Everything You wanted to Know about Smart Healthcare

Keynote – OITS International Conference on Information Technology (OCIT) 2021

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Saraju P. Mohanty

University of North Texas, USA.

Email: saraju.mohanty@unt.edu, Website: http://www.smohanty.org

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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

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Healthcare
to
# Smart Healthcare

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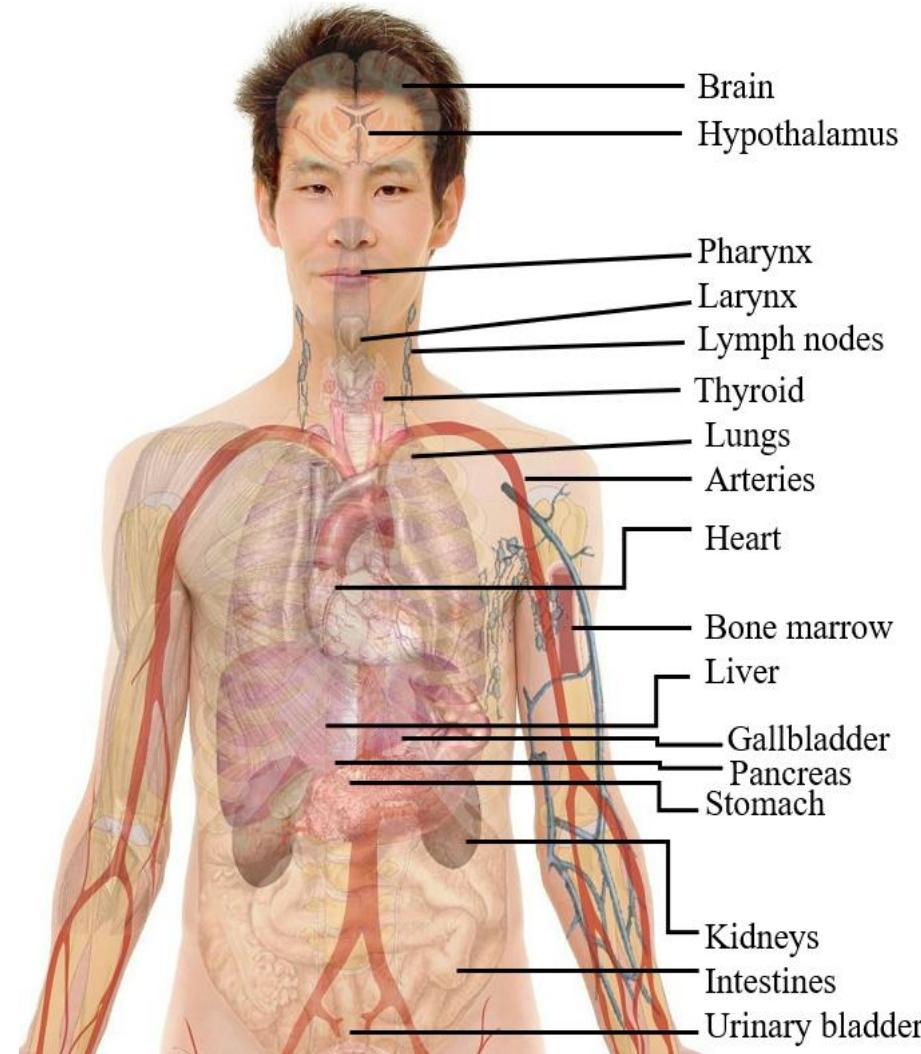
Human Body and Health

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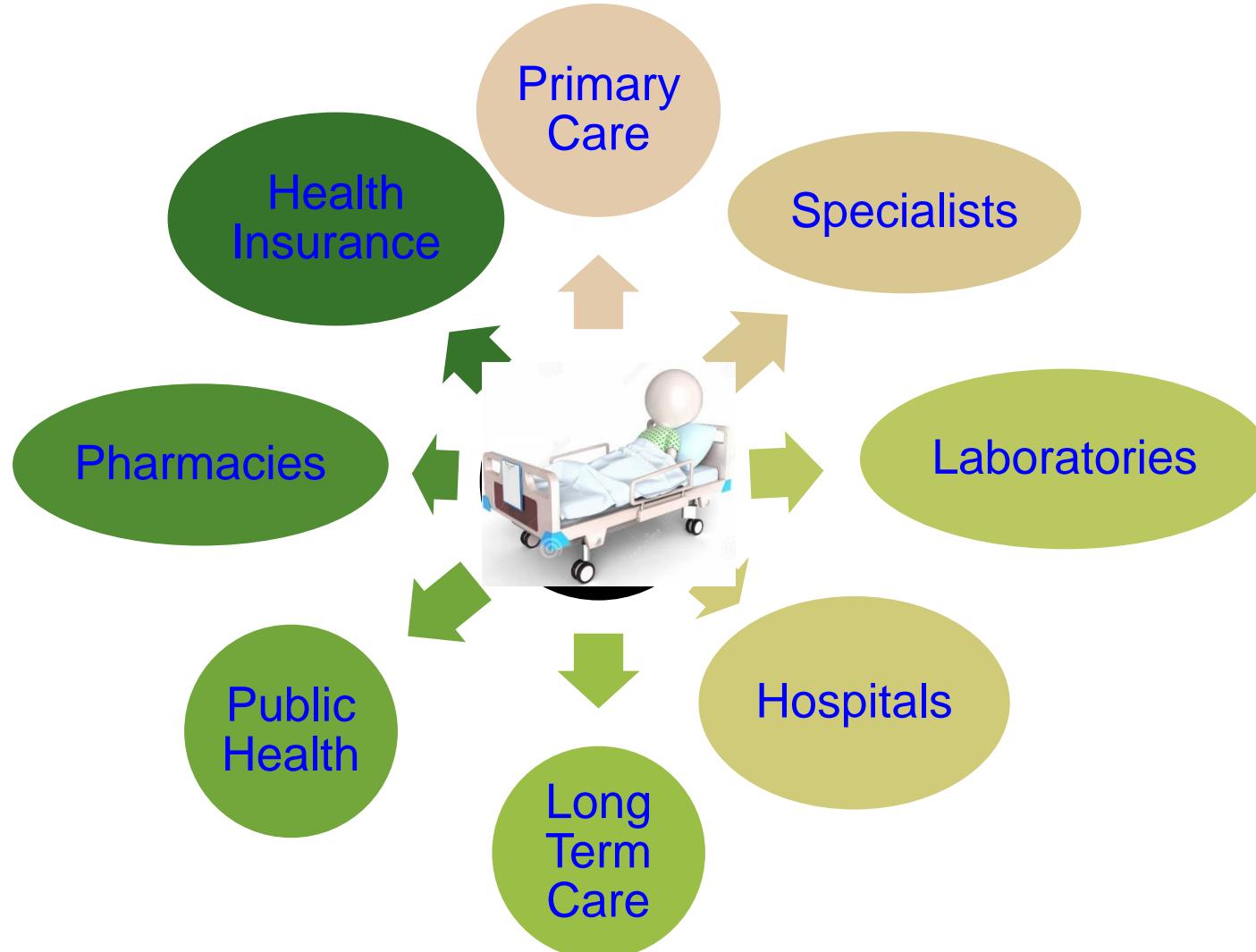
- From an engineering perspective - Human body can be defined as a combination of multi-disciplinary subsystems (electrical, mechanical, chemical …).

Health

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

Brain
Hypothalamus
Pharynx
Larynx
Lymph nodes
Thyroid
Lungs
Arteries
Heart
Bone marrow
Liver
Gallbladder
Pancreas
Stomach
Kidneys
Intestines
Urinary bladder

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Traditional Healthcare

Primary Care

Health Insurance

Specialists

Pharmacies

Laboratories

Public Health

Hospitals

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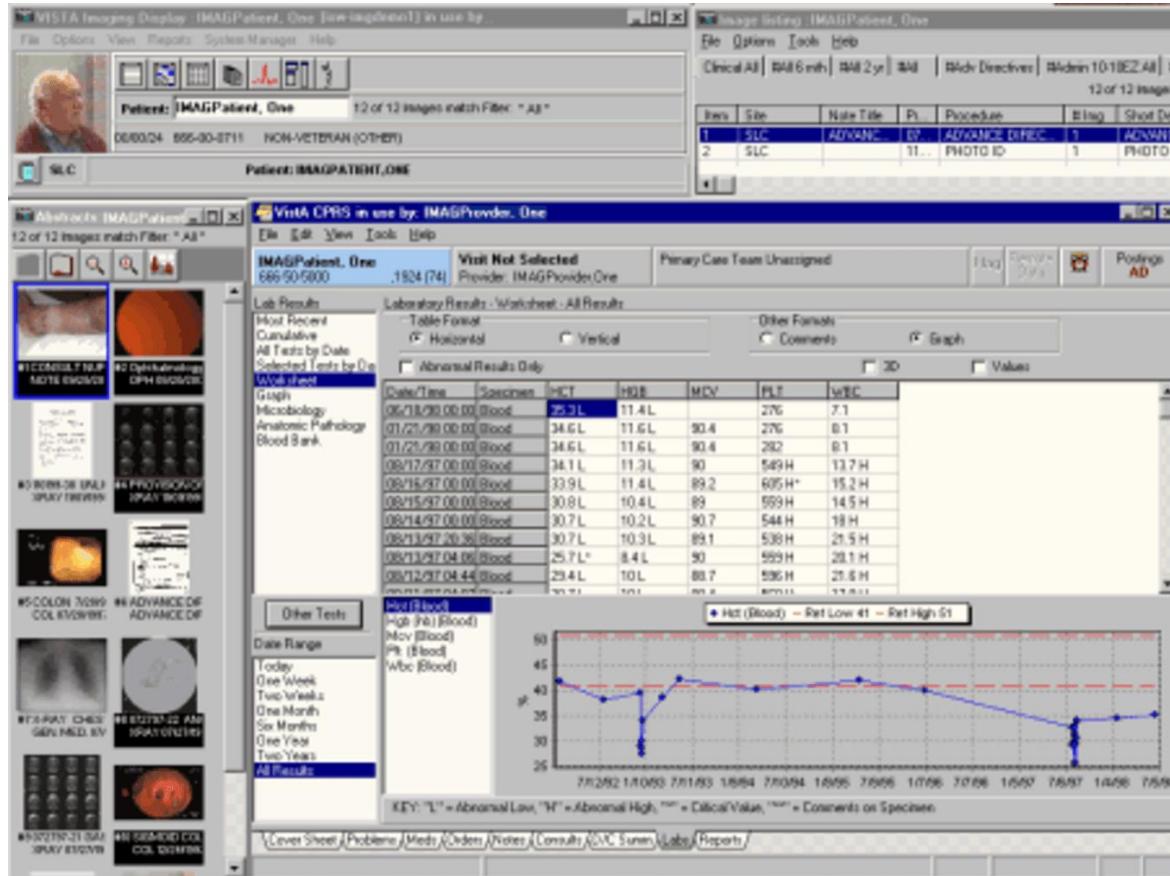
- ➢ Physical presence needed
- ➢ Deals with many stakeholders
- ➢ Stakeholders may not interact
- ➢ May not be personalized
- ➢ Not much active feedback
- ➢ Less effective follow-up from physicians

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Telemedicine

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

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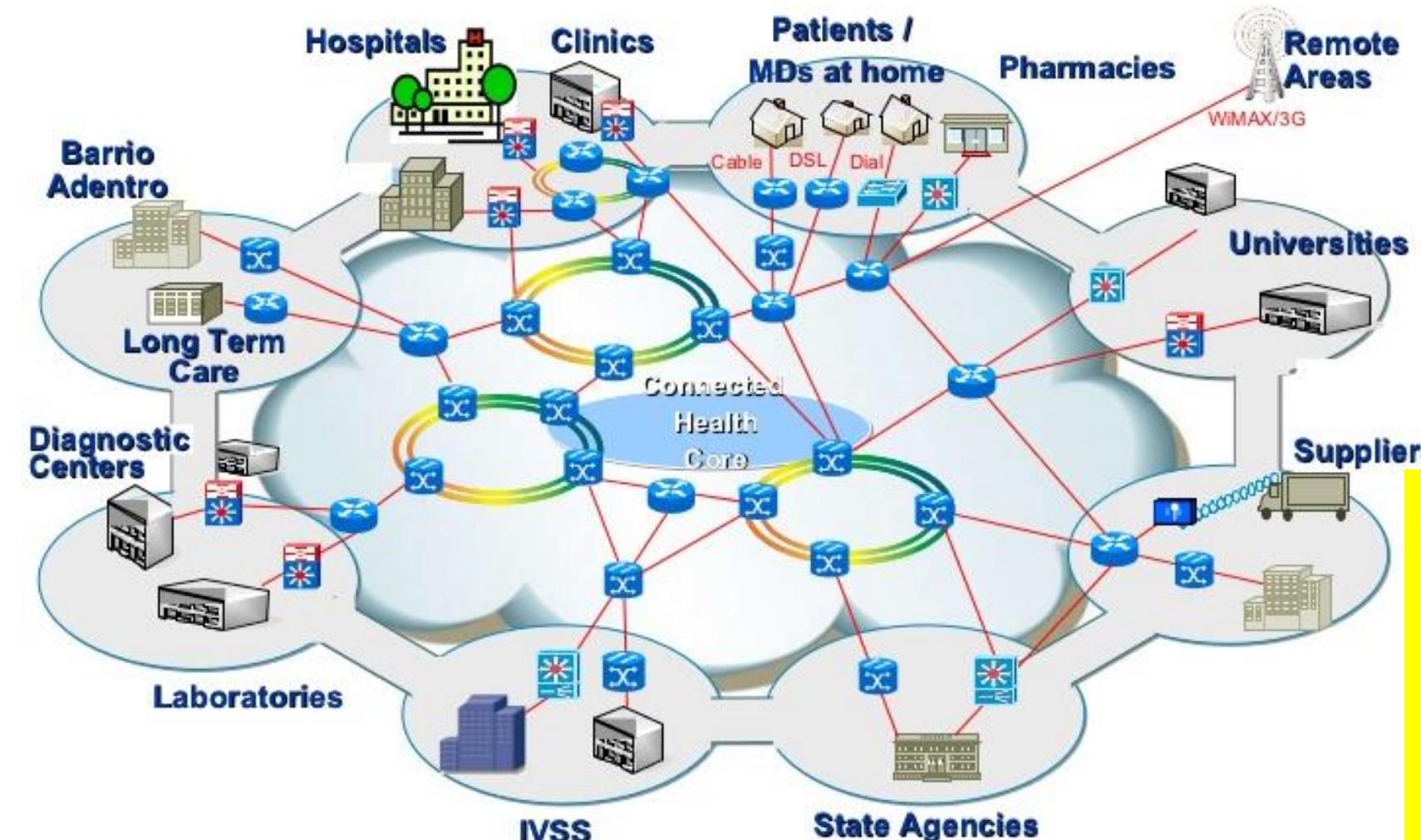
Electronic Health (eHealth)

eHealth: The use of information technology 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.

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.

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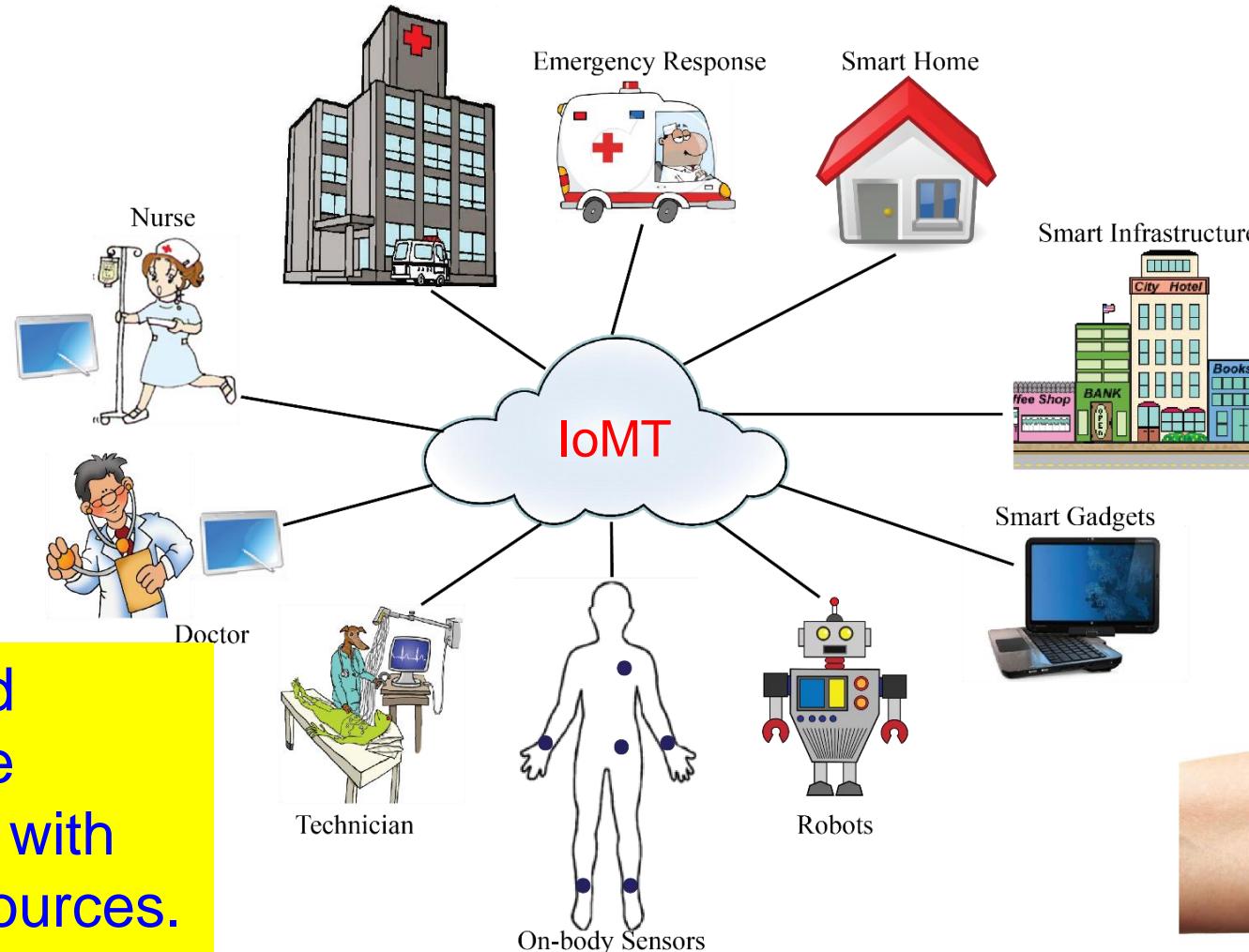
mHealth: Healthcare supported by *mobile devices* that uses mobile telecommunications and multimedia technologies for the delivery of healthcare services and health information.

