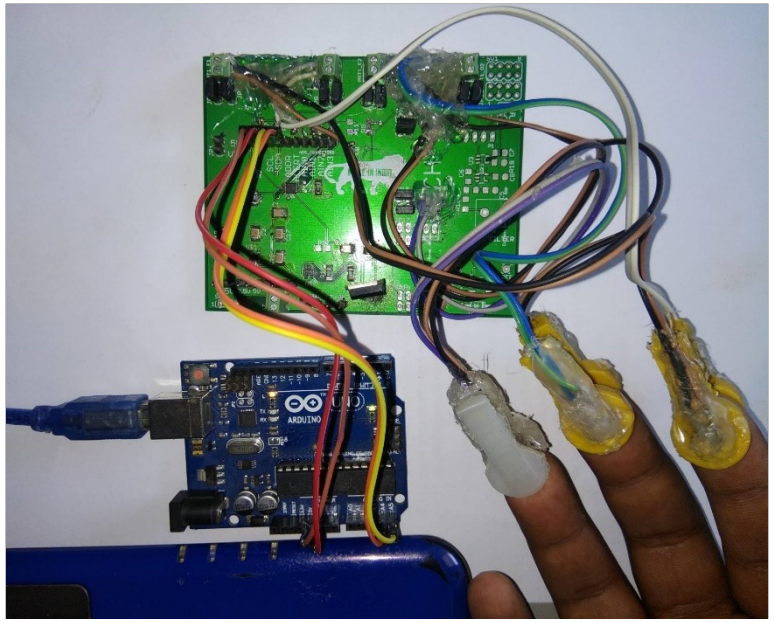
Unique Near Infrared Spectroscopy for iGLU



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 – Design Implementation



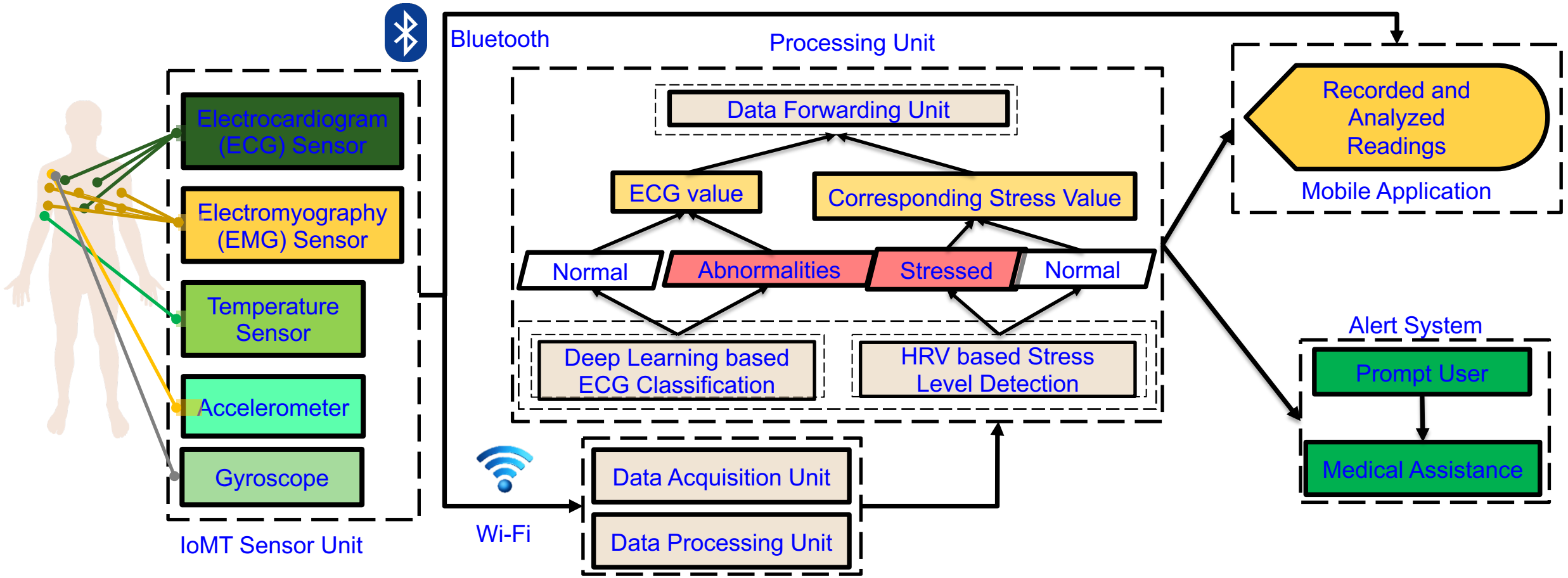


Clinically tested in an hospital.

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.

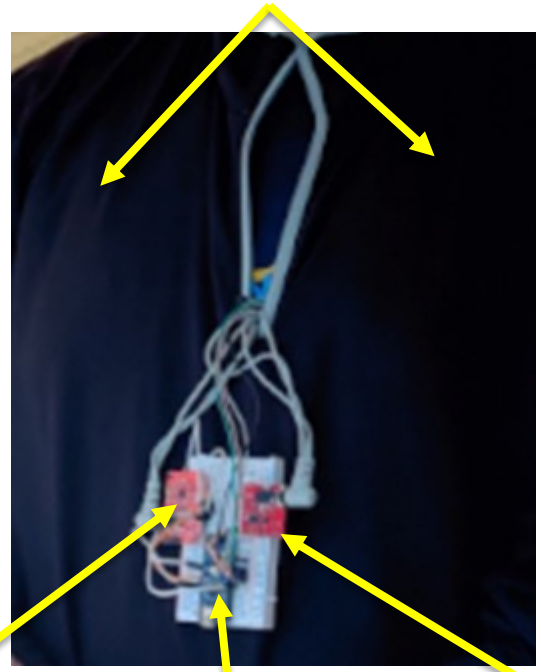
MyWear – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG