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)

Smart Hospital

Emergency Response

Smart Home

Smart Infrastructure

Nurse

Doctor

Technician

On-body Sensors

Robots

Smart Gadgets

IoMT

Fitness Trackers

Headband with Embedded Neurosensors

Embedded Skin Patches

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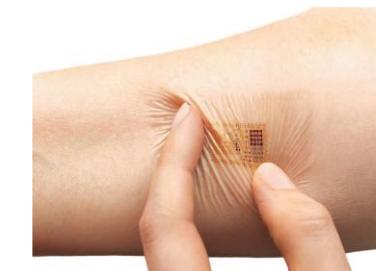
Source: P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. Ganapathiraju, "Everything You Wanted to Know about Smart Health Care", *IEEE Consumer Electronics Magazine (MCE)*, Vol. 7, Issue 1, January 2018, pp. 18-28.

Smart Healthcare - Characteristics

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What is Smart Healthcare?

Smart Healthcare

$\leftarrow$

Conventional Healthcare
+ Body sensors
+ Information & Communication Technology (ICT)
+ AI/ML
+ Smart Technology (BCI, VR, etc.)
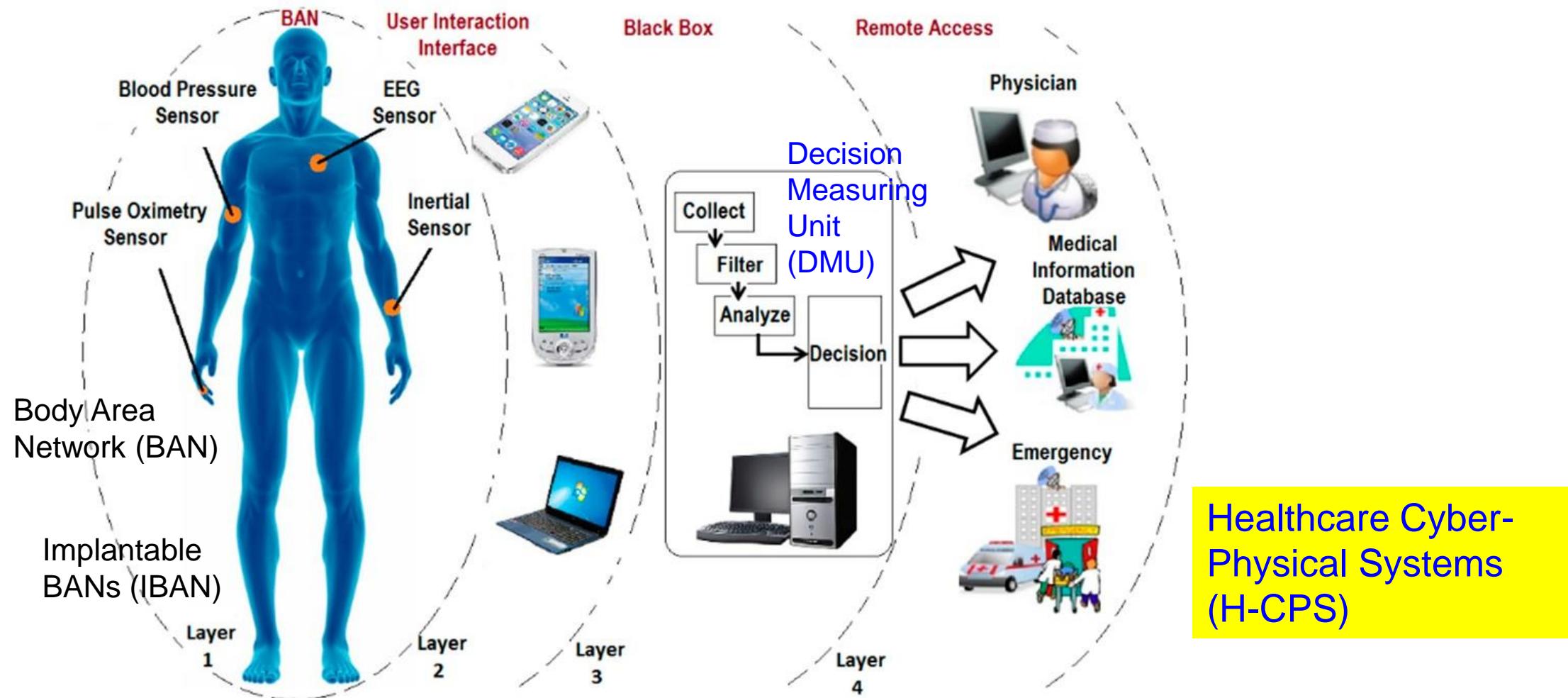
Internet of Medical Things (IoMT)   Internet of Health Things (IoHT)

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.

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Smart Healthcare - 4-Layer Architecture

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

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

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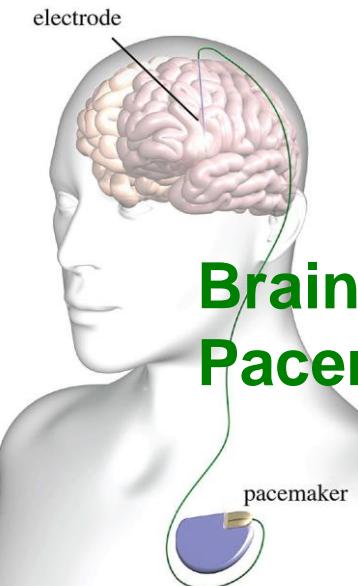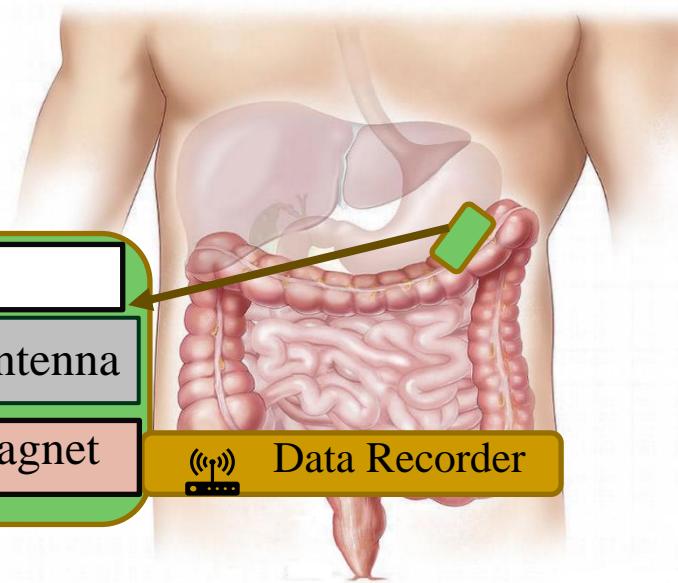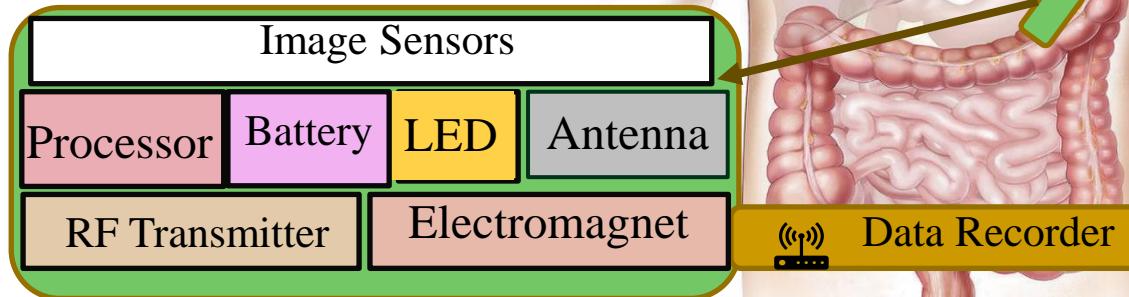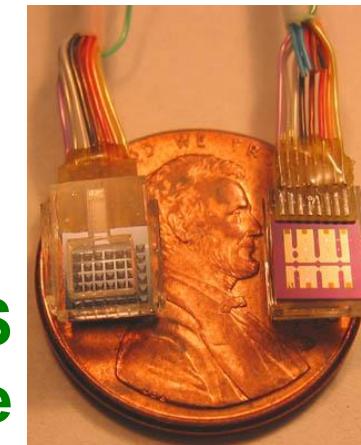
Implantable Medical Devices (IMDs)

Pill Camera

Brain Pacemaker

electrode

pacemaker

Image Sensors			
Processor	Battery	LED	Antenna
RF Transmitter		Electromagnet	

Data Recorder

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

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Smart Healthcare – 7Ps

7P

- Participatory
- Persuasive
- Predictive
- Personalized
- Preventative
- Programmable
- Perpetual

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
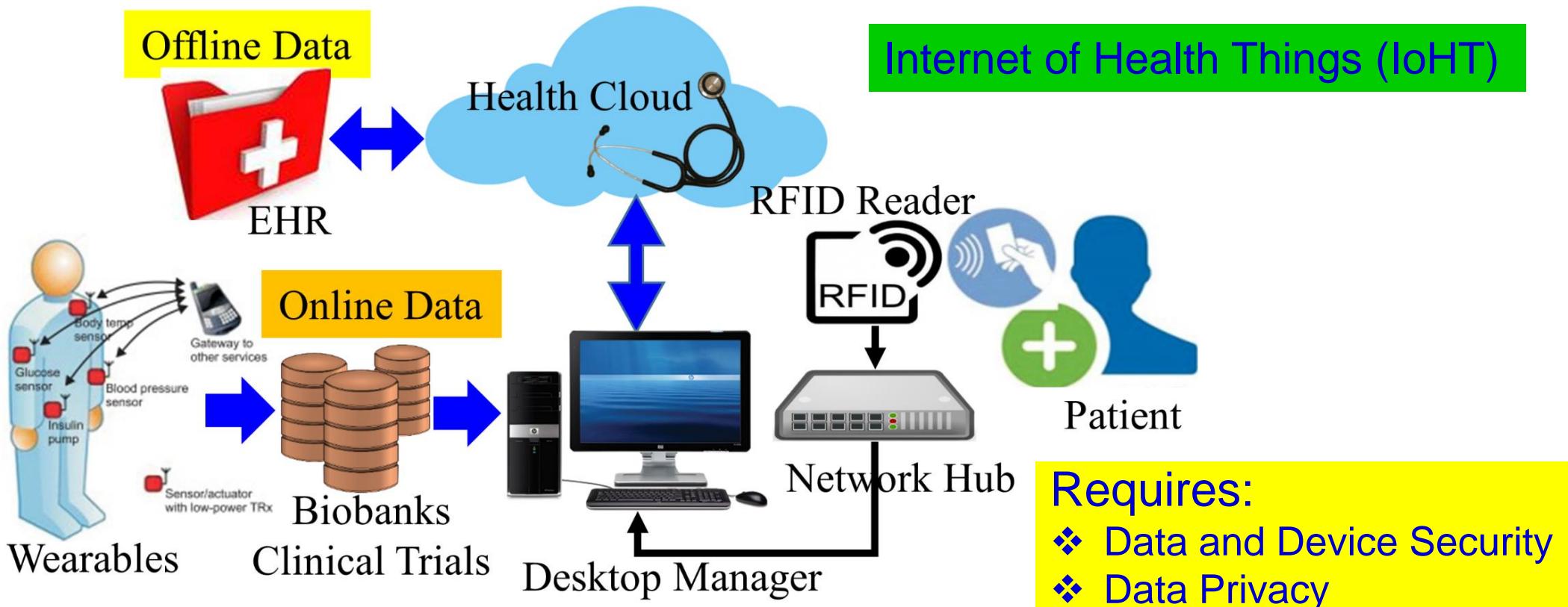
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Smart Healthcare - Components

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Internet of Medical Things (IoMT)

Internet of Health Things (IoHT)

Requires:
- ❖ Data and Device Security
- ❖ Data Privacy
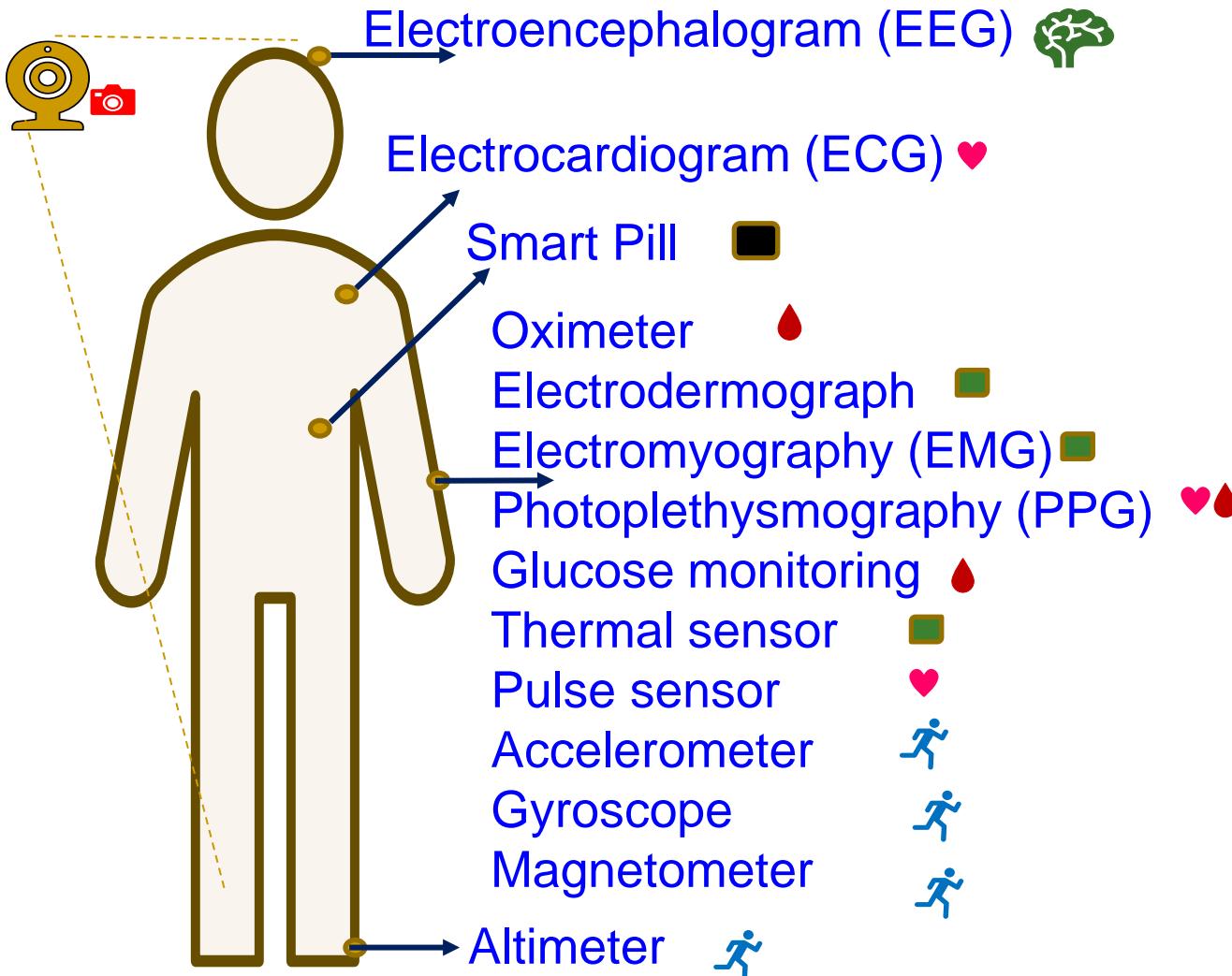
IoMT is a collection of medical sensors, devices, healthcare database, and applications that connected through Internet.

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

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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 Medical Record (EMR)

- ➢ 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.

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)

Systems & Analytics

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

Machine Learning Engine

Machine Learning Engine

Data

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

Data

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

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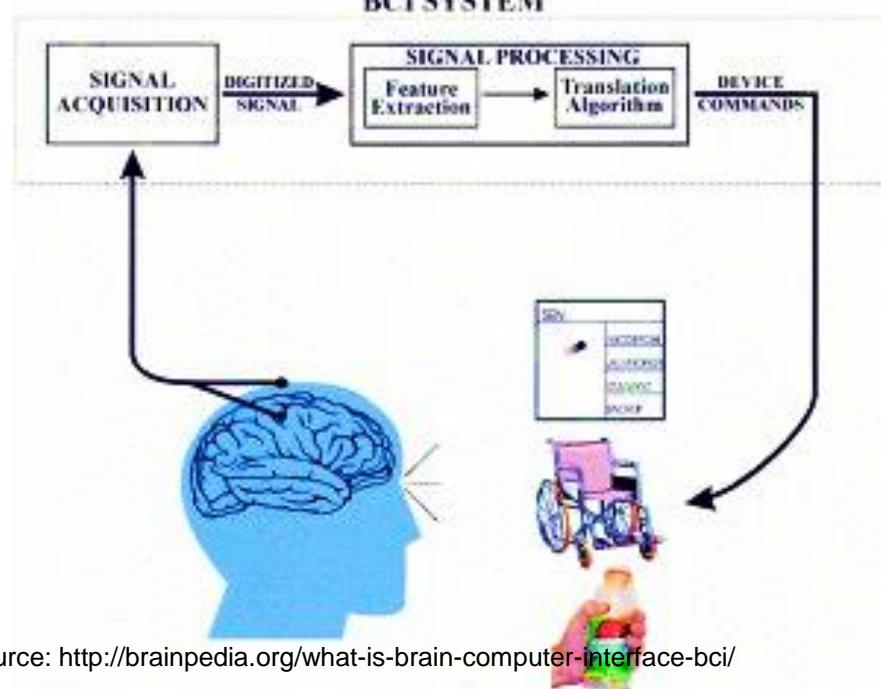
"Currently, people interact with their devices by thumb-typing on their phones. A high-bandwidth interface to the brain would help achieve a symbiosis between human and machine intelligence and could make humans more useful in an AI-driven world."

-- Neuralink - neurotechnology company - Elon Musk.

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

Brain Computer Interface (BCI)

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

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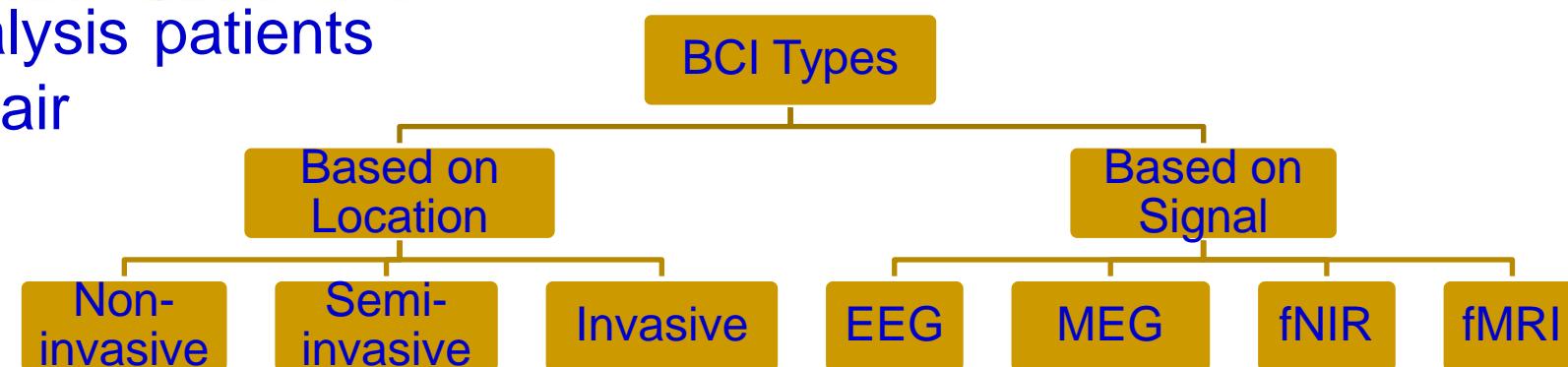
BCI Allows paralysis patients to Type

BCI Allows paralysis patients move a wheelchair

```
                          BCI Types
            ┌─────────────────┴──────────────────┐
      Based on                              Based on
      Location                               Signal
   ┌──────┼───────┐              ┌──────┬──────┬──────┐
  Non-    Semi-  Invasive       EEG    MEG    fNIR   fMRI
invasive invasive
```

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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

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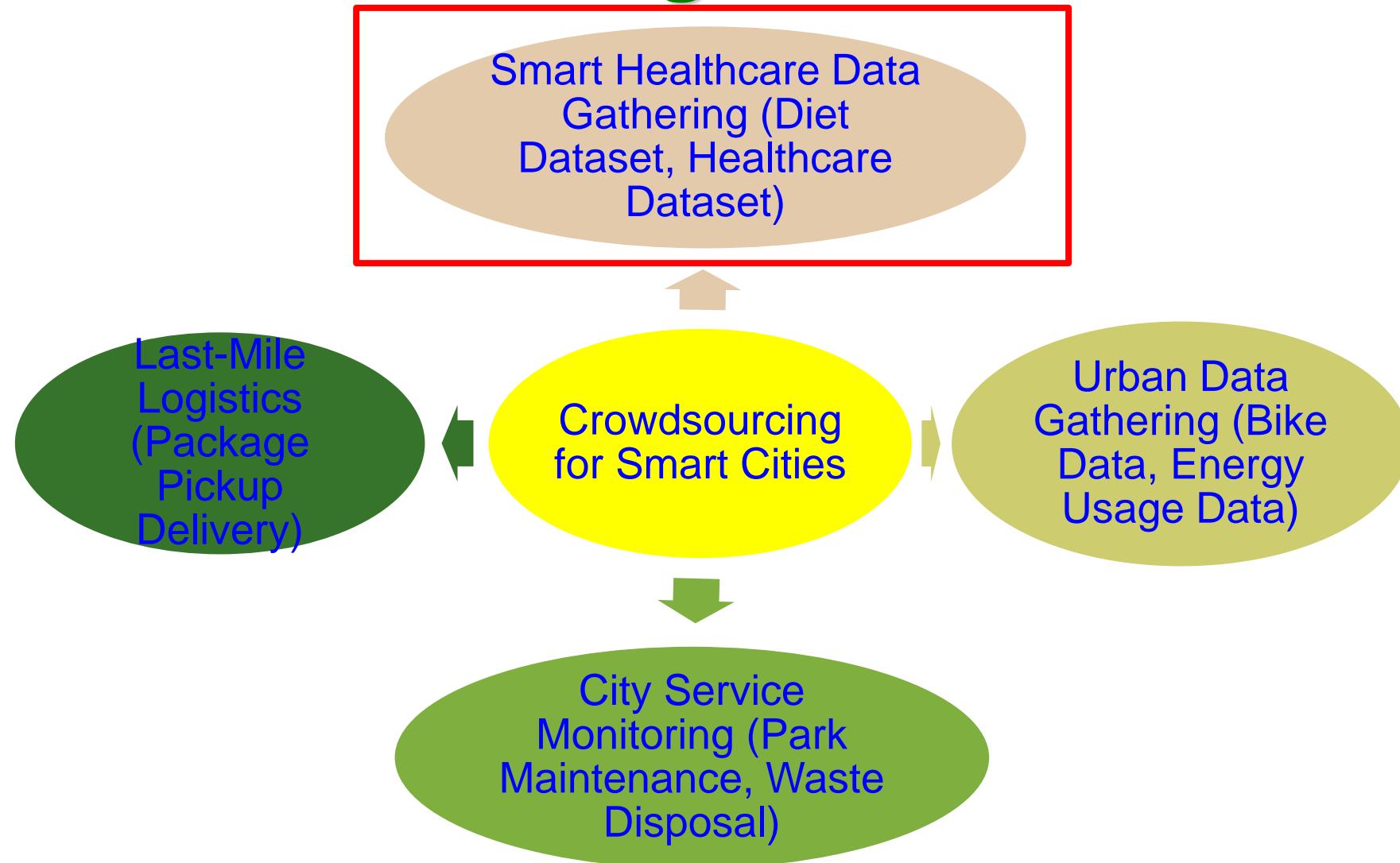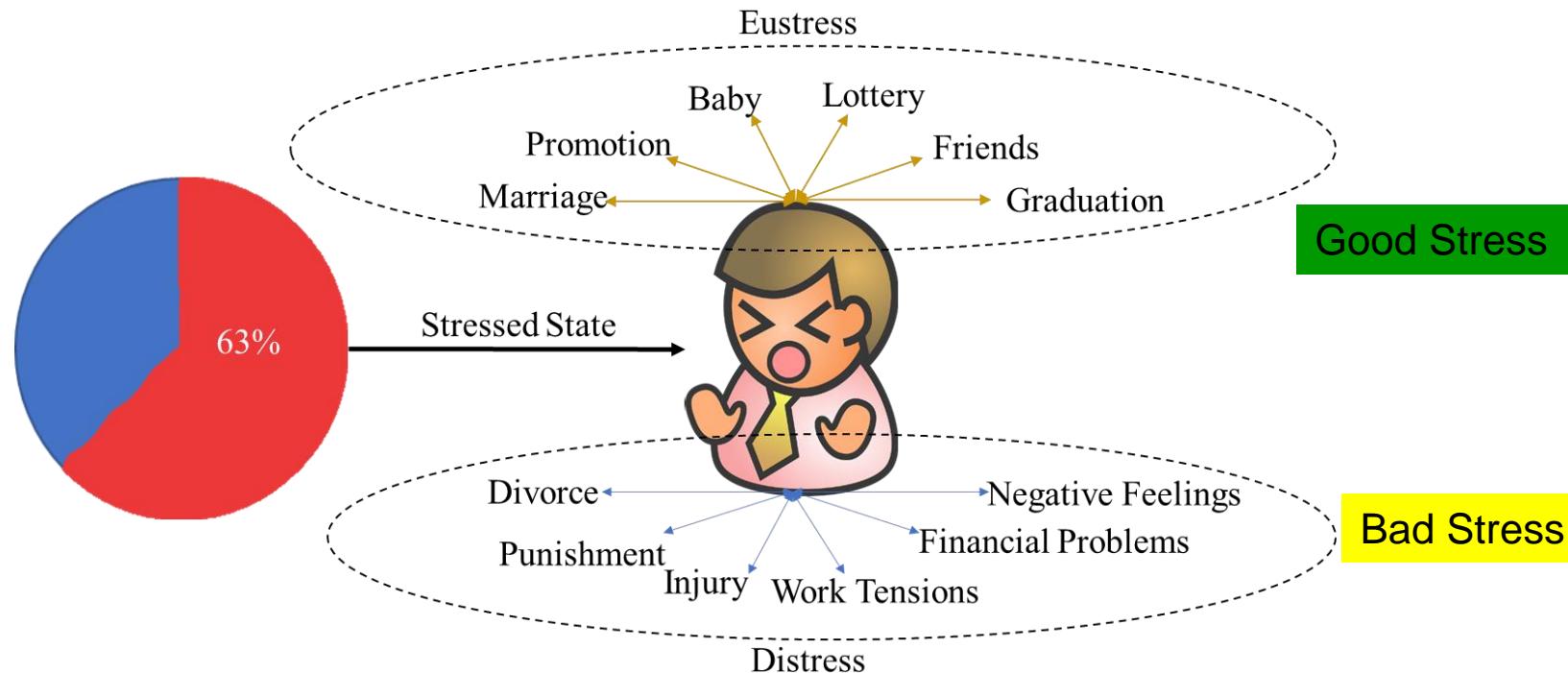
Crowdsourcing for Smart Cities

Smart Healthcare Data Gathering (Diet Dataset, Healthcare Dataset)

Last-Mile Logistics (Package Pickup Delivery)

Crowdsourcing for Smart Cities

Urban Data Gathering (Bike Data, Energy Usage Data)

City Service Monitoring (Park Maintenance, Waste Disposal)

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Smart Healthcare – Specific Examples

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What is Stress?

Eustress

Baby   Lottery

Promotion   Friends

Marriage   Graduation

Good Stress

63%   Stressed State

Divorce   Negative Feelings

Punishment   Financial Problems

Injury   Work Tensions

Bad Stress

Distress

❑ 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 Monitoring and Control is Needed

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

Sudden encounter with **stress**
→Brain floods **body** with chemicals and hormones
(adrenaline and cortisol)

Distress

➢ 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

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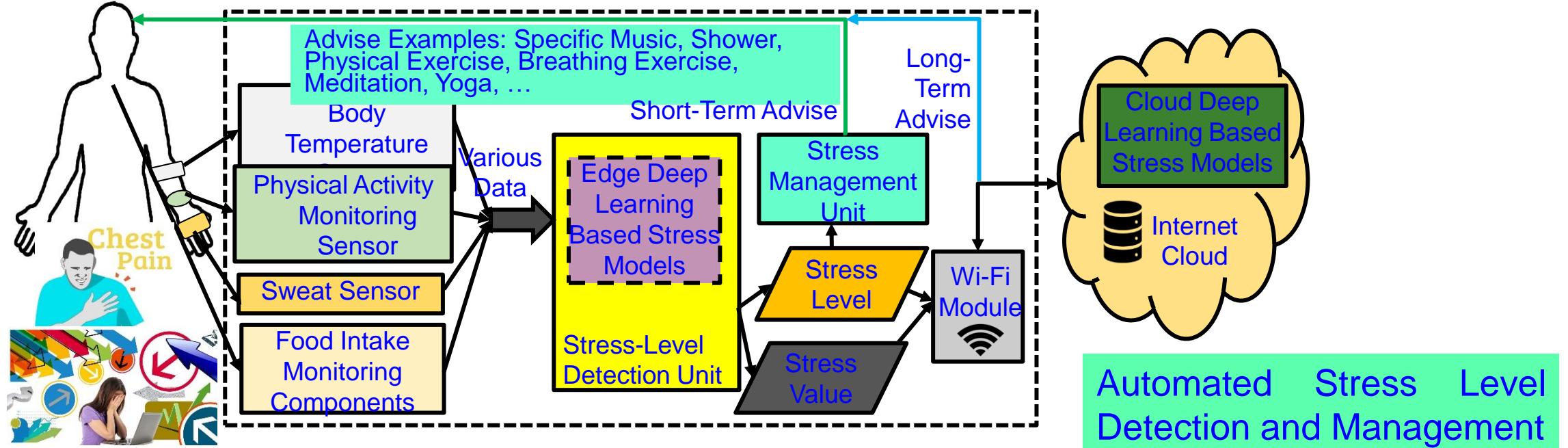
Stress is a Global Issue
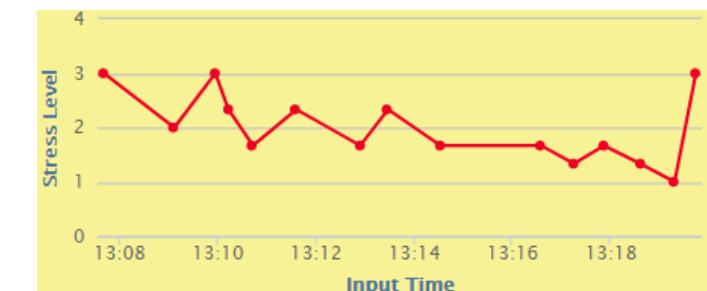
- In major global economies - 6 in 10 workers experiencing increased workplace stress.