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

Embedded Electrodes inside MyWear



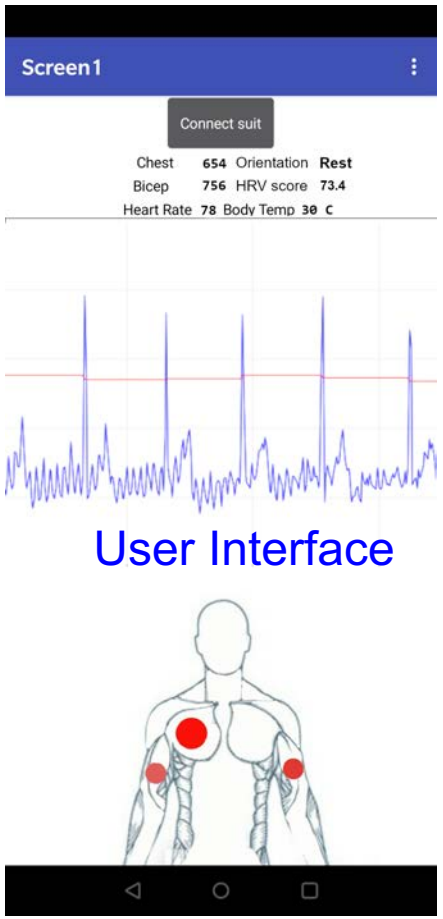
ECG Sensor

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%

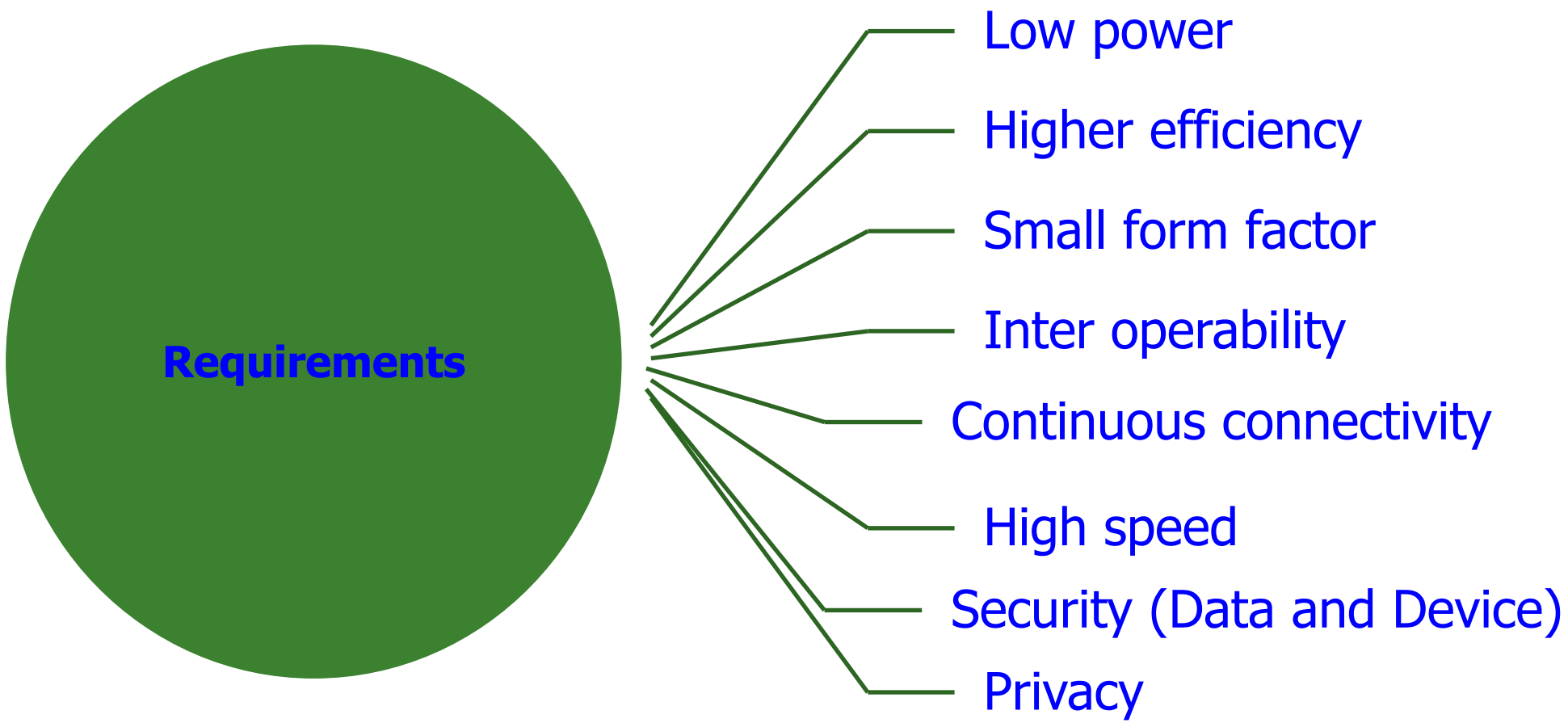


User Interface

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



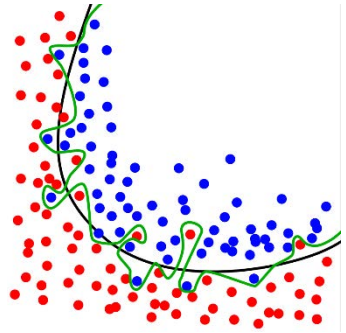
Smart Healthcare – Data Quality

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

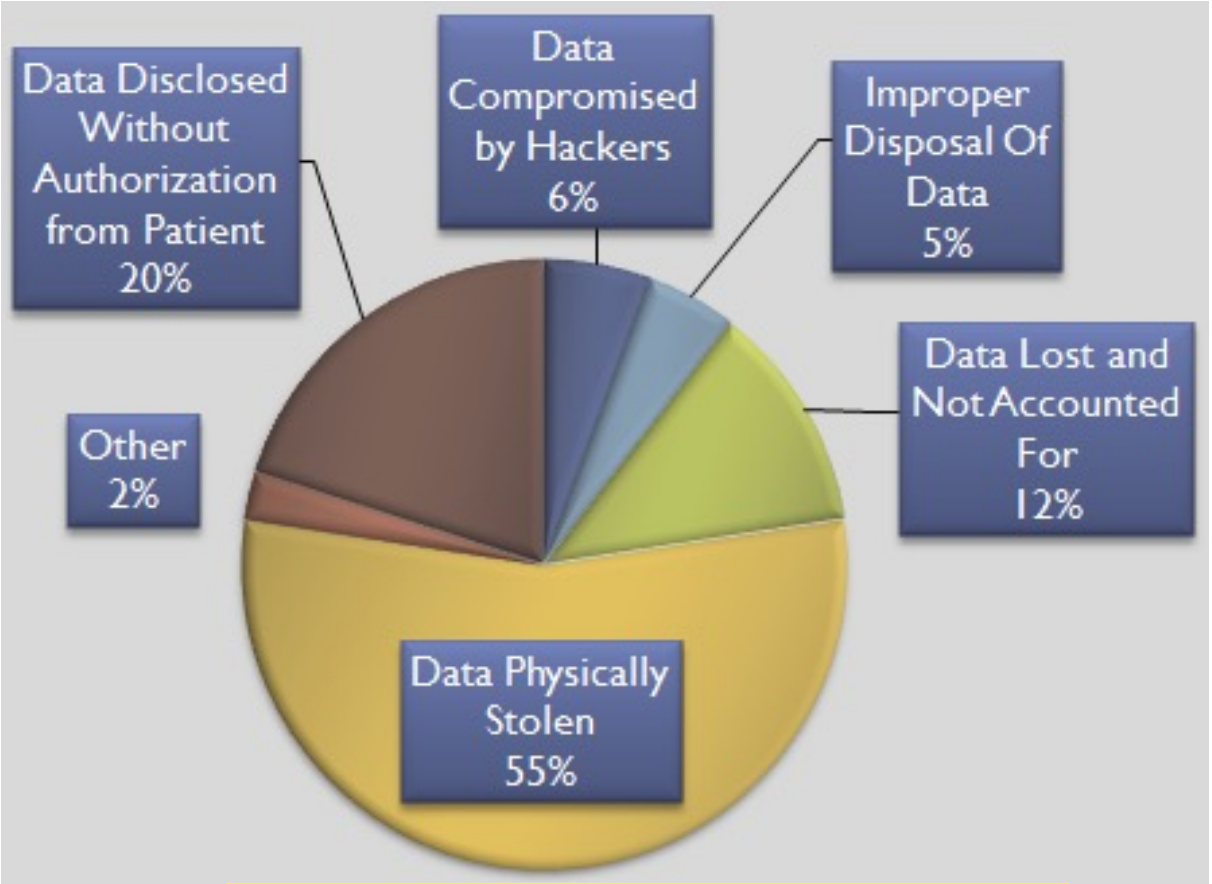


Source: Mohanty ISCT Keynote 2019

Smart Healthcare - Security Challenges

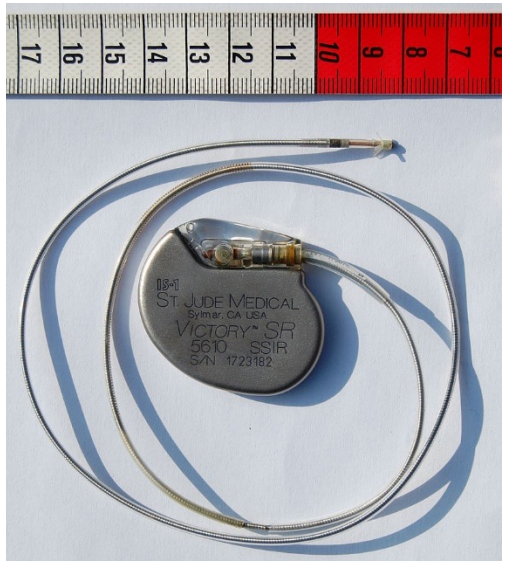
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (CEM)*, Volume 7, Issue 1, January 2018, pp. 18-28.

Health Insurance Portability and Accountability Act (HIPPA)



HIPPA Privacy Violation by Types

IoMT Security Measures is Hard – Energy Constrained



Pacemaker
Battery Life
- 10 years

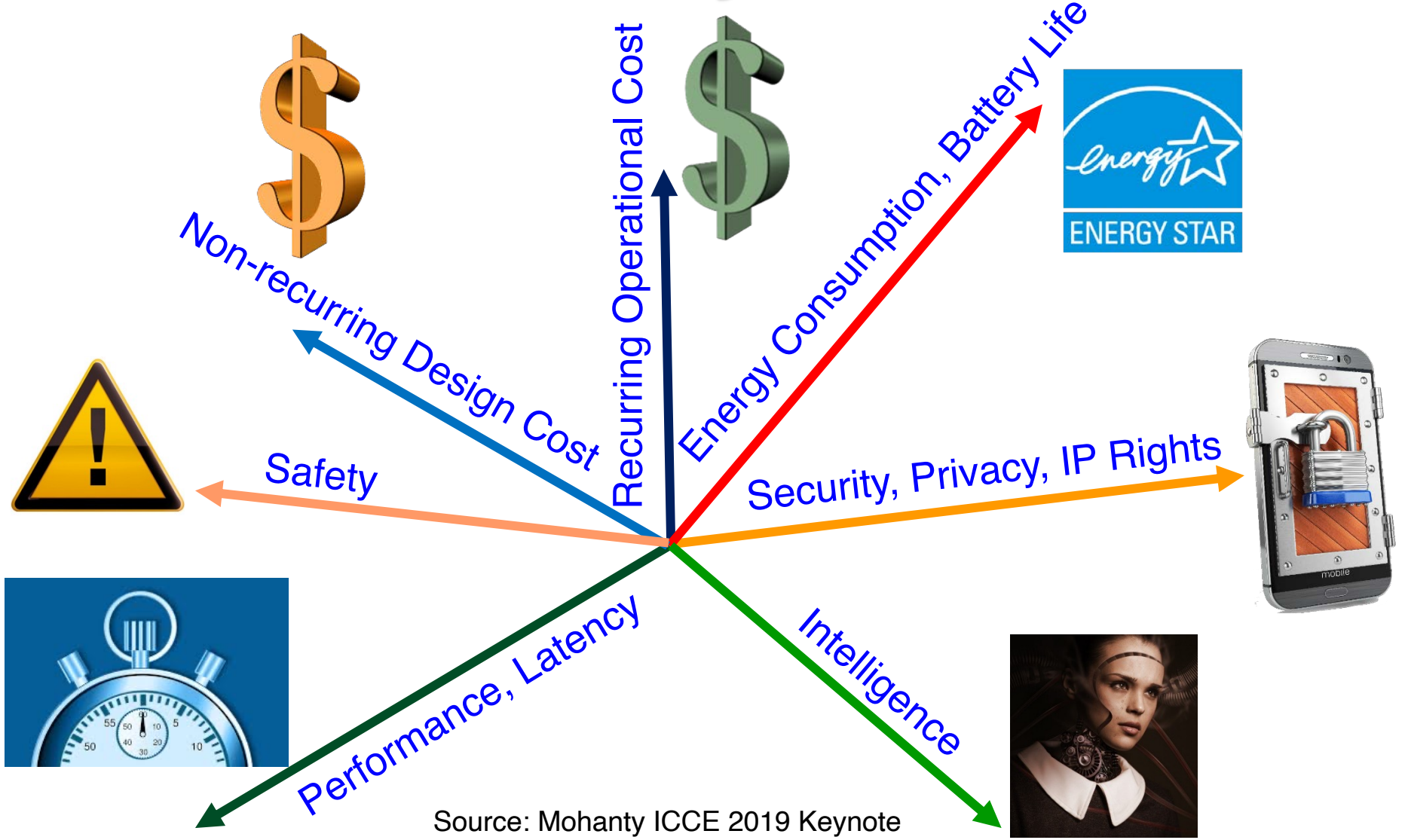
Neurostimulator
Battery Life
- 8 years

- 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.