- 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/

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Stress Monitoring & Control – Our Vision

Advise Examples: Specific Music, Shower, Physical Exercise, Breathing Exercise, Meditation, Yoga, …

Body Temperature

Physical Activity Monitoring Sensor

Sweat Sensor

Food Intake Monitoring Components

Various Data

Short-Term Advise

Edge Deep Learning Based Stress Models

Stress-Level Detection Unit

Stress Management Unit

Stress Level

Stress Value

Wi-Fi Module

Long-Term Advise

Cloud Deep Learning Based Stress Models

Internet Cloud

Automated Stress Level Detection and Management

Chest Pain

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 °F	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
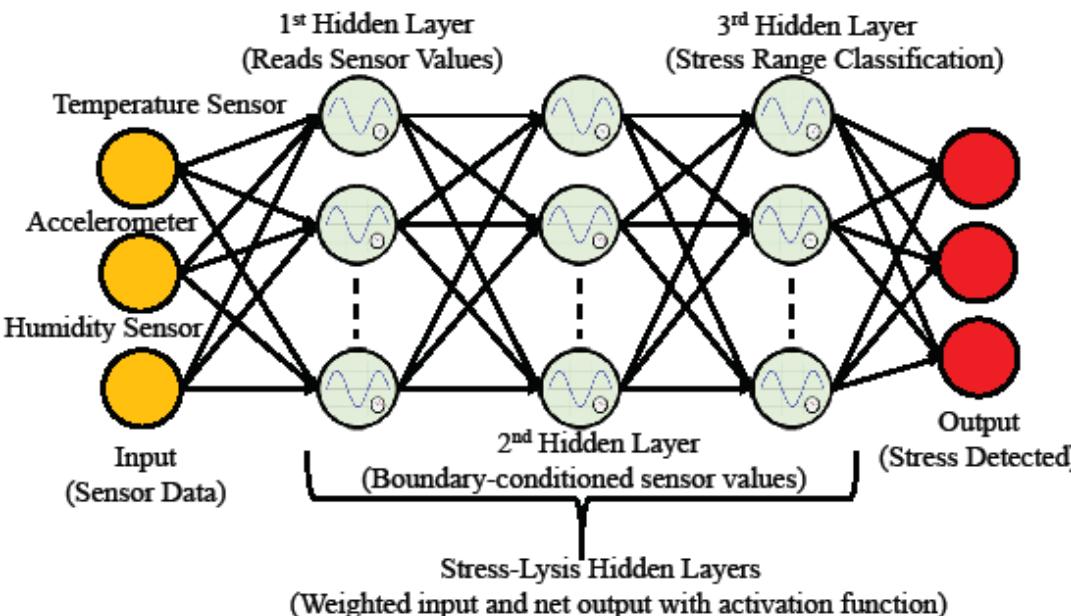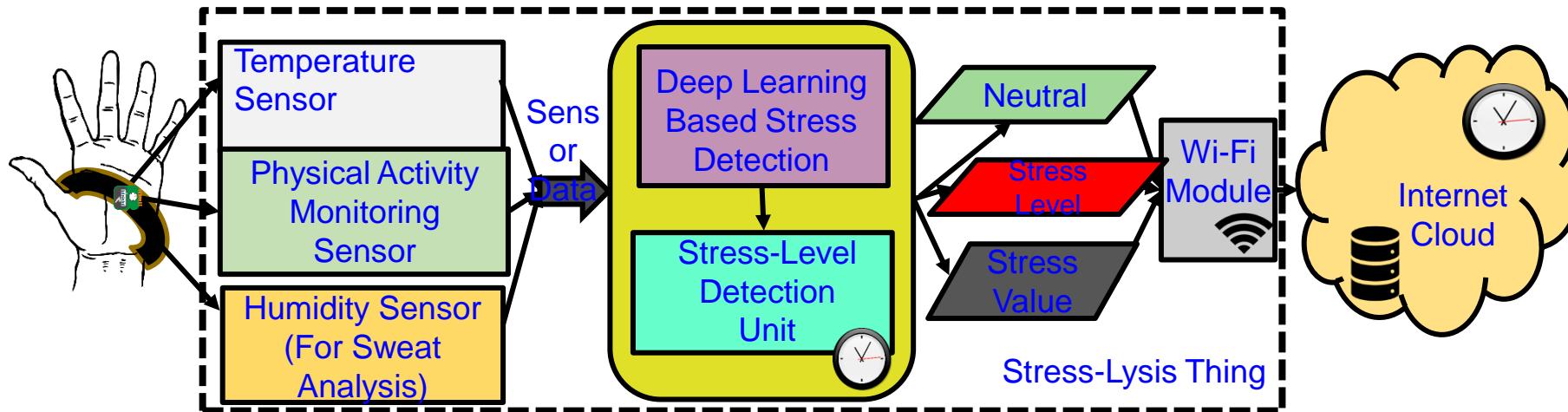
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Consumer Electronics Sleep Trackers

| 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.

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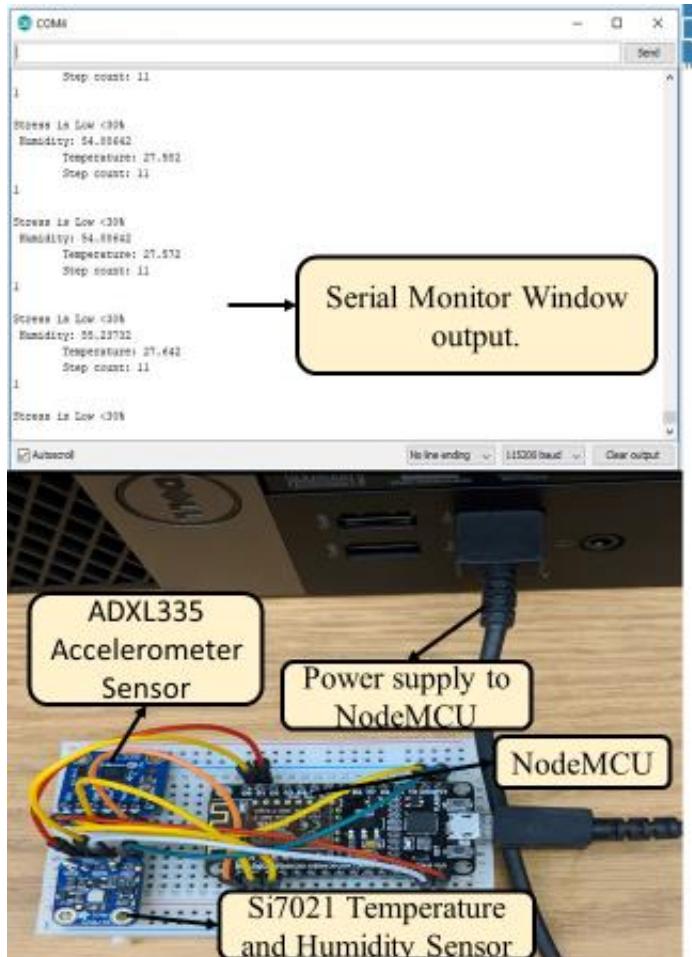
# Stress-Lysis: From Physiological Signals

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.
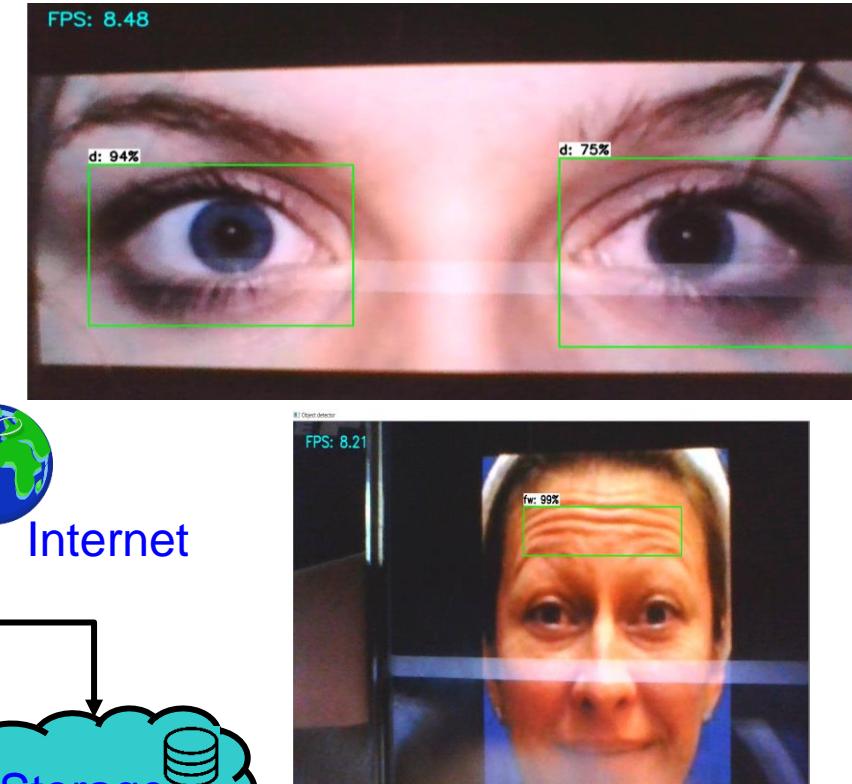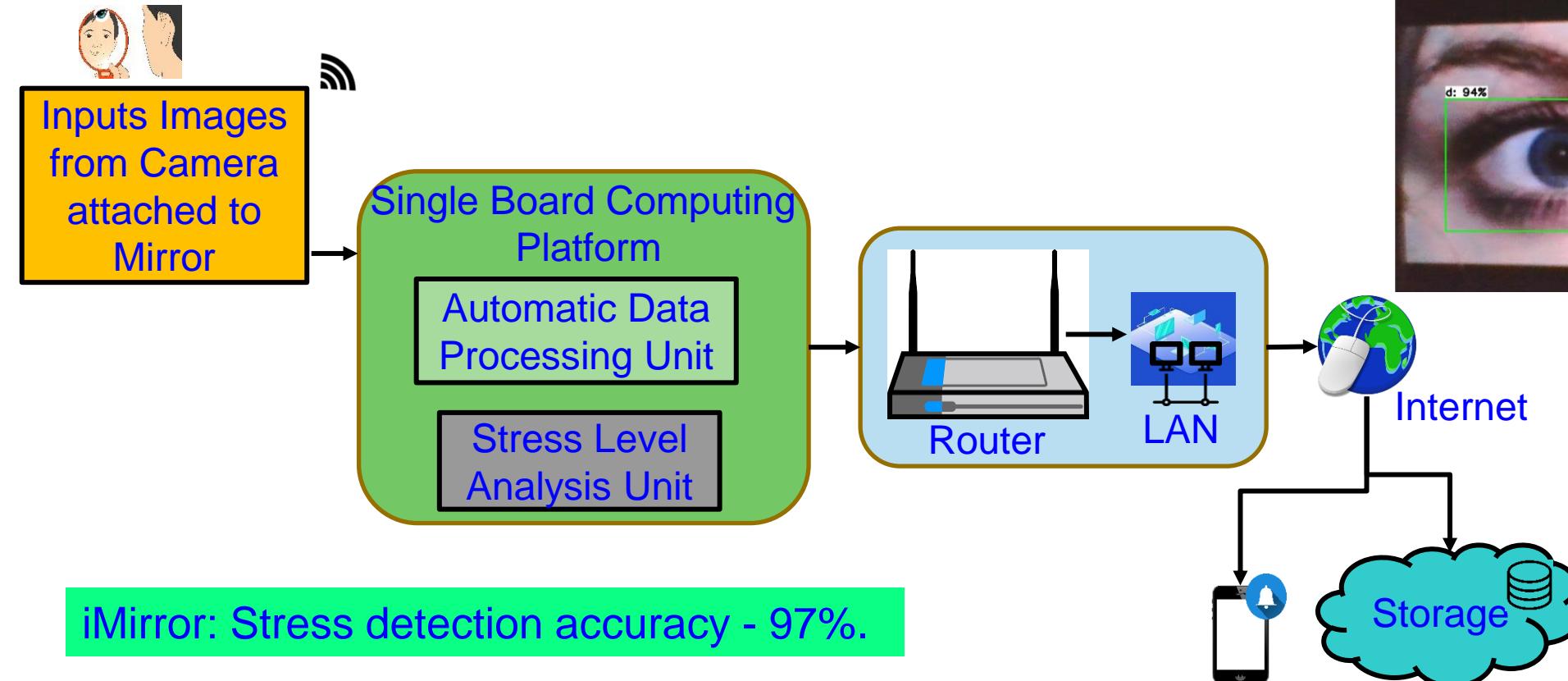
Stress-Lysis: Experiments

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.

# iMirror: Our Smart Mirror for Stress Detection from Facial Features

Inputs Images from Camera attached to Mirror

Single Board Computing Platform

Automatic Data Processing Unit

Stress Level Analysis Unit

Router

LAN

Internet

Storage

FPS: 8.48
d: 94%
d: 75%

FPS: 8.21
fw: 99%

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.

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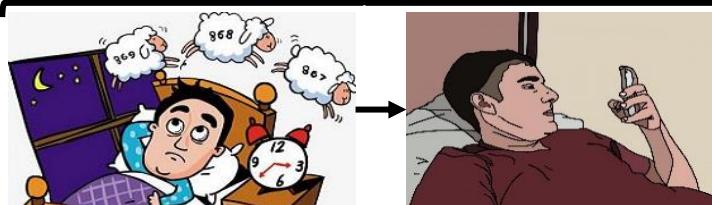
Smart-Yoga Pillow (SaYoPillow) - Sleeping Pattern

Person On Pillow:
Physiological Sensor Data Monitoring Starts

Person Off Pillow:
Physiological Sensor Data Monitoring Ends

ON

OFF

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 Access

Secure Data Storage
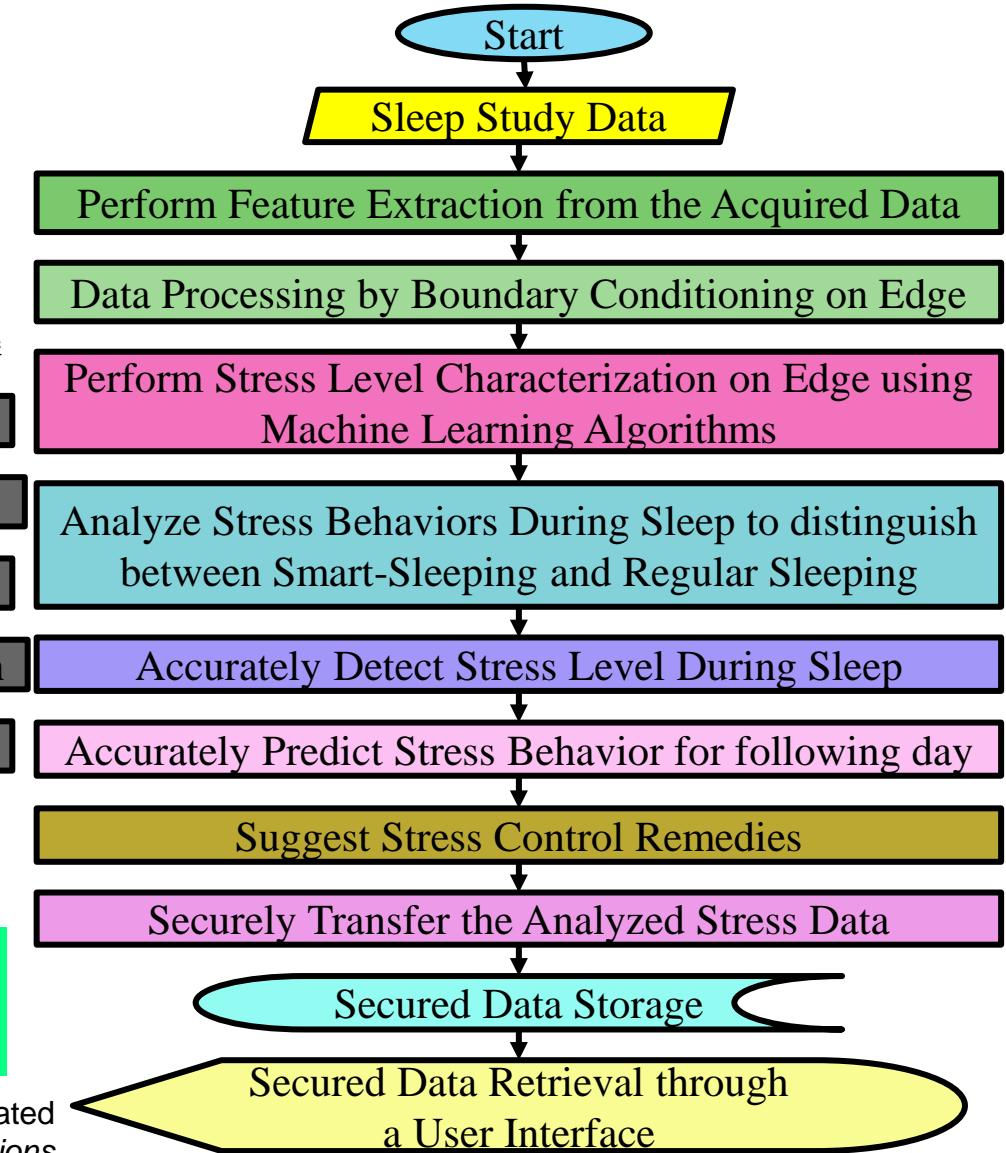
User Applications

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.

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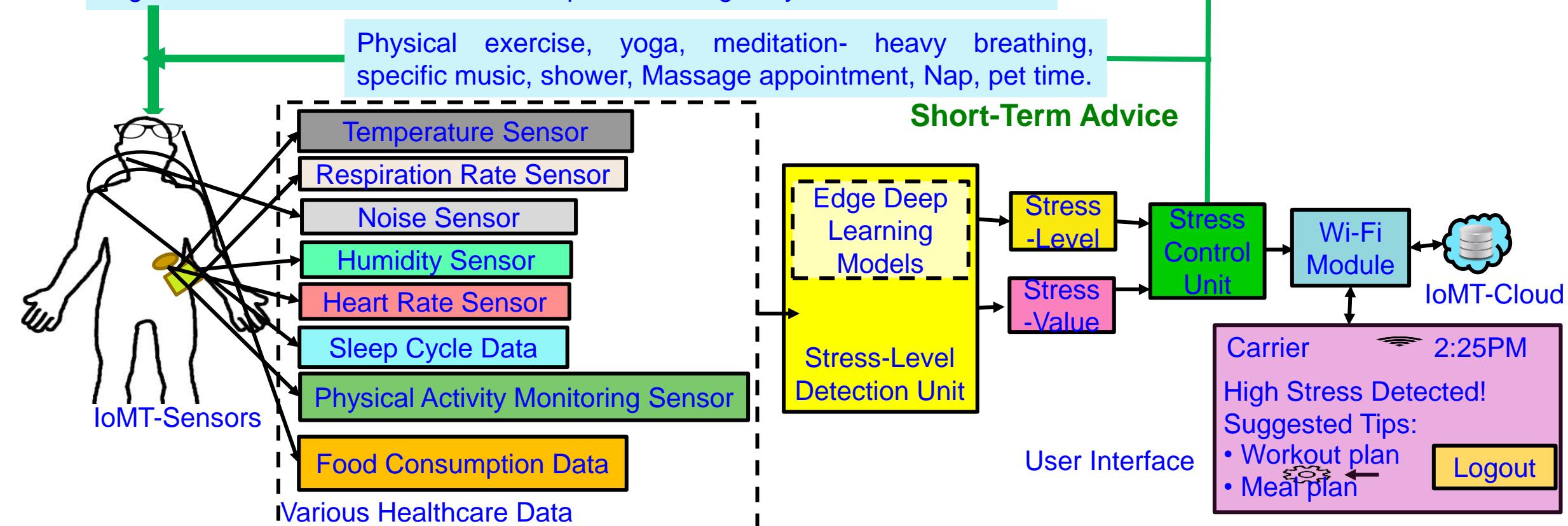
SaYoPillow – Uses deep learning for 96% accuracy with blockchain based security features

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.