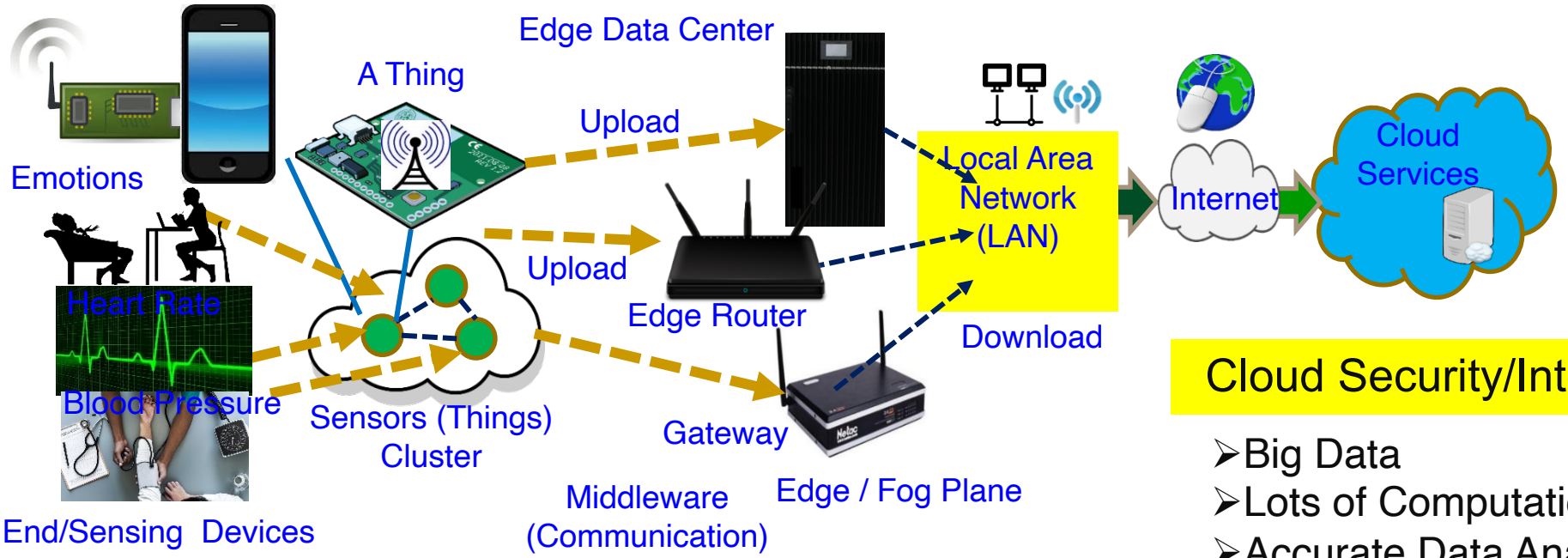
Smart Healthcare – Some Solutions

H-CPS - Multi-Objective Tradeoffs



Source: Mohanty ICCE 2019 Keynote

Smart Healthcare – Edge Vs Cloud



End Security/Intelligence

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

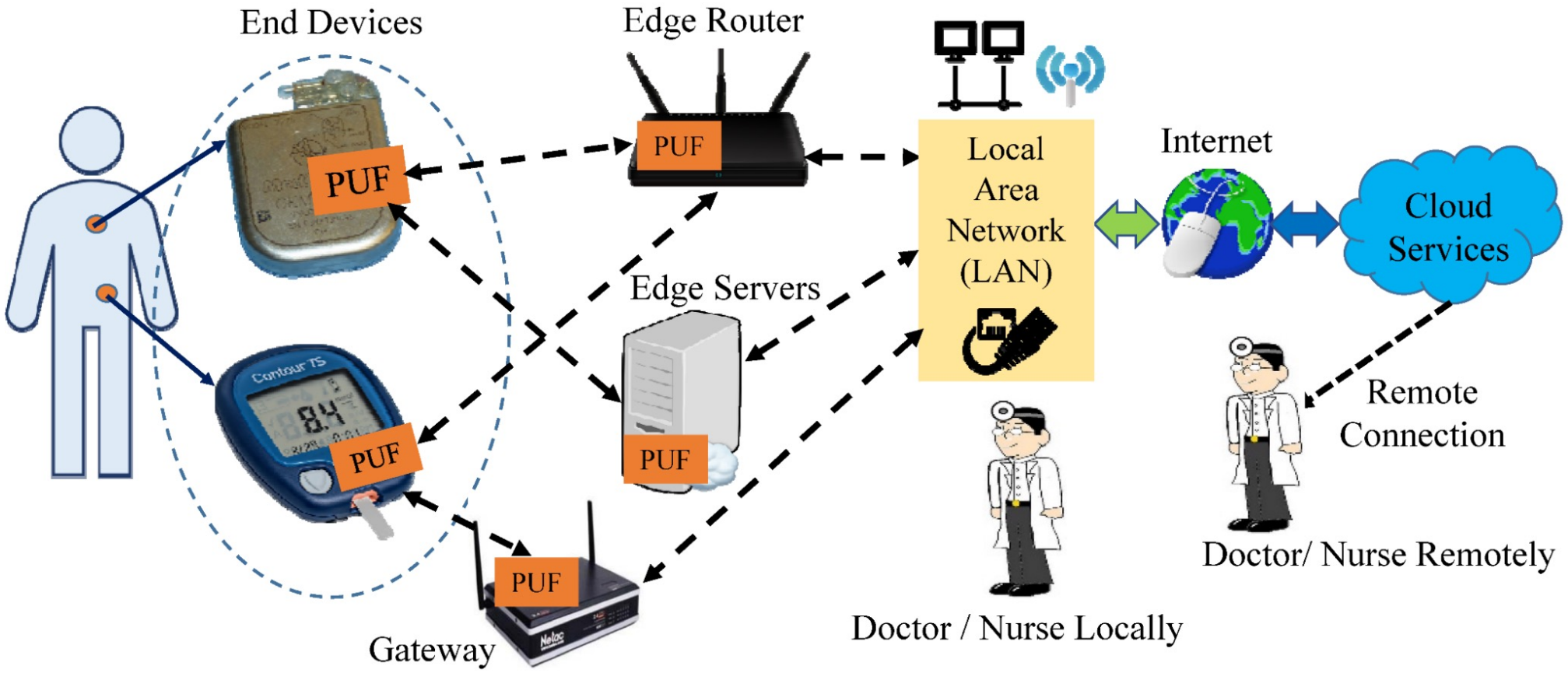
Edge Security/Intelligence

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

Cloud Security/Intelligence

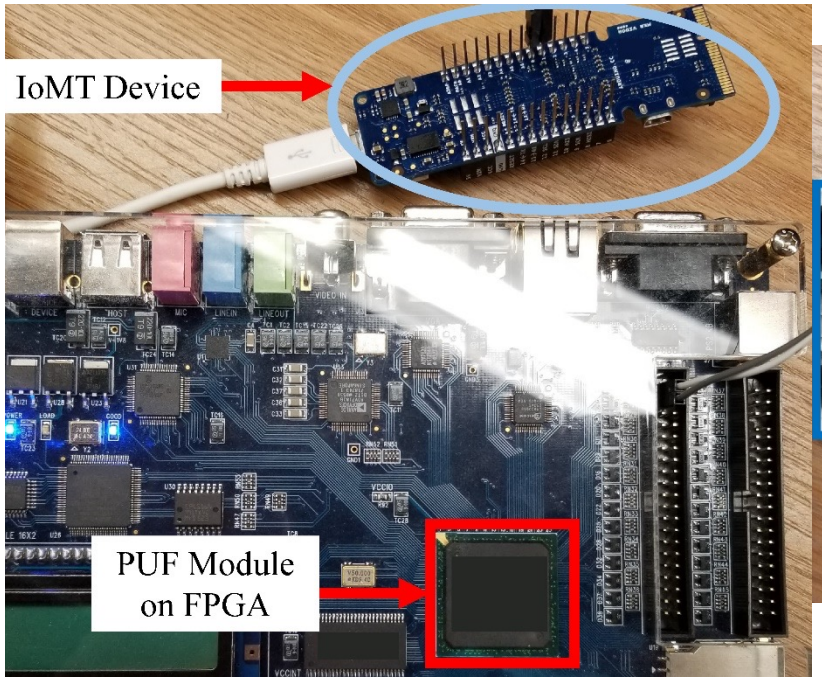
- Big Data
- Lots of Computational Resource
- Accurate Data Analytics
- Latency in Network
- Energy overhead in Communications