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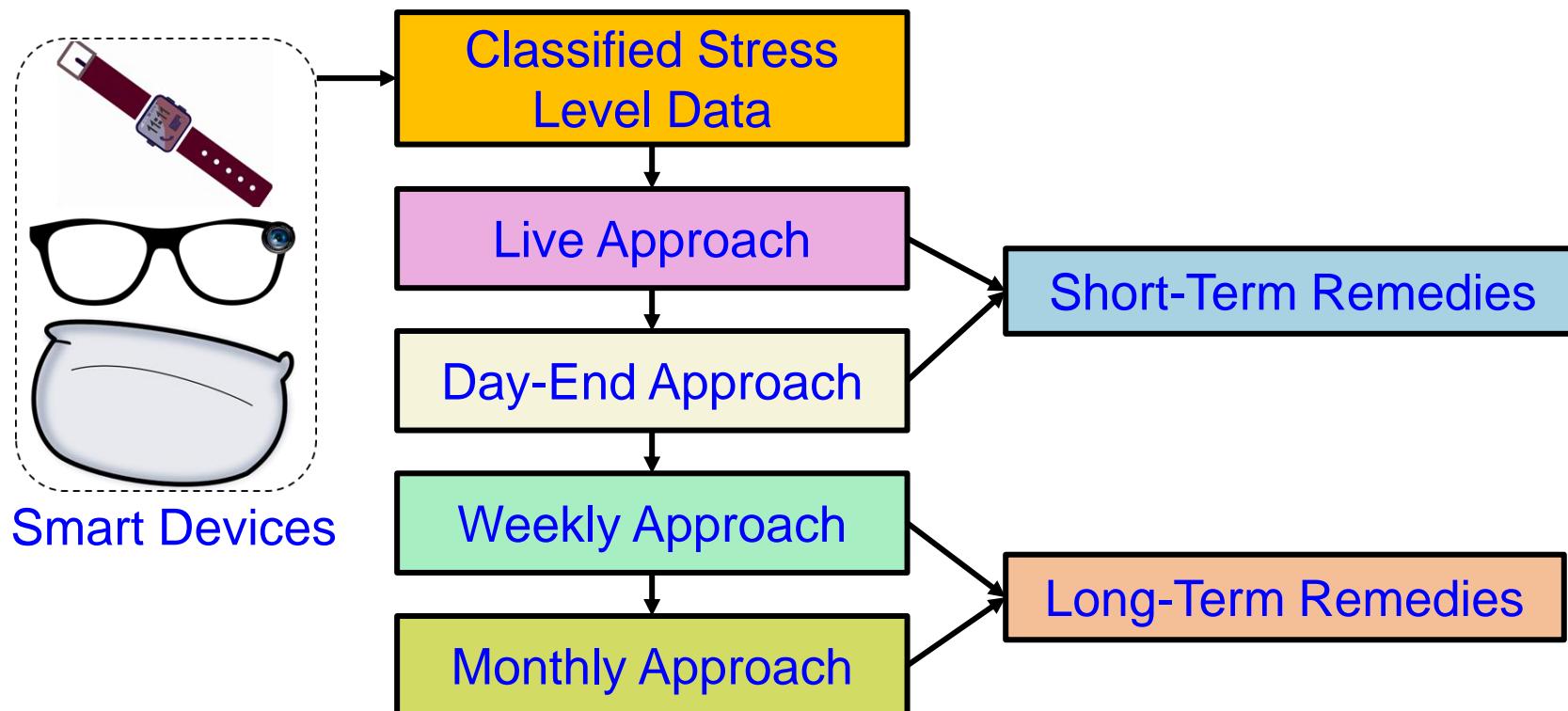
Stress Control by iFeliz: Our Proposed System

Generate workout plan, meal plan, sleep schedule, display stress relief paintings, play music in the background, suggest videos to play, quick 2 min breathe exercise, display positive and inspirational quotes, nearby therapy dog's location, automatic slide show of photos from gallery.

Long-Term Advice

Physical exercise, yoga, meditation- heavy breathing, specific music, shower, Massage appointment, Nap, pet time.

Short-Term Advice

IoMT-Sensors

Temperature Sensor
Respiration Rate Sensor
Noise Sensor
Humidity Sensor
Heart Rate Sensor
Sleep Cycle Data
Physical Activity Monitoring Sensor
Food Consumption Data

Various Healthcare Data

Edge Deep Learning Models

Stress-Level Detection Unit

Stress-Level

Stress-Value

Stress Control Unit

Wi-Fi Module

IoMT-Cloud

User Interface

Carrier   2:25PM

High Stress Detected!
Suggested Tips:
• Workout plan
• Meal plan

Logout

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.

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UNT EST. 1890 DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING College of Engineering

iFeliz: Stress Control Approaches

Smart Devices

Classified Stress Level Data → Live Approach → Day-End Approach → Short-Term Remedies

Day-End Approach → Weekly Approach → Monthly Approach → 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

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

Imbalance Diet is a Global Issue
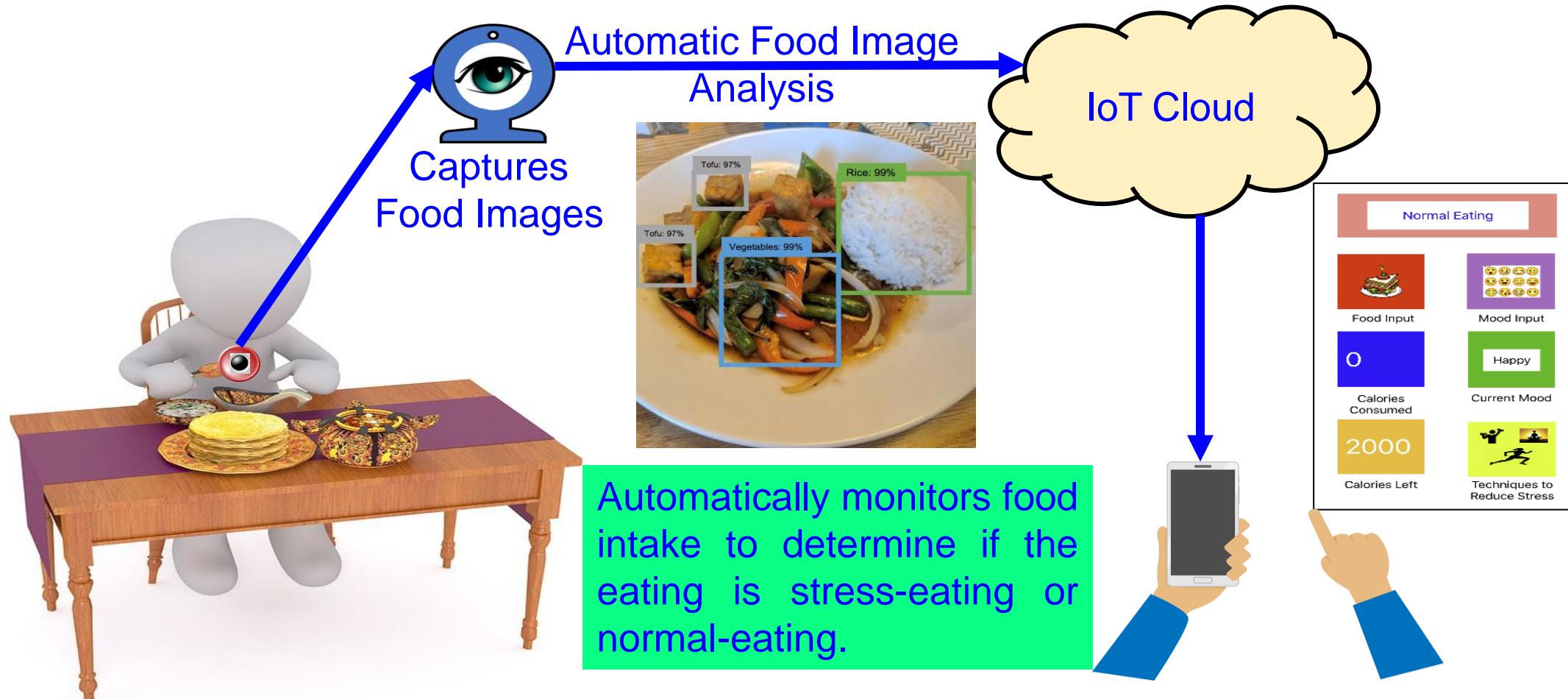
- Imbalanced diet can be either more or fewer of certain nutrients than the body needs.

- 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
> Coronary heart disease
> High blood pressure

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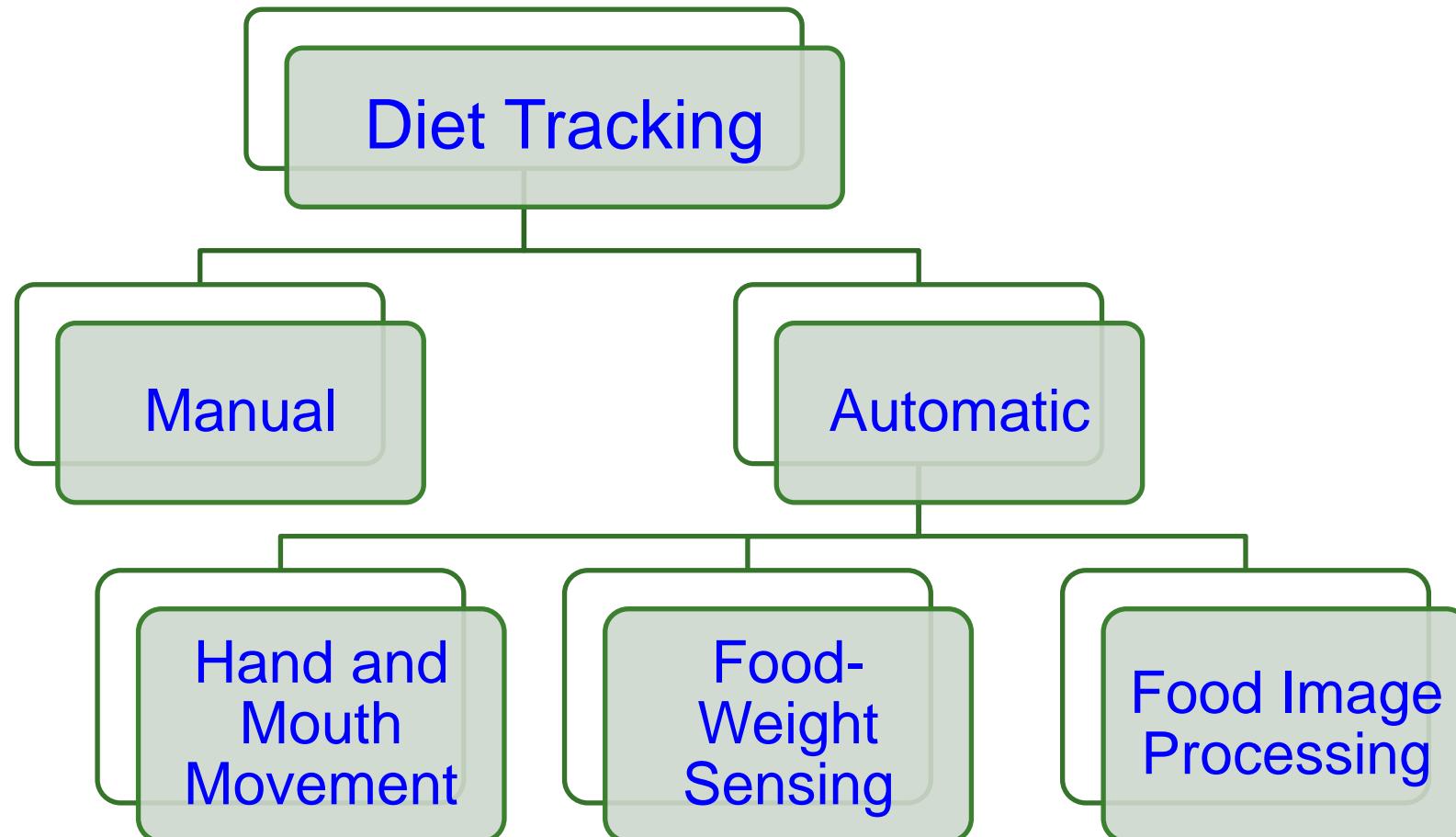
Source: https://obesity-diet.nutritionalconference.com/events-list/imbalanced-diet-effects-and-causes
https://www.thelancet.com/article/S0140-6736(19)30041-8/fulltext

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Automatic Diet Monitoring & Control - Our Vision

Automatic Food Image Analysis

Captures Food Images

IoT Cloud

Tofu: 97%
Rice: 99%
Tofu: 97%
Vegetables: 99%

Normal Eating

Food Input | Mood Input
0 | Happy
Calories Consumed | Current Mood
2000 | Techniques to Reduce Stress
Calories Left |

Automatically monitors food intake to determine if the eating is stress-eating or normal-eating.

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 -- Prof./Dr. Saraju P. Mohanty

Smart Electronic Systems Laboratory (SESL)

Diet Tracking Approaches

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
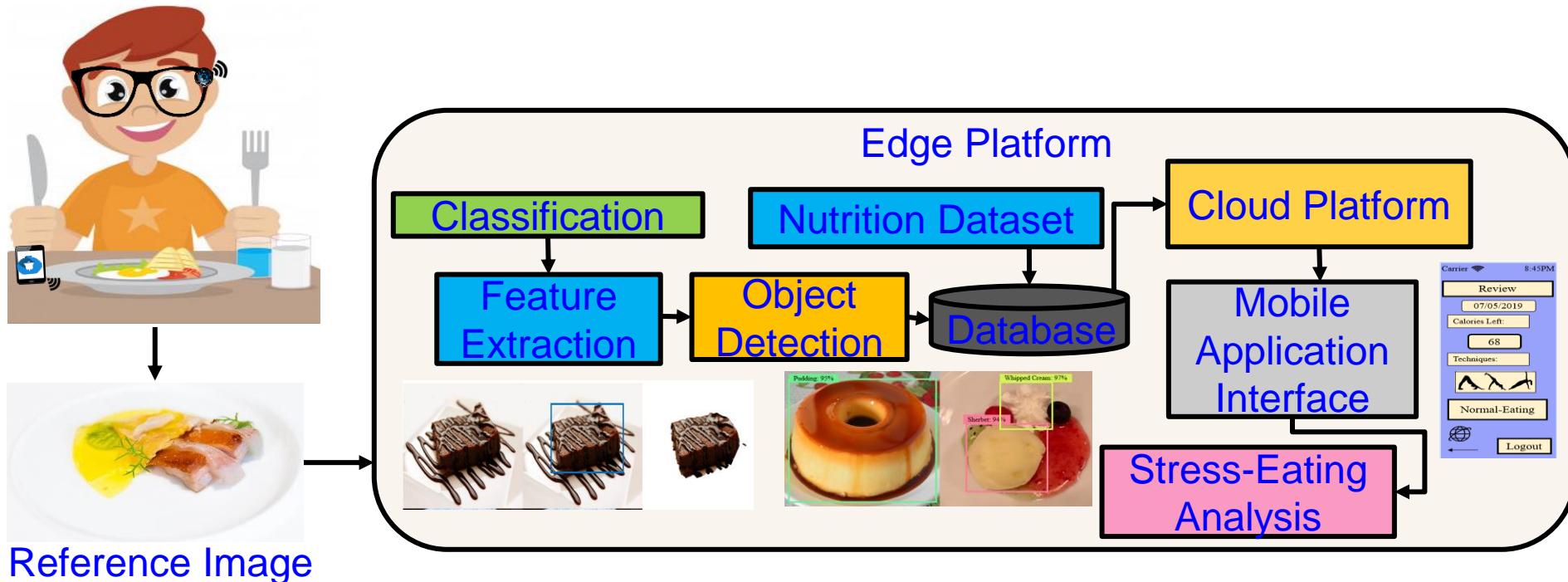
Food Tracking Apps

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

App Name	Downloads	Reviews	Rating	Image — Auto	Food-Label in Image — Manual	Food-Label in Image — Crowd Sourced	Manual	Scanning	Speech	Database search	Calories	Nutrition
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	

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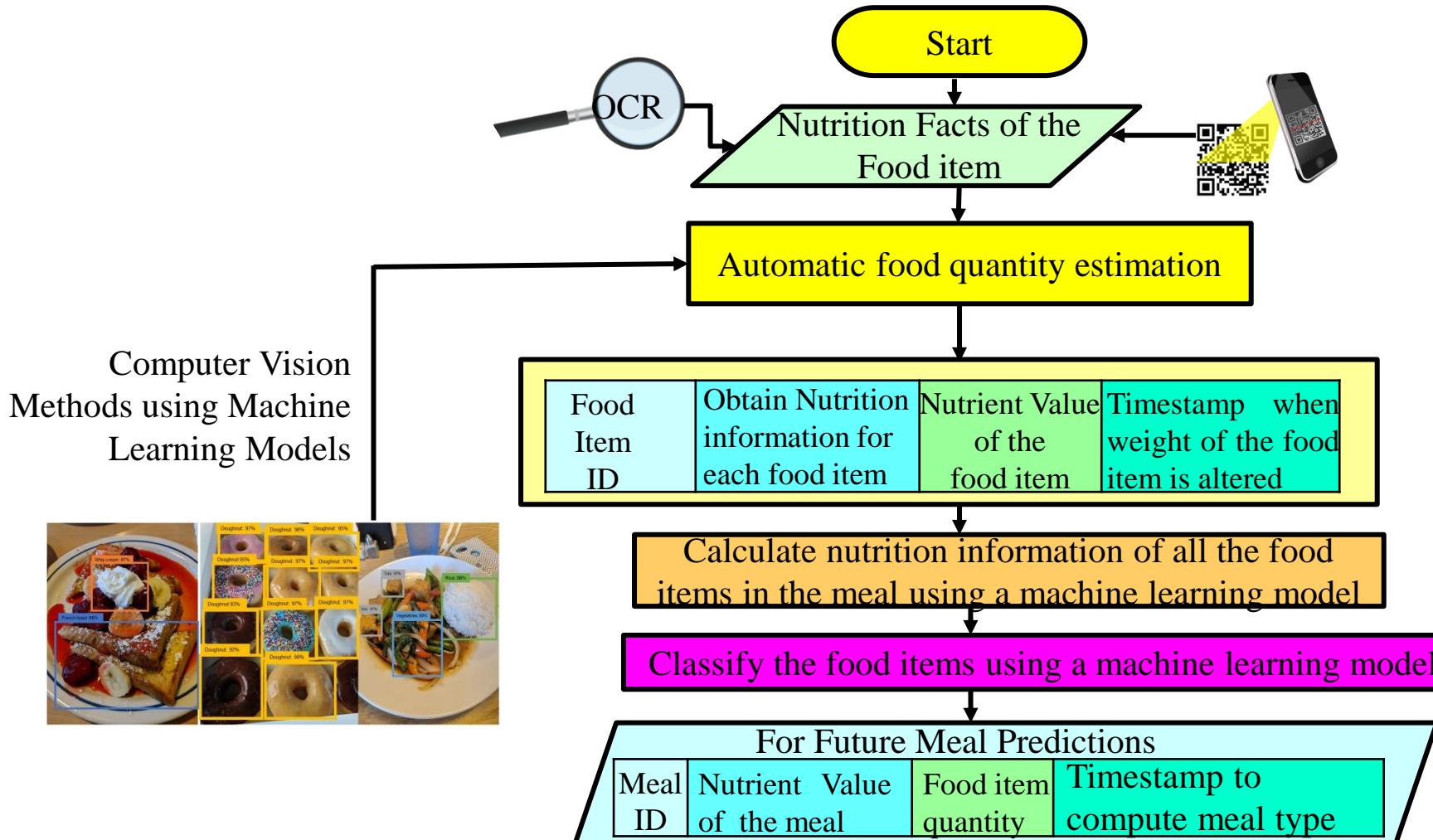
Smart Healthcare – Diet Monitoring - iLog

Reference Image

Edge Platform

- Classification
- Feature Extraction
- Object Detection
- Nutrition Dataset
- Database
- Cloud Platform
- Mobile Application Interface
- Stress-Eating Analysis

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.

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Smart Healthcare – Diet Prediction – Smart-Log

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.

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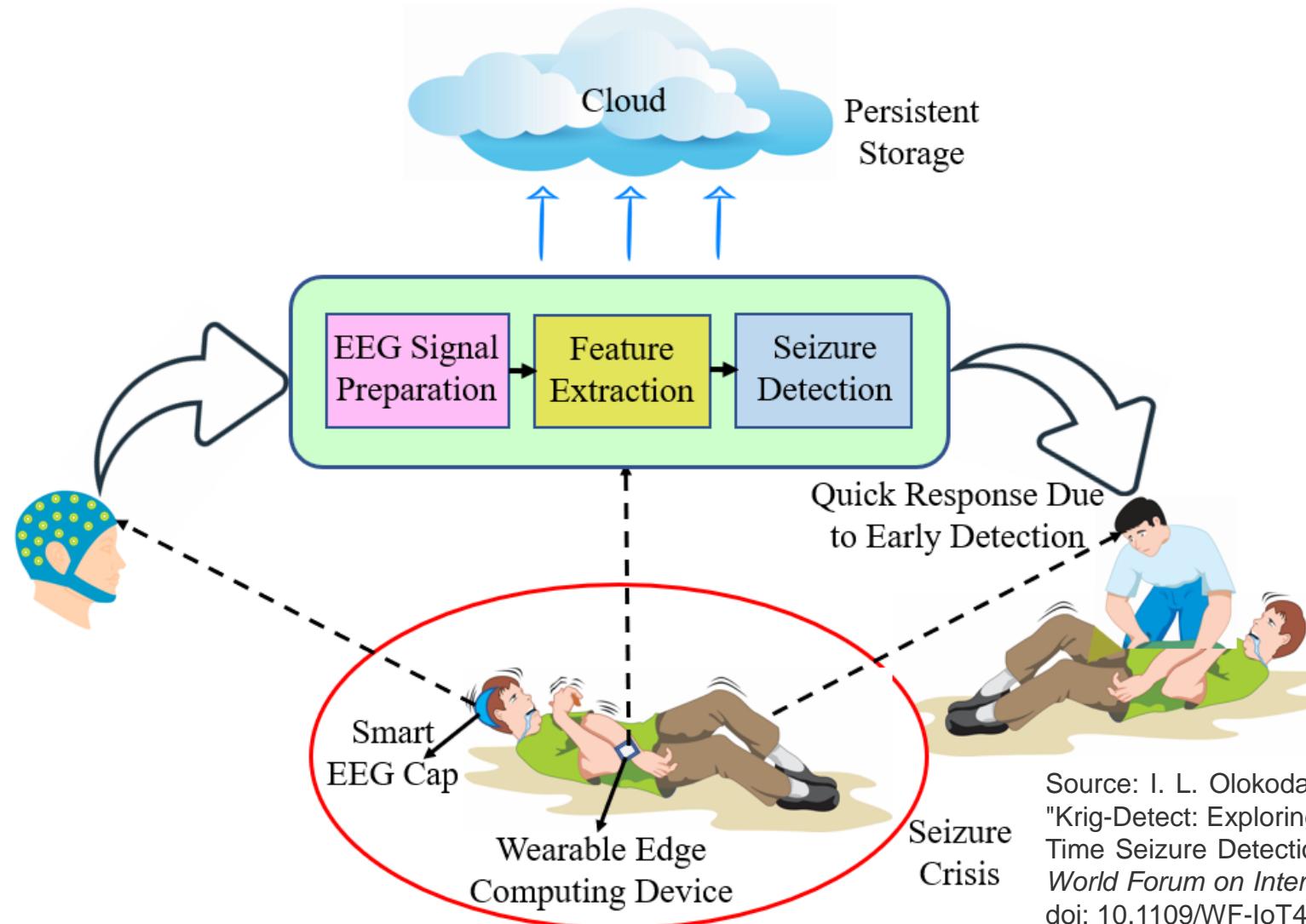
A seizure is an abnormal activity in the nervous system which causes its sufferers to lose consciousness and control.

- 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

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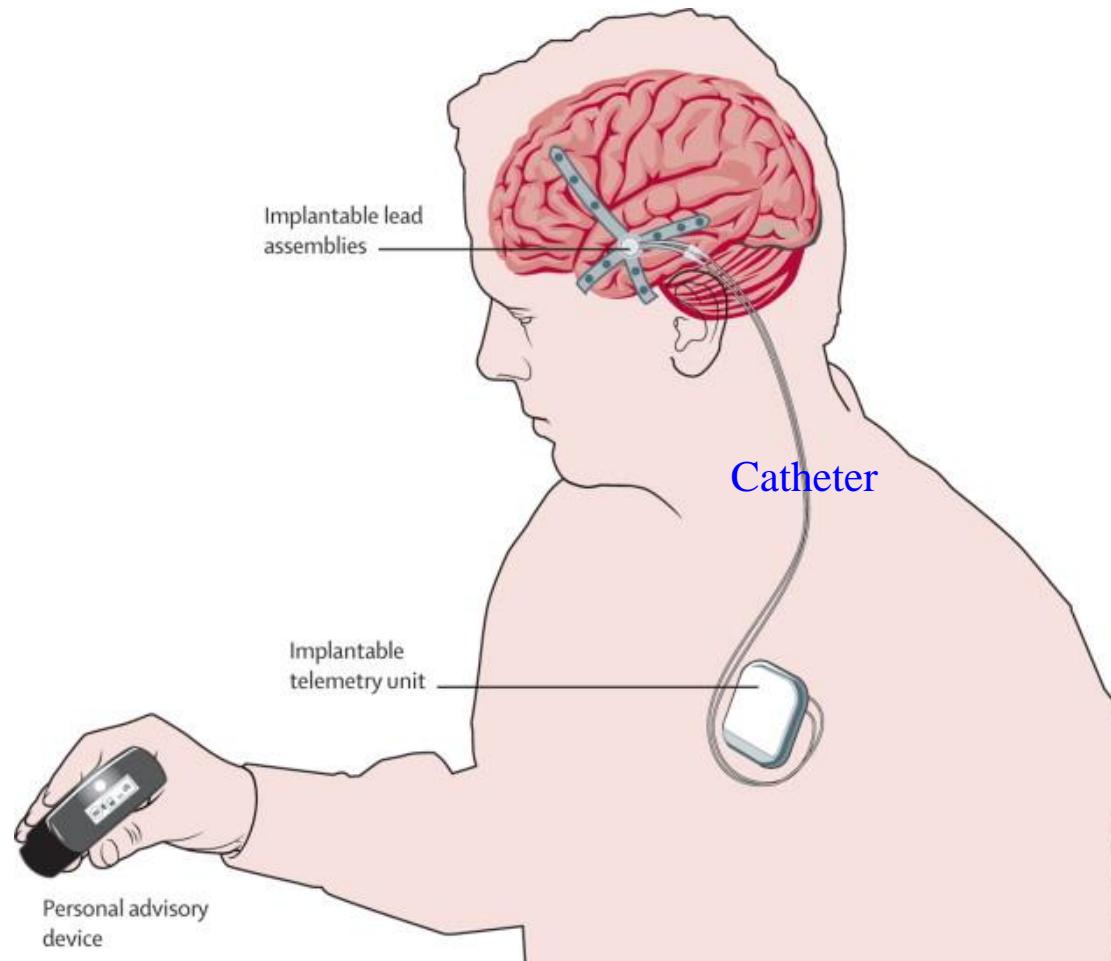
Epileptic Seizure - Our Vision
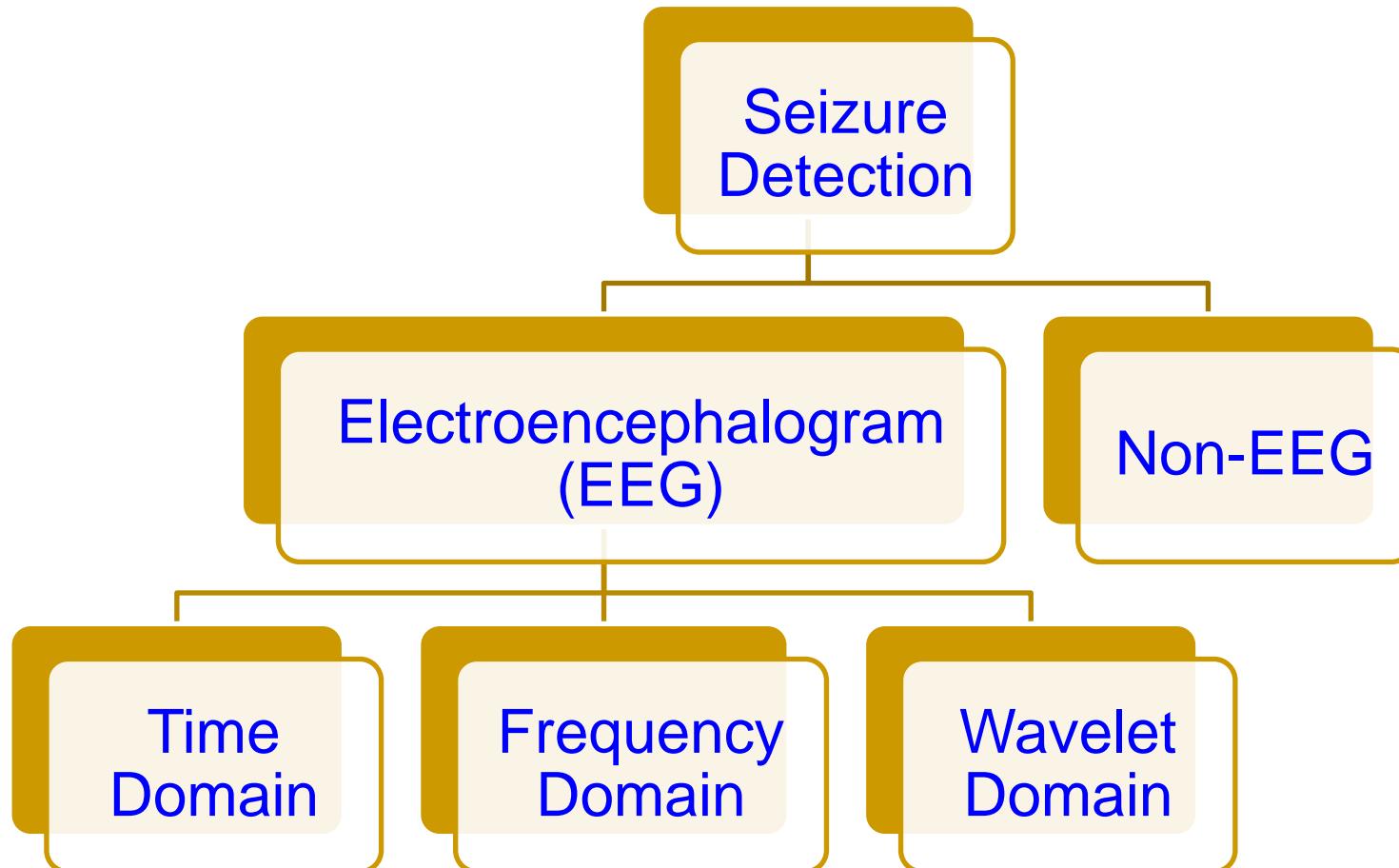
Source: I. L. Olokodana, S. P. Mohanty and E. Kougianos, "Krig-Detect: Exploring Alternative Kriging Methods for Real-Time Seizure Detection from EEG Signals," *2020 IEEE 6th World Forum on Internet of Things (WF-IoT)*, 2020, pp. 1-6, doi: 10.1109/WF-IoT48130.2020.9221260.