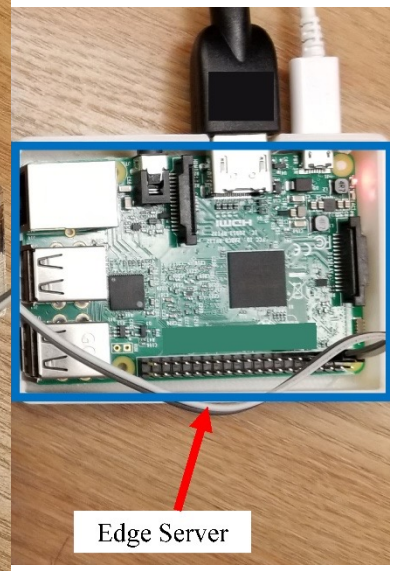
Our Secure by Design Approach for Robust Security in Healthcare CPS



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



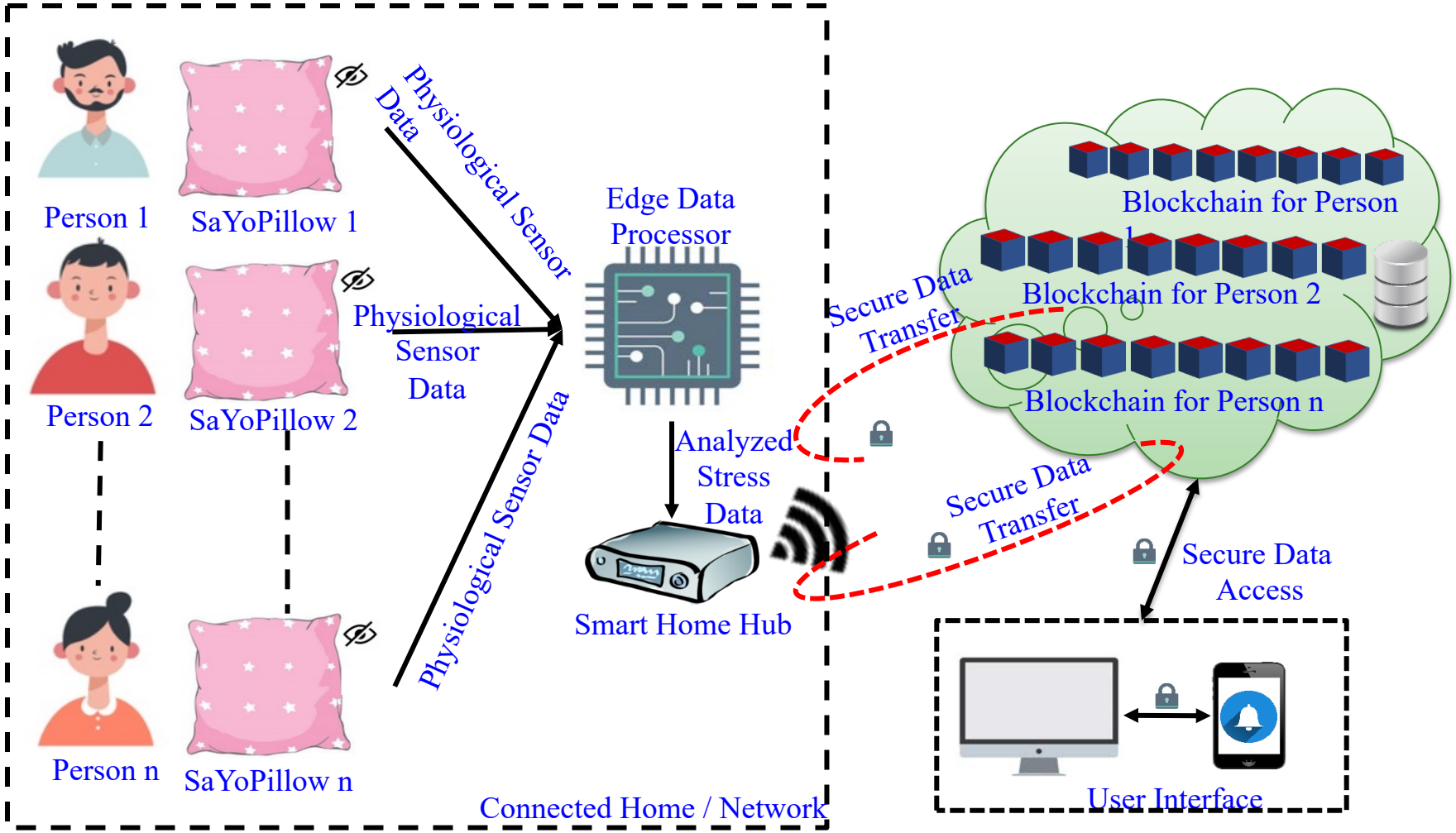


Average Power Overhead –
~ 200 μW or 0.2 mW

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

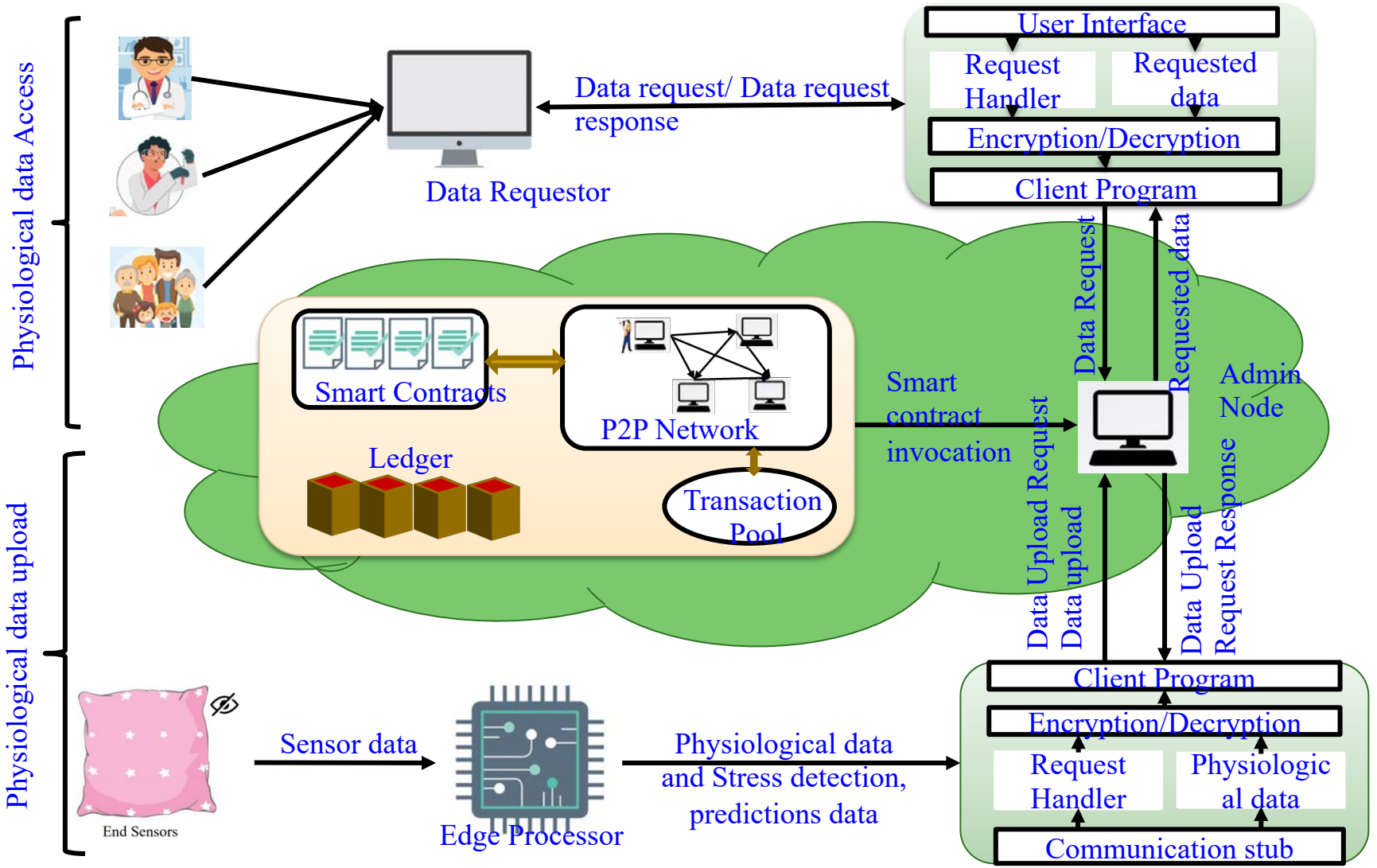
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

Our Smart-Yoga Pillow (SaYoPillow)