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Implantable for Seizure Detection and Control

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

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Seizure Detection Methods

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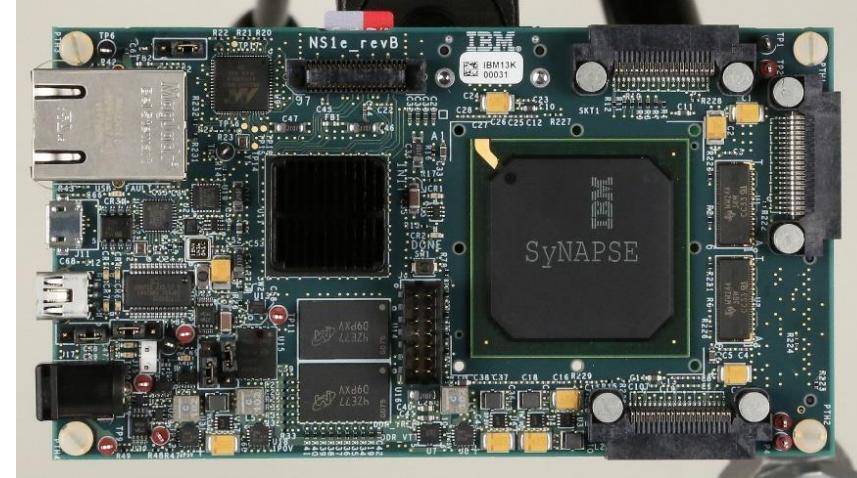
Seizure Detection Methods – Non-EEG

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

DETECTION METHODS / NON-EEG SEIZURE MANIFESTATIONS

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

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

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Smart Electronic Systems Laboratory (SESL)

IBM's Implantable Seizure Detector

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

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

Consumer Electronics for Seizure Detection

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

Source: https://www.empatica.com/embrace2/
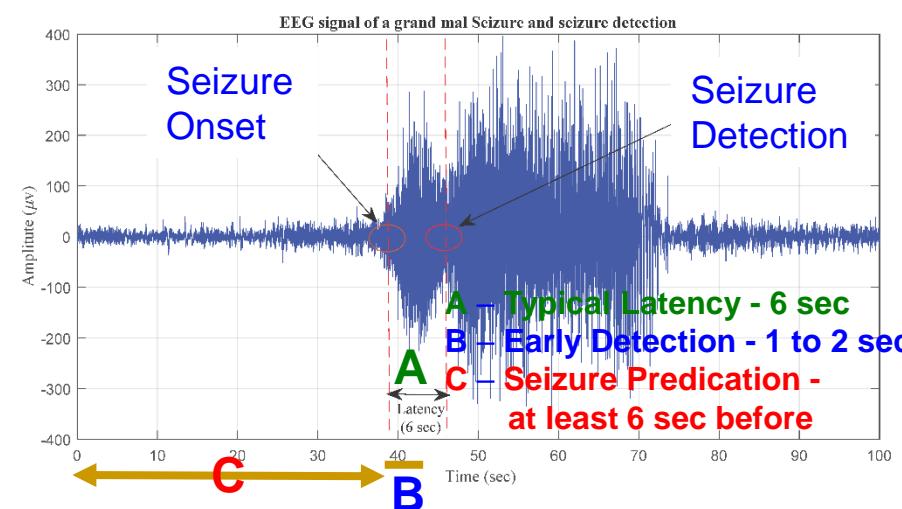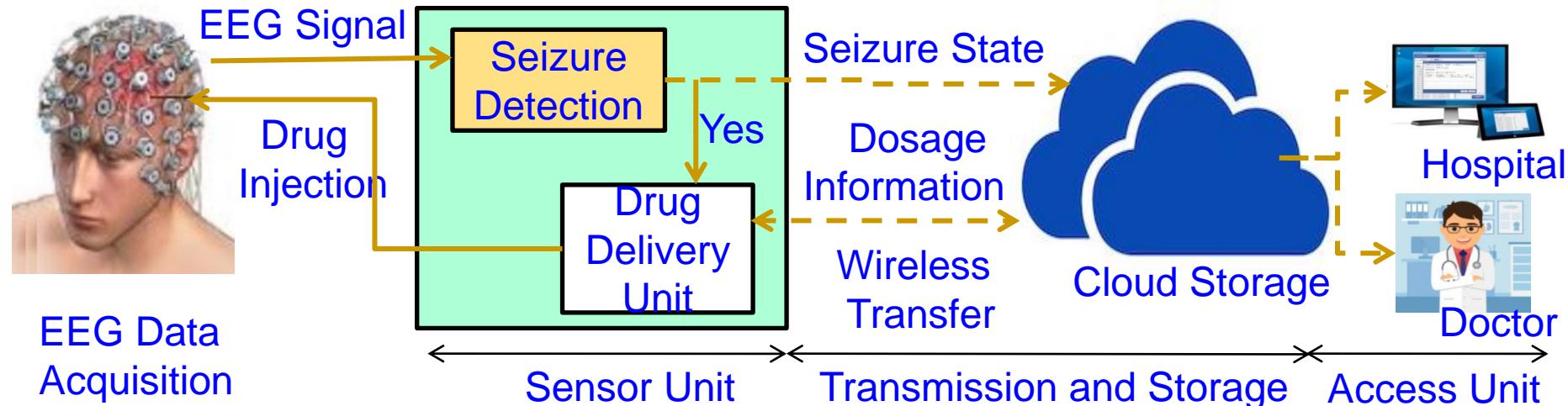
- Embrace2: Smart-band which uses machine learning to detect convulsive Seizures and notifies caregivers.
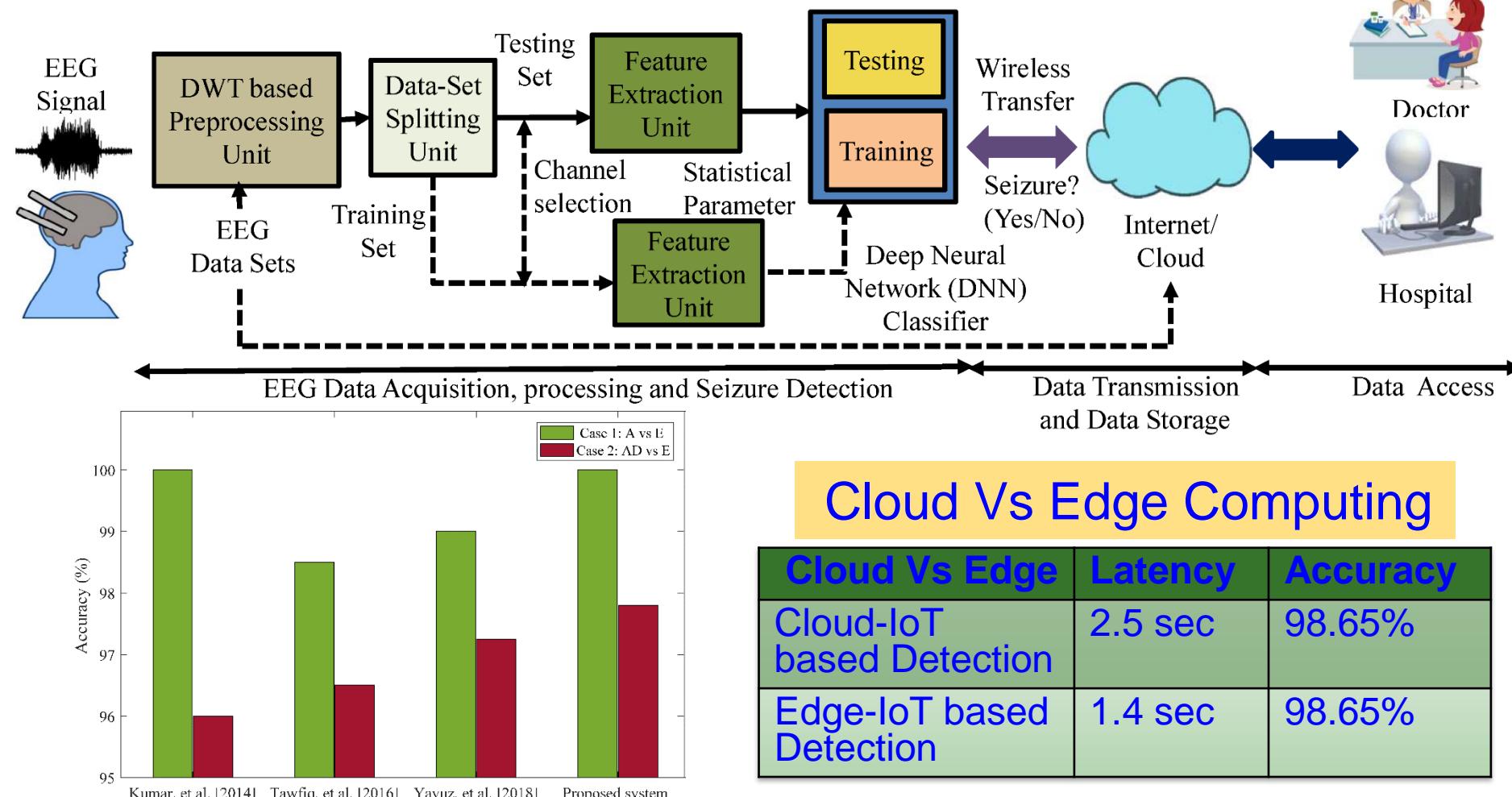
- Medical grade smart watch: It detects generalized clonic-tonic Seizures and notifies physicians.

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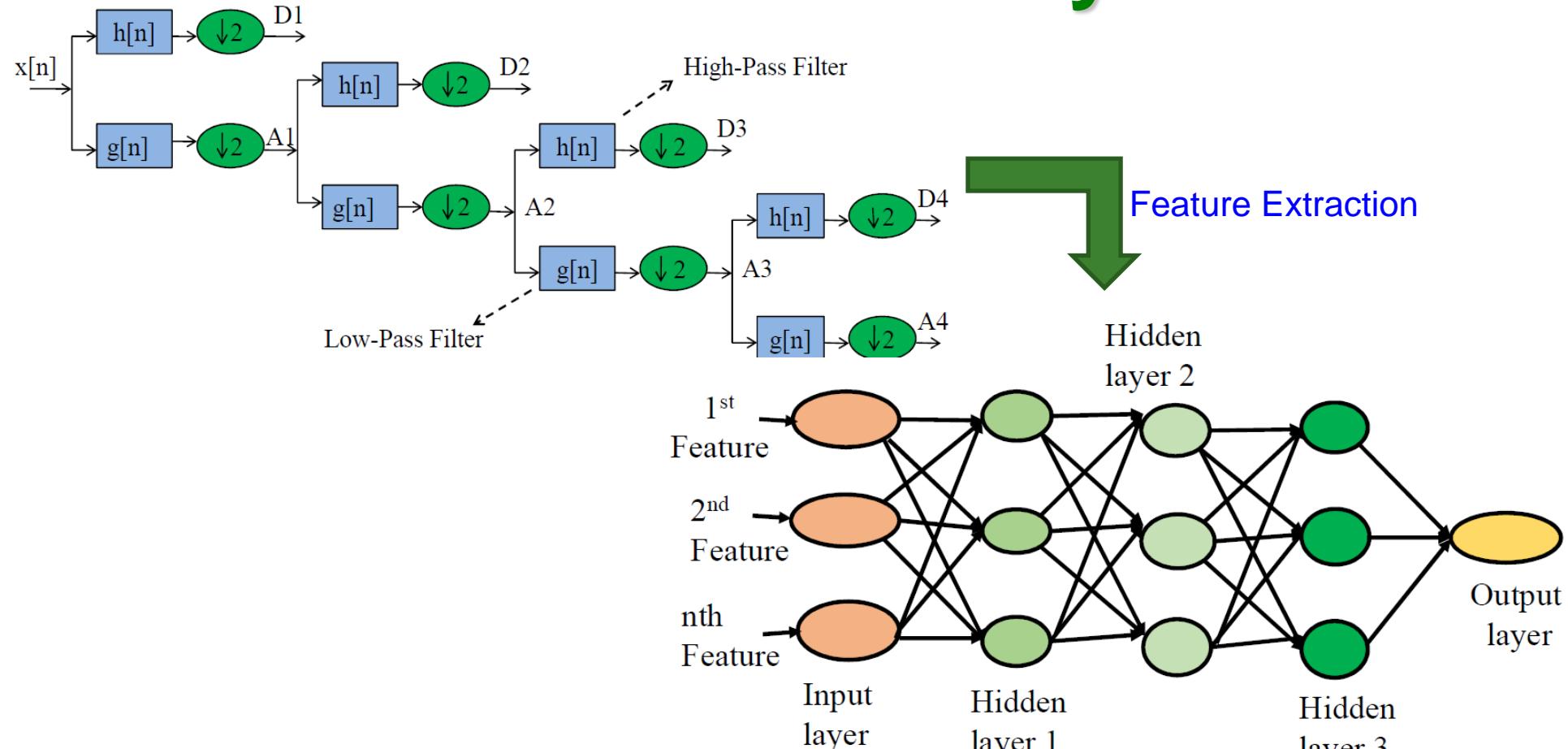
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "eSeiz: An Edge-Device for Accurate Seizure Detection for Smart Healthcare", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 379--387.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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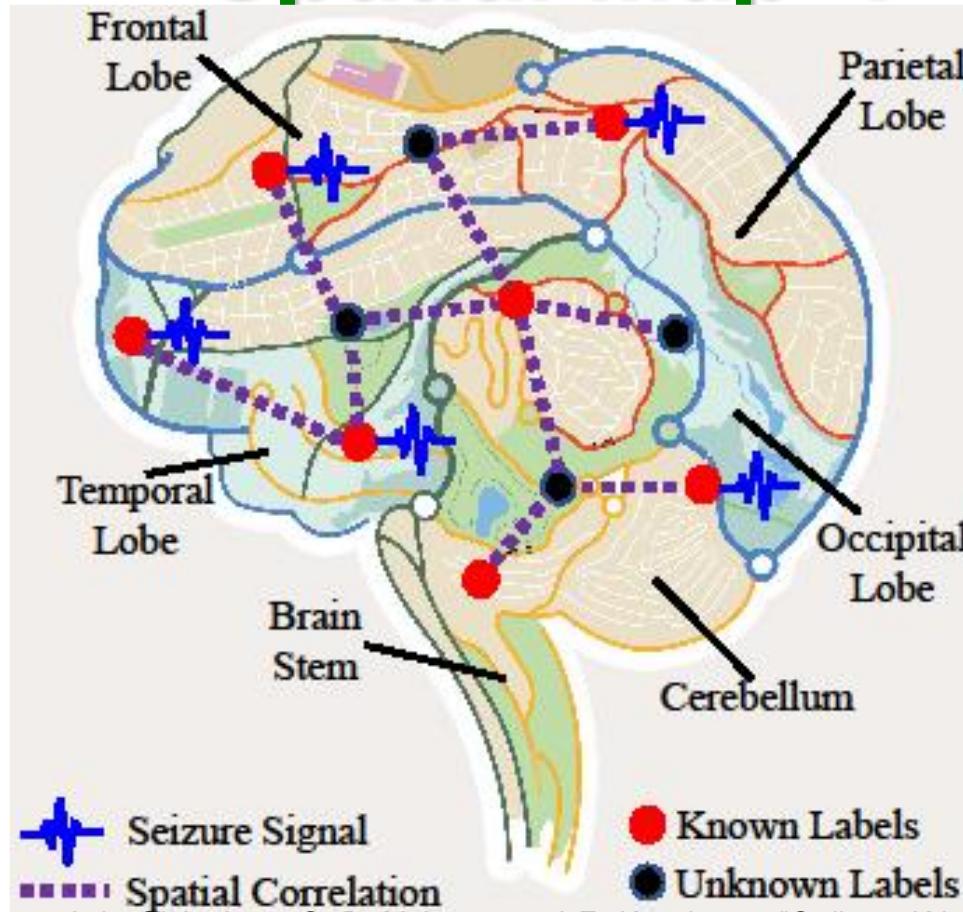
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, No 3, Aug 2019, pp. 359--368.

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%

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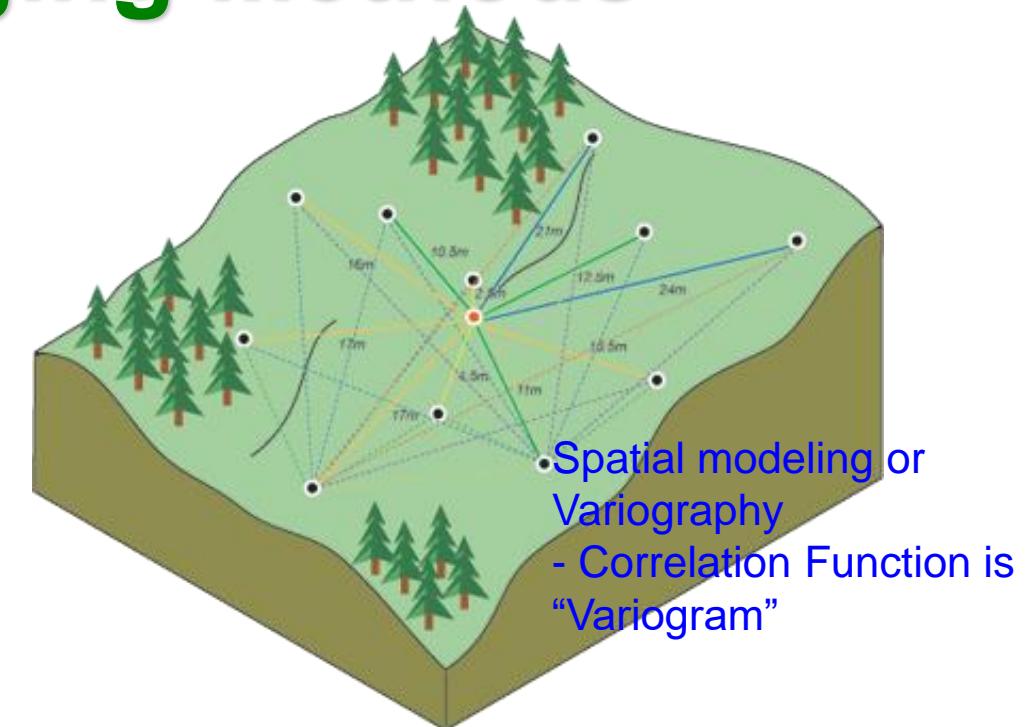
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri , "Neuro-Detect: A Machine Learning Based Fast and Accurate Seizure Detection System in the IoMT", *IEEE Transactions on Consumer Electronics (TCE)*, Vol 65, Issue 3, Aug 2019, pp. 359-368.