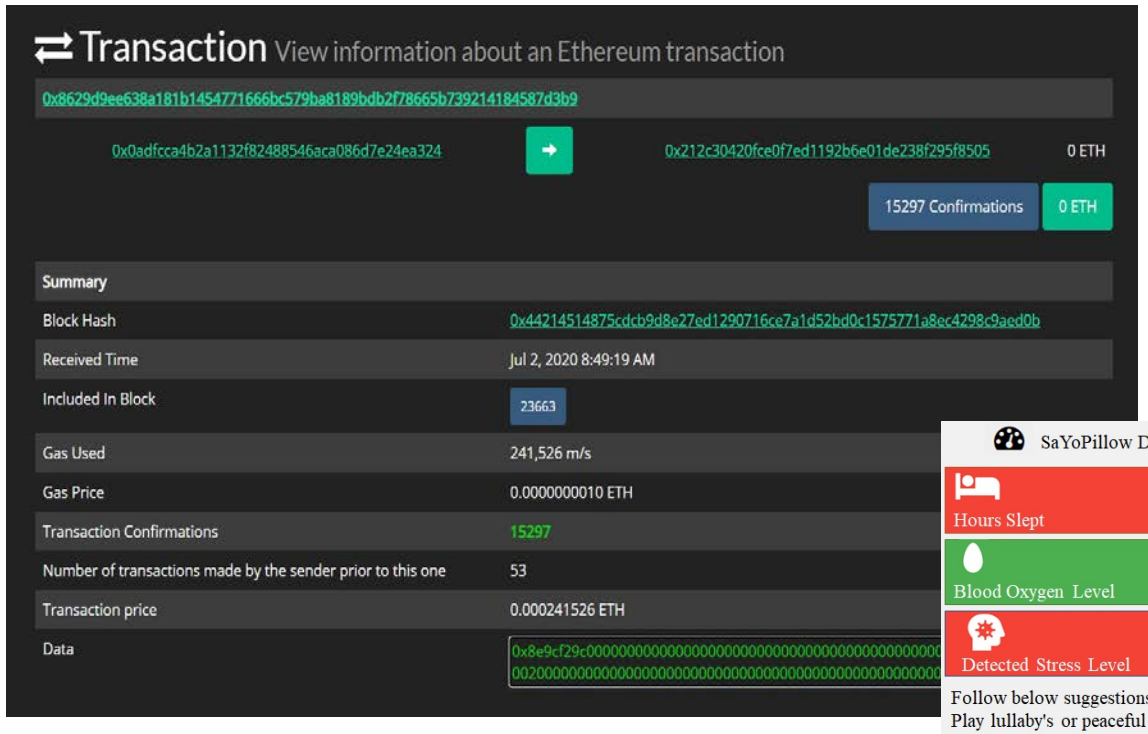
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

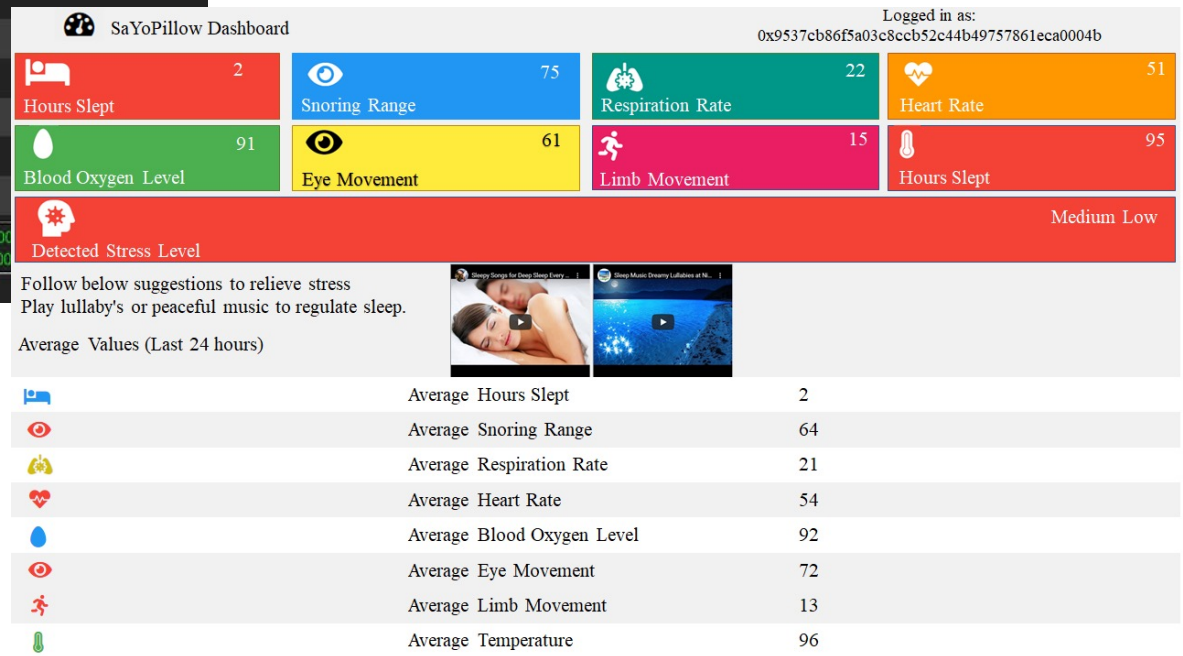
SaYoPillow: Blockchain Details



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





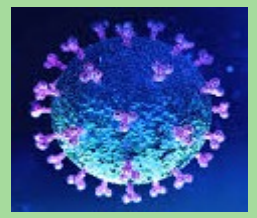
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

Smart Healthcare – COVID-19 Perspectives

Comorbidities with Pre-existing medical conditions for COVID-19

Diabetes (9.2%)

Chronic Respiratory Disease (8.0%)



SARS-CoV-2 (COVID-19)

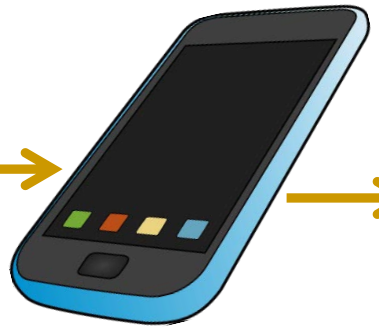
Cardiovascular Disease (13.2 %)

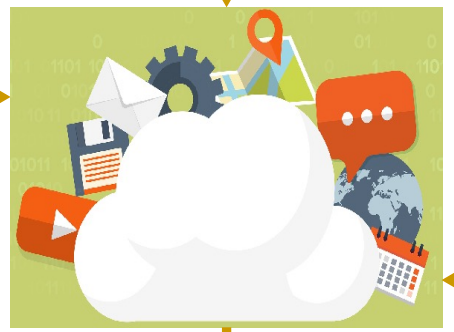
Hypertension (8.4%)

Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

iGLU - Our Intelligent Non-Invasive Glucose Monitoring with Insulin Control Device

Noninvasive Glucometer (iGLU)

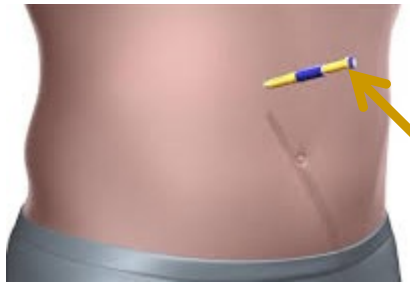




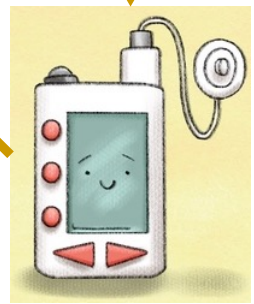
IoMT-Cloud

Hospital

Healthcare Provider



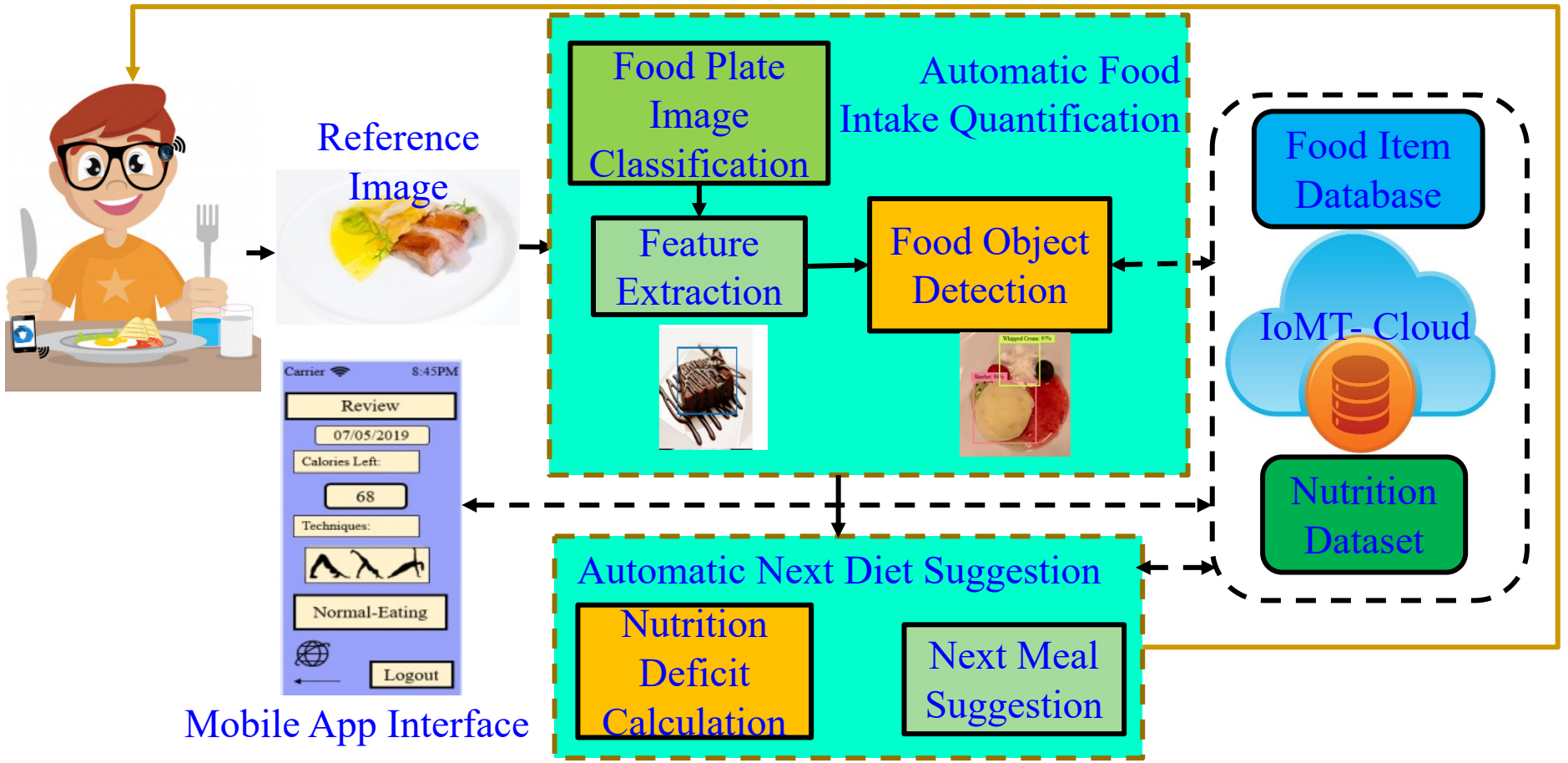
Insulin Secretion through Pump



Insulin Pump

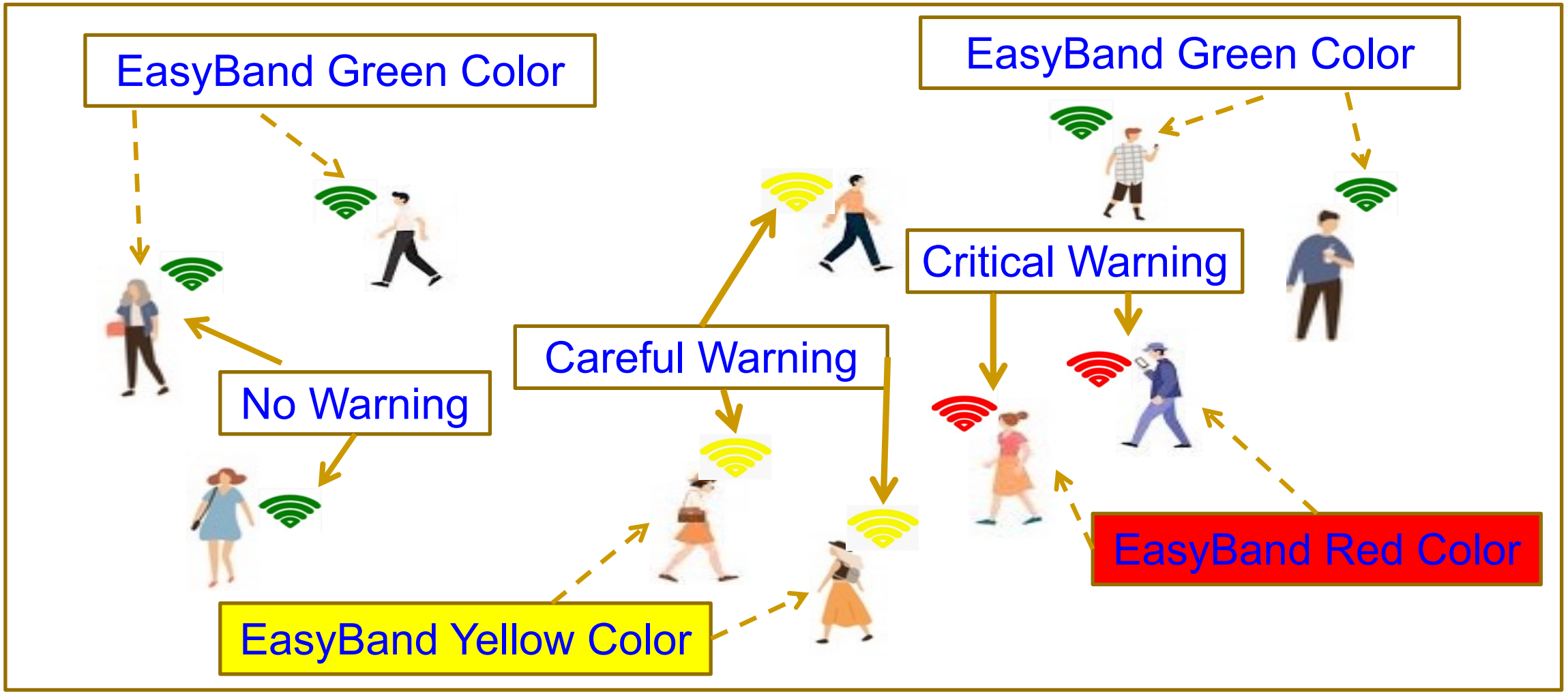
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

iLog + iGLU - Our Diet Automatic Monitoring and Control for Blood Glucose Level



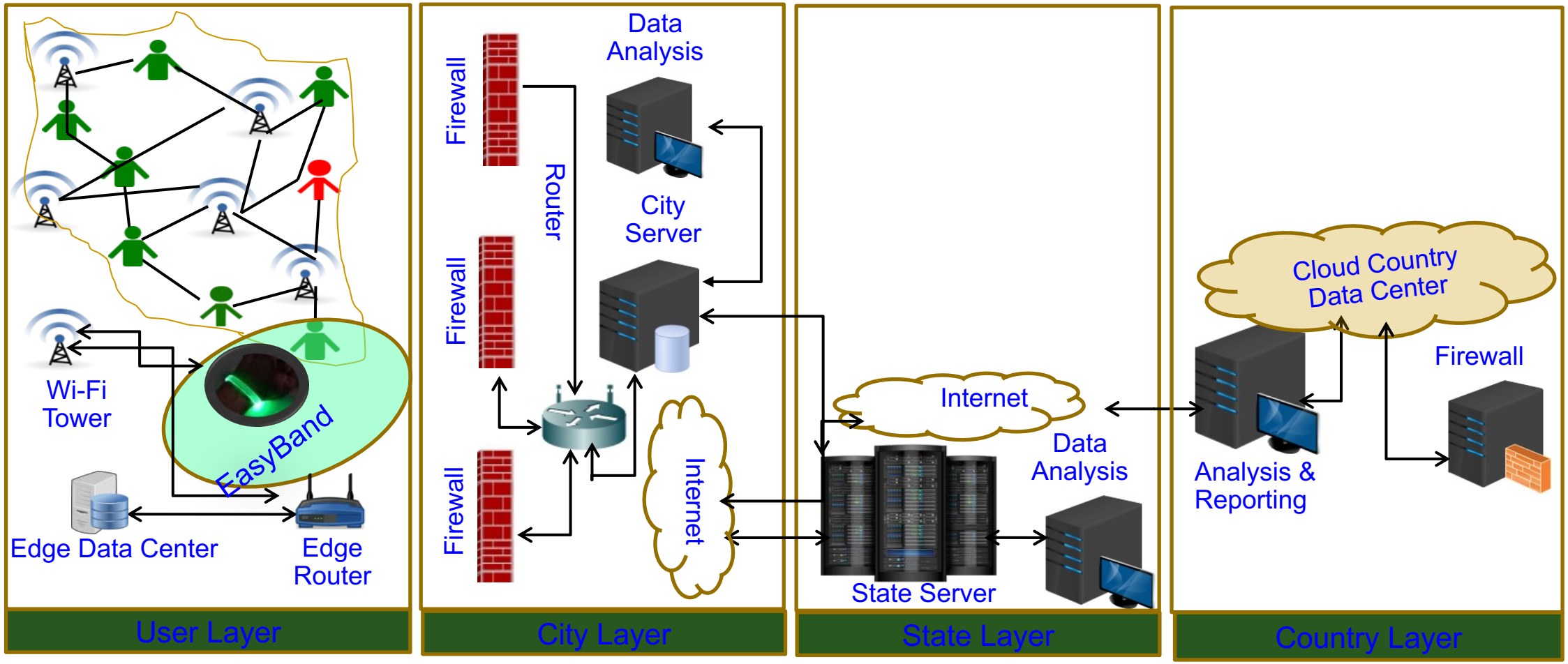
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

EasyBand – Safety-Aware Mobility during Pandemic



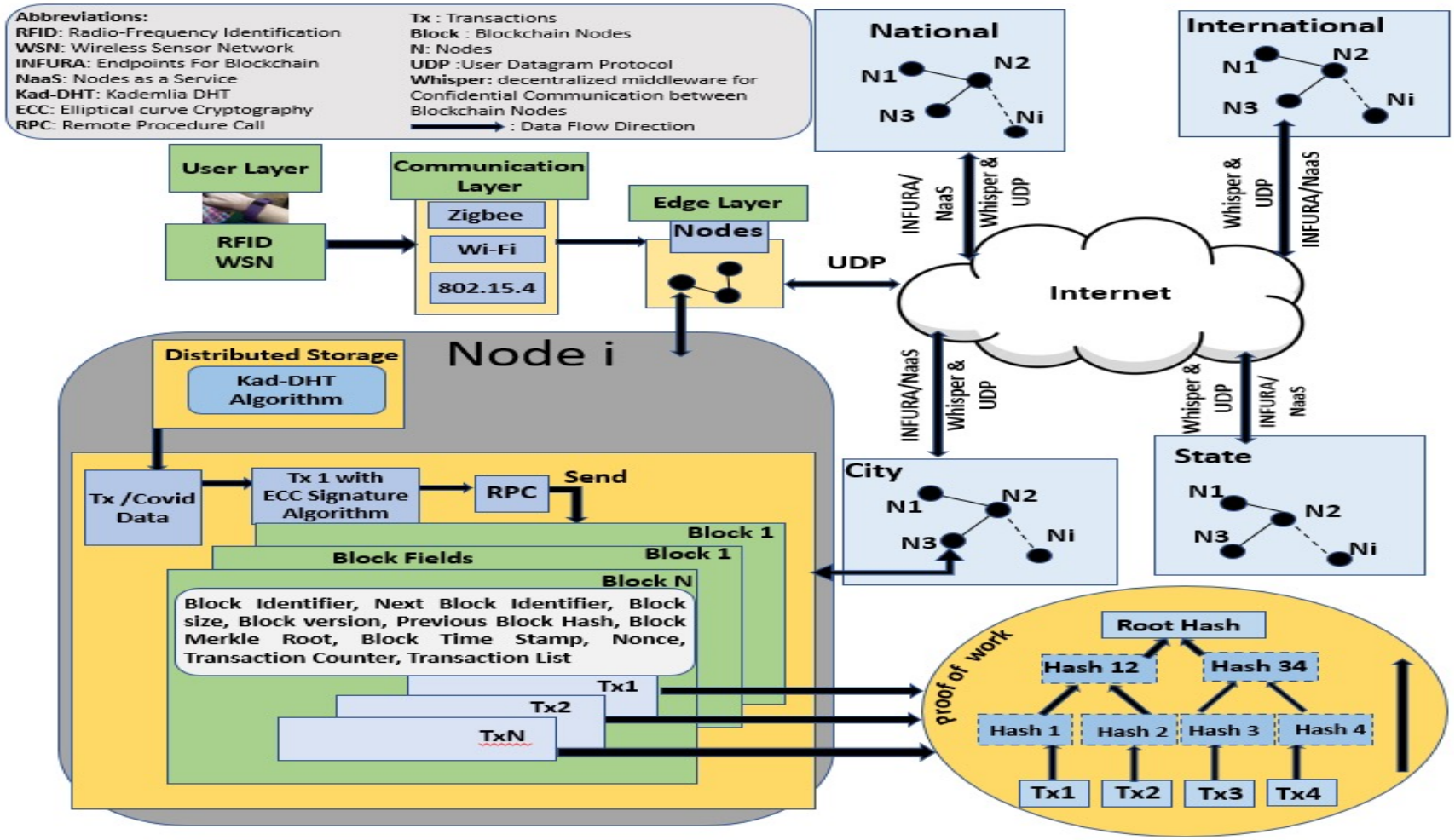
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

EasyBand in Healthcare CPS (H-CPS)



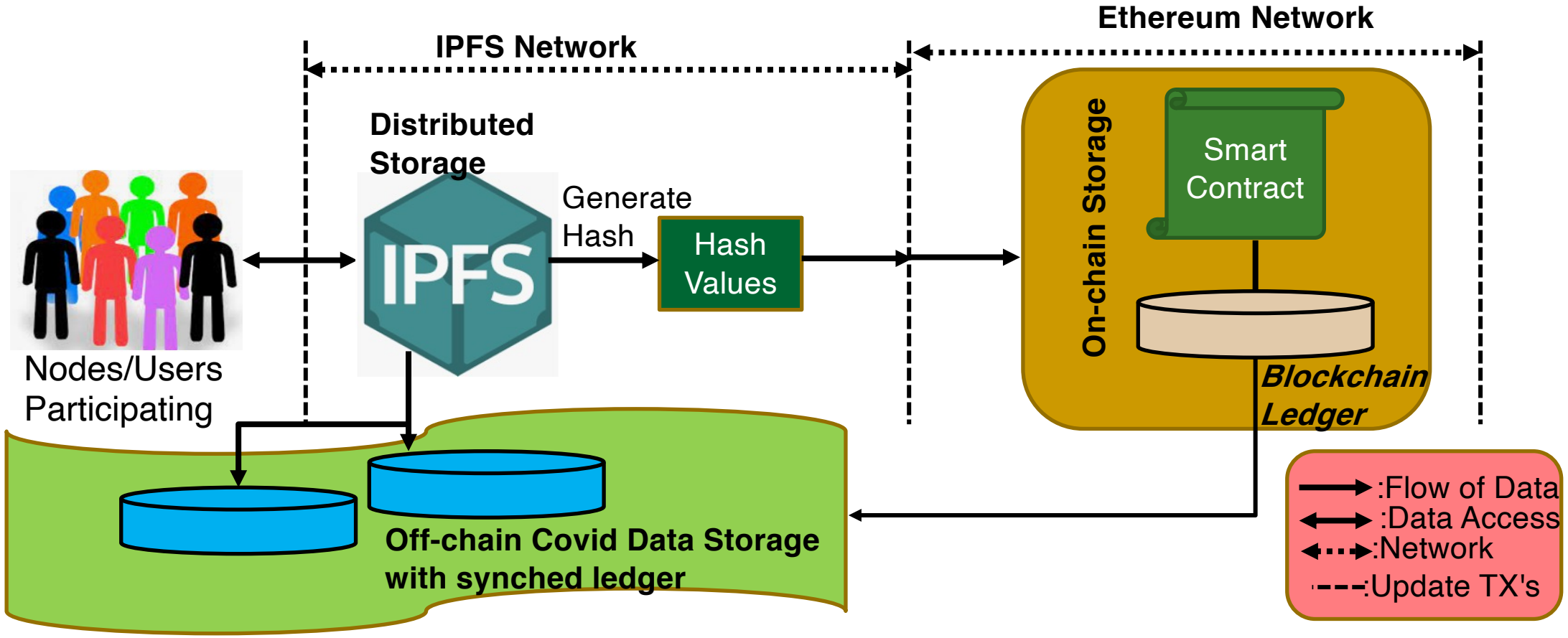
Source: A. K. Tripathy, A. G. Mohapatra, S. P. Mohanty, E. Kougianos, A. M. Joshi and G. Das, "EasyBand: A Wearable for Safety-Aware Mobility During Pandemic Outbreak," *IEEE Consumer Electronics Magazine*, vol. 9, no. 5, pp. 57-61, 1 Sept. 2020, doi: 10.1109/MCE.2020.2992034..

CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS



Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, "CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks", Springer Nature Computer Science (SN-CS), Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS

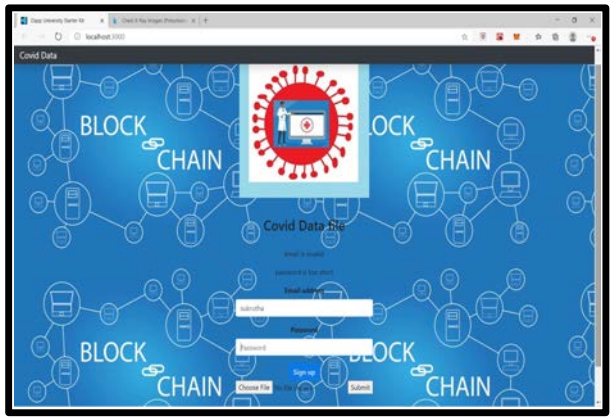


Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, "CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks", Springer Nature Computer Science (SN-CS), Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

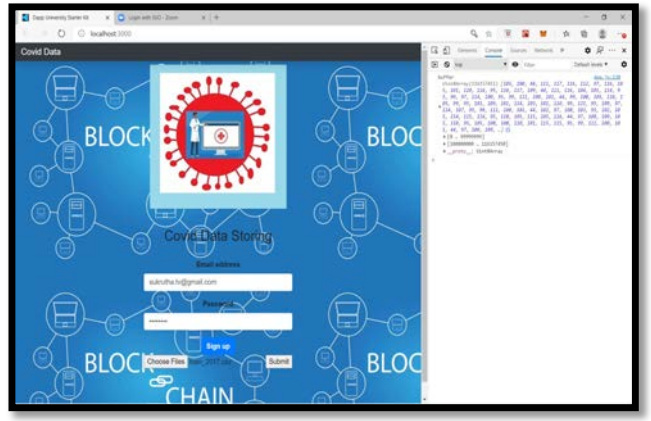
CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS

- From the front-end, Covid file is submitted to the IPFS and store it.
- Once the file is stored, the hash of the file is returned to the browser console.
- The hash generated from IPFS is stored on the blockchain, instead of the actual file.

1. User Interface

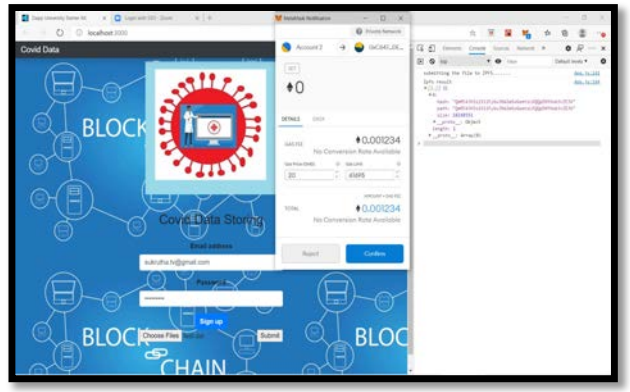


2. File Converted to Buffer



3. IPFS returning Hash

4. Confirming Metamask



Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, "CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks", Springer Nature Computer Science (SN-CS), Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

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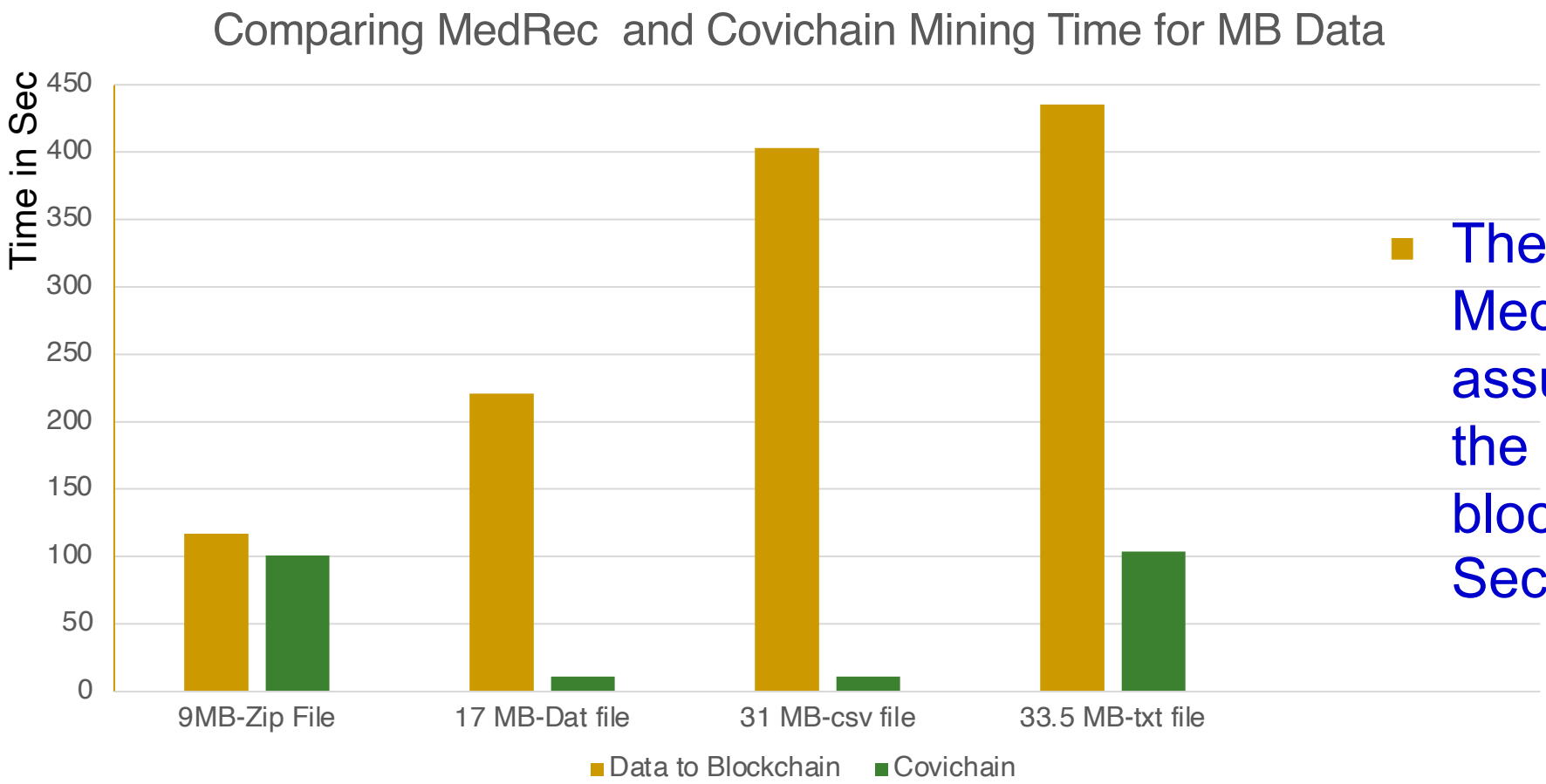


- The times for data in MedRec are calculated assuming the mining time of the conventional Ethereum blockchain to be 13 Seconds for 1MB Data.

Source: S. L. T. Vangipuram, S. P. Mohanty, and E. Kougianos, "CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems during Pandemic Outbreaks", Springer Nature Computer Science (SN-CS), Vol. 2, No. 2, June 2021, Article: 346, 16-pages.

Pandemic – Trusted Food Supply Chain

How to ensure quality food through legitimate supply chain?

Consumption By Users

Trading

Retails Service of Food

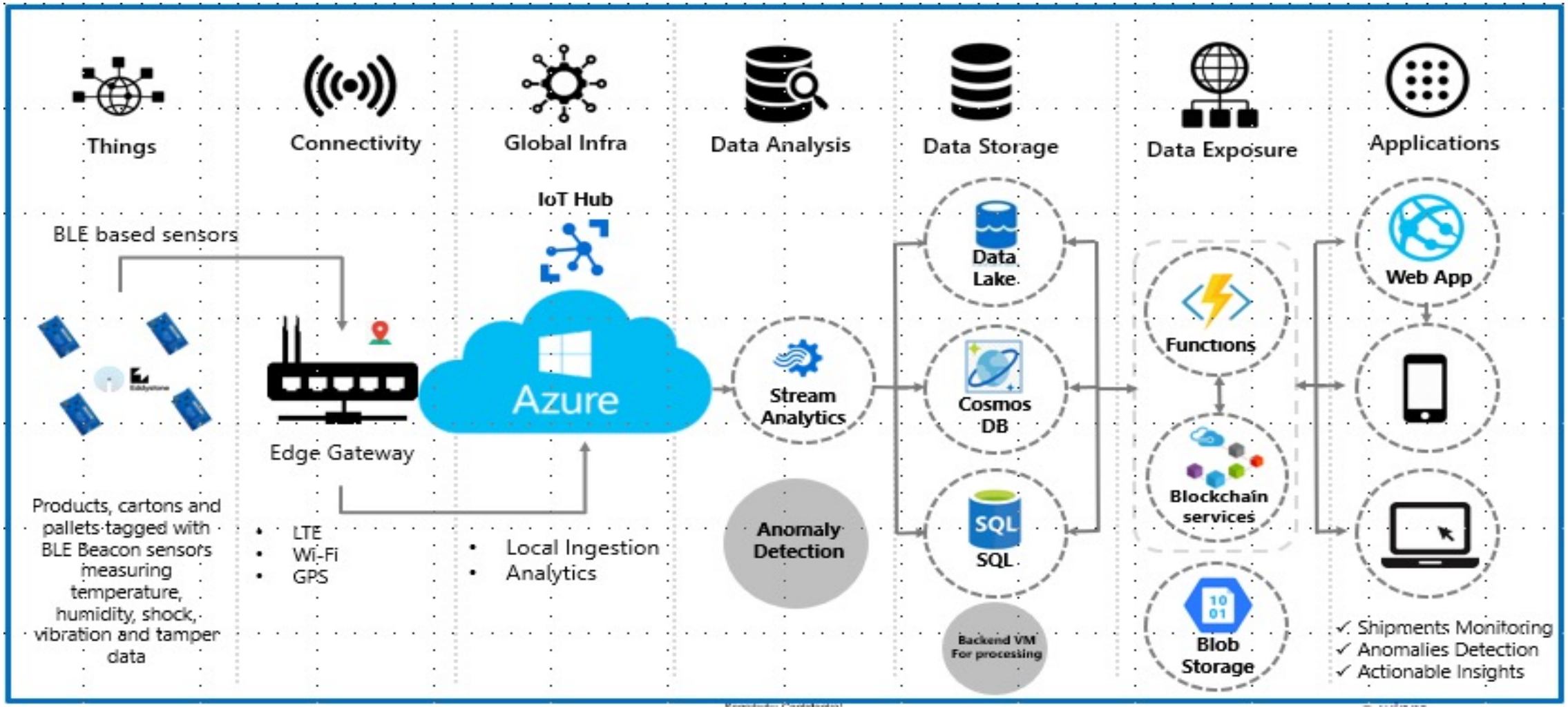
Transportation

Processing

Farming & Growing

Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Pandemic - Trusted Pharmaceutical Supply Chain



Source: http://ilikesqldata.com/securing-the-pharmaceutical-supply-chain-with-azure-iot/

Conclusions and Future Research

Conclusions

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

Future Research

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

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.