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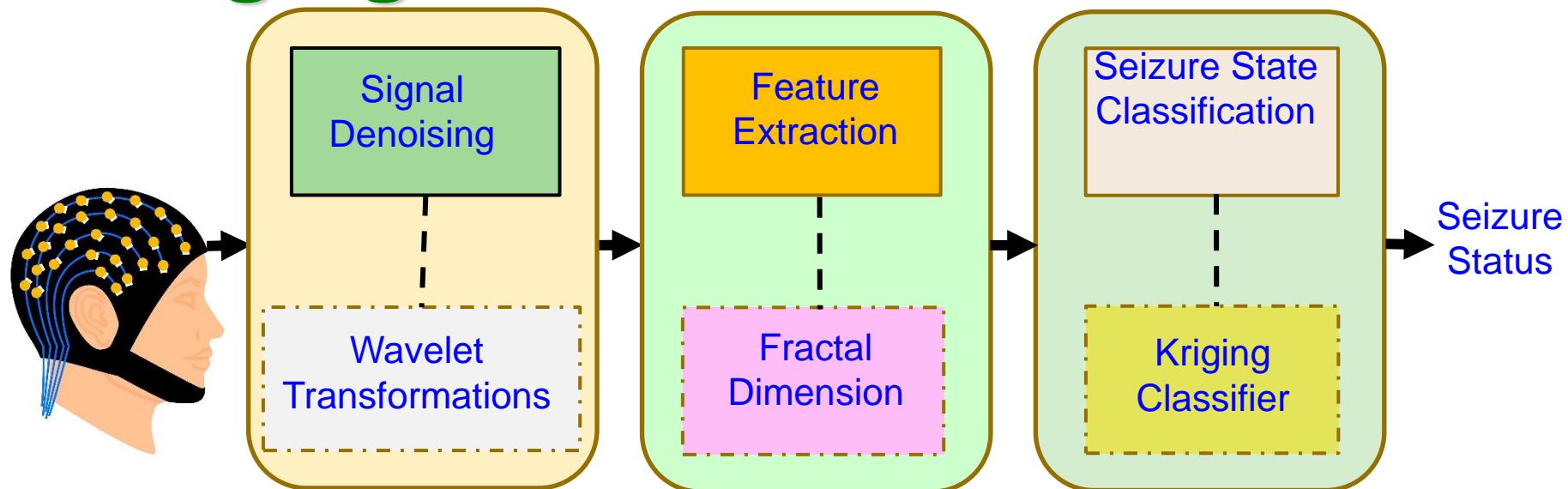
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Ordinary-Kriging Based Real-Time Seizure Detection in an Edge Computing Paradigm", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

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

Spatial modeling or Variography
- Correlation Function is "Variogram"

Spatial autocorrelation principle - things that are closer are more alike than things farther
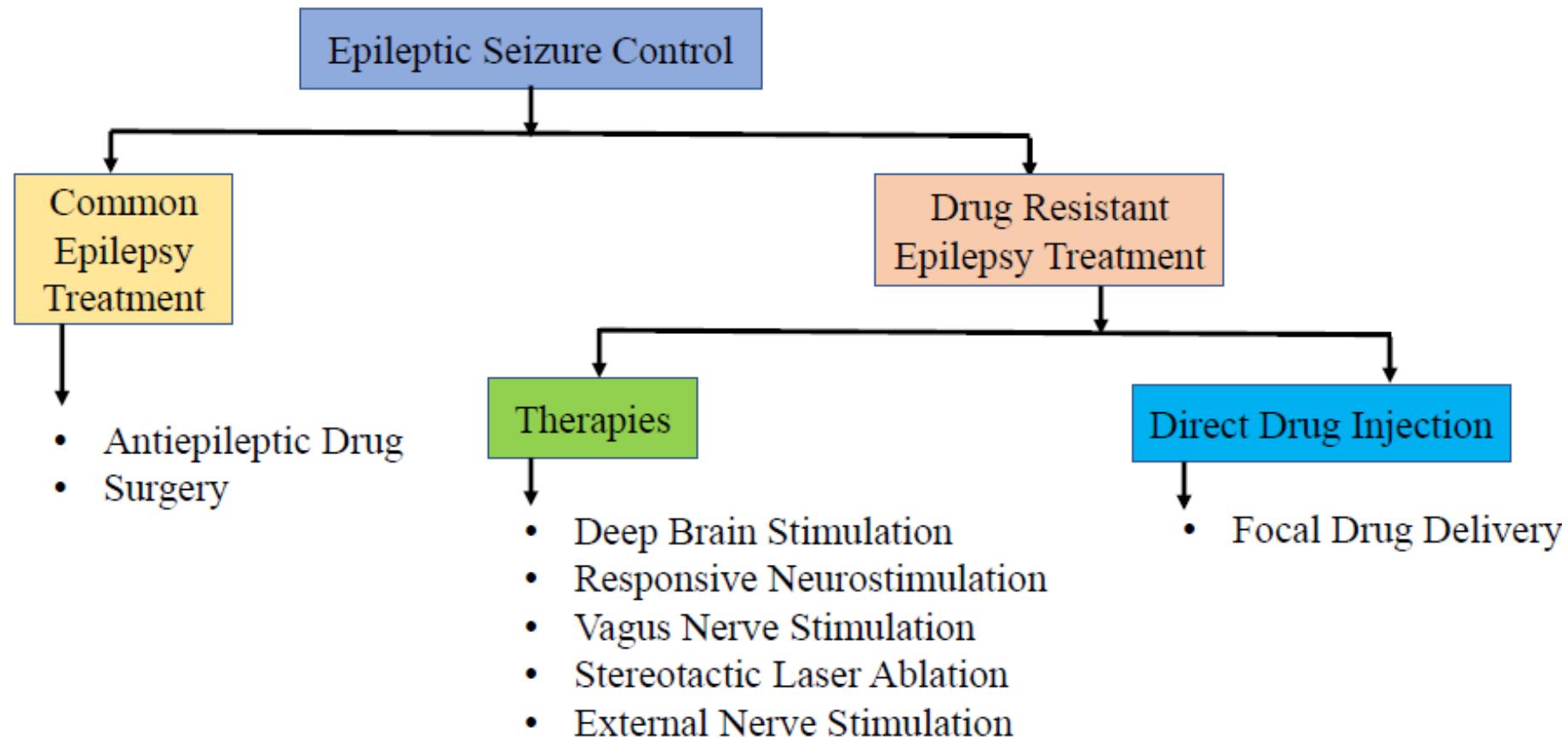
Kriging based Seizure Detection

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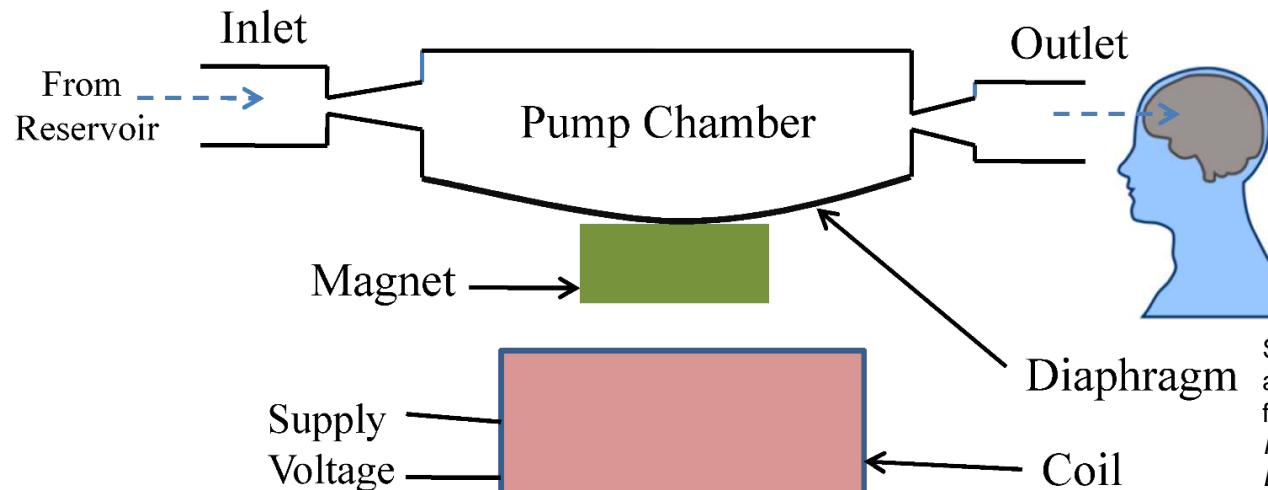
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Ordinary-Kriging Based Real-Time Seizure Detection in an Edge Computing Paradigm", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE)*, 2020.

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.

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Seizure Control Methods

Electromagnetic: Latency – 1.8 Sec, Power – 12.81 mW, Flow Rate – 0.34 mL/min
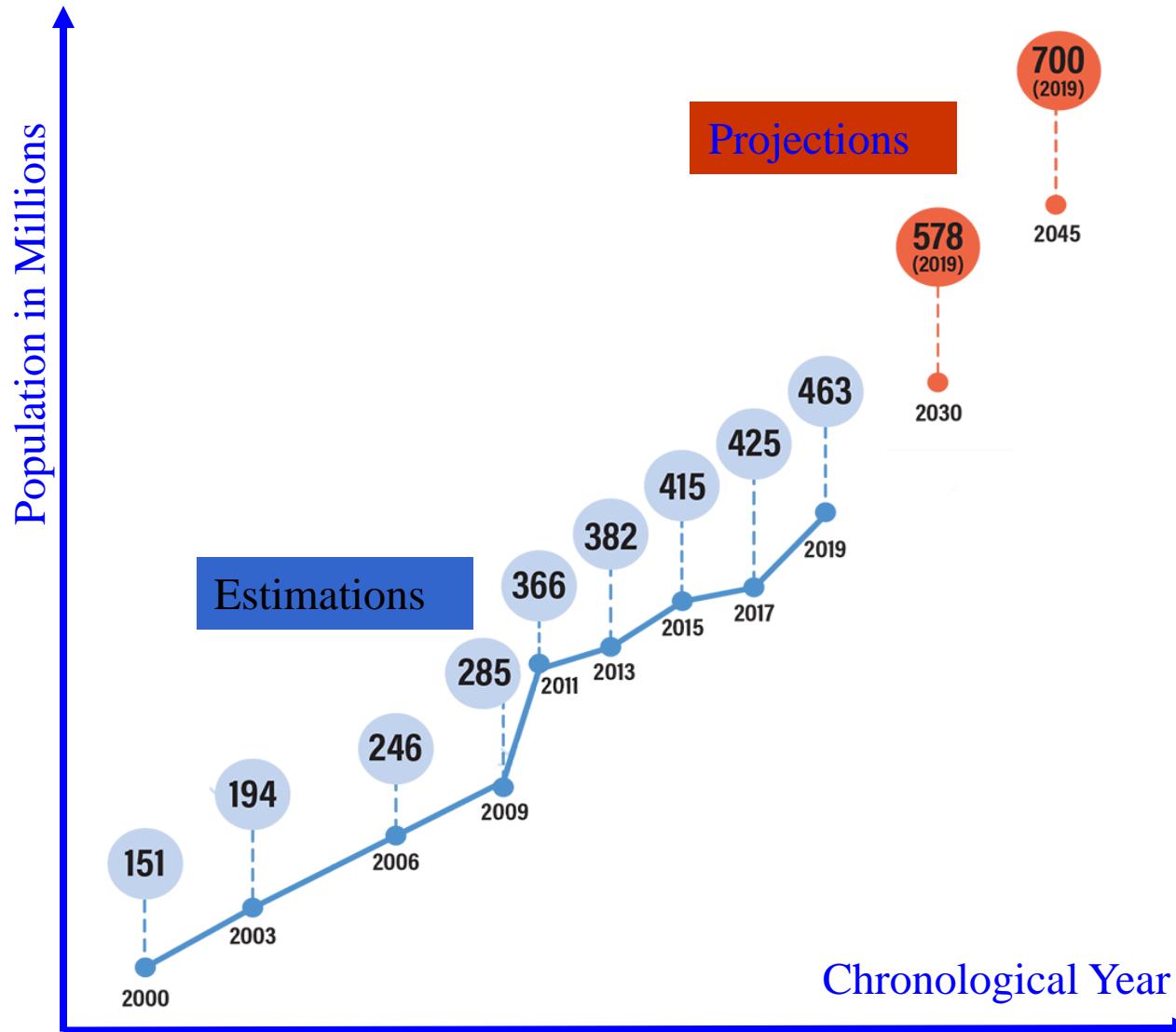
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "An IoT-based Drug Delivery System for Refractory Epilepsy", in *Proceedings of the 37th IEEE International Conference on Consumer Electronics (ICCE)*, 2019.

Piezoelectric: Latency – 1.8 Sec, Power – 29 mW, Flow Rate – 3 mL/min
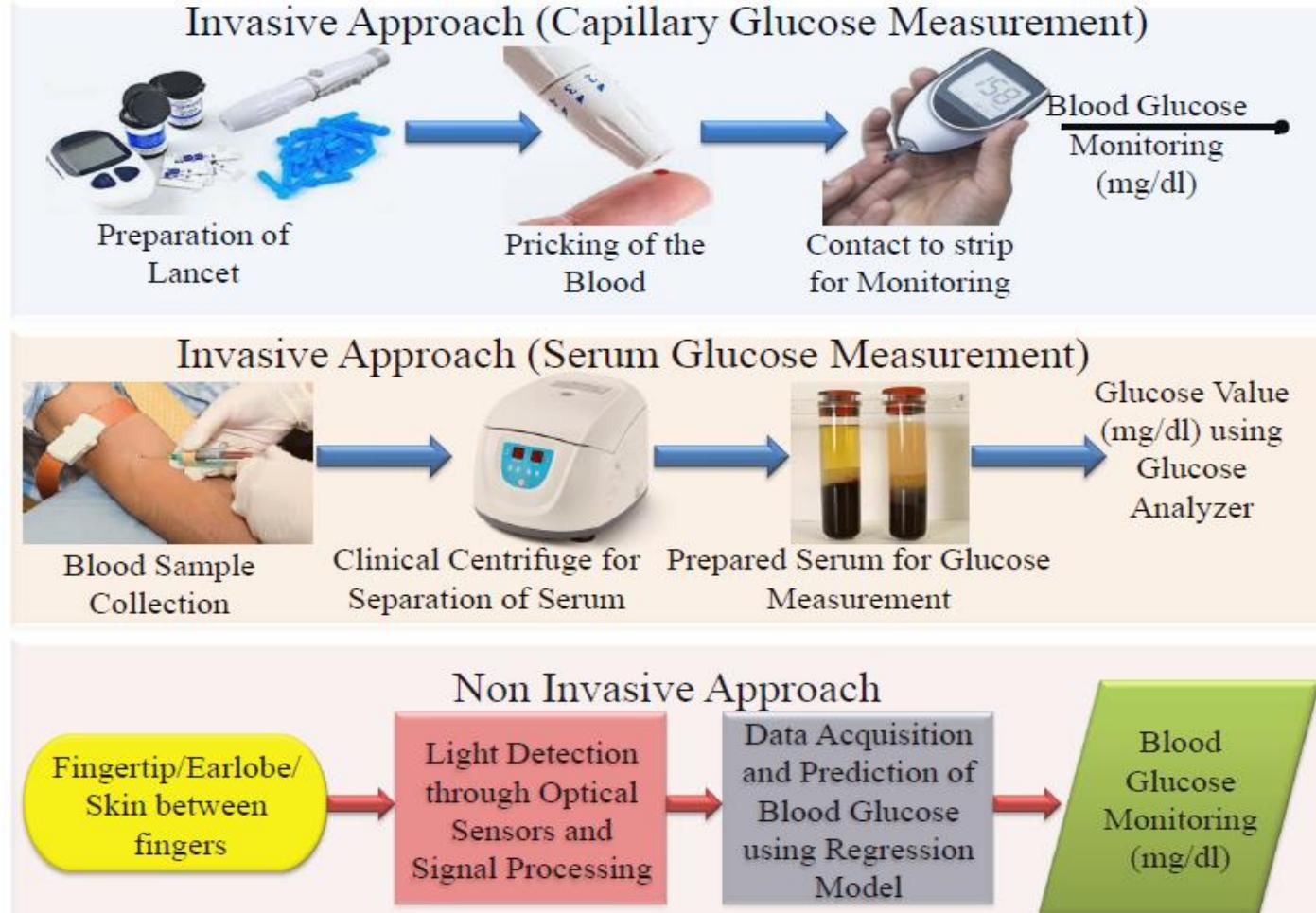
Source: M. A. Sayeed, S. P. Mohanty, E. Kougianos, and H. Zaveri, "iDDS: An Edge-Device in IoMT for Automatic Seizure Control using On-Time Drug Delivery", in *Proceedings of the 38th IEEE International Conference on Consumer Electronics (ICCE),* 2020.

Diabetes is a Global Crisis

Blood Glucose Monitoring – Invasive Vs Noninvasive

Invasive Approach (Capillary Glucose Measurement)

Preparation of Lancet → Pricking of the Blood → Contact to strip for Monitoring → Blood Glucose Monitoring (mg/dl)

Invasive Approach (Serum Glucose Measurement)

Blood Sample Collection → Clinical Centrifuge for Separation of Serum → Prepared Serum for Glucose Measurement → Glucose Value (mg/dl) using Glucose Analyzer

Non Invasive Approach

Fingertip/Earlobe/Skin between fingers → Light Detection through Optical Sensors and Signal Processing → Data Acquisition and Prediction of Blood Glucose using Regression Model → Blood Glucose Monitoring (mg/dl)

Traditional – Finger Pricking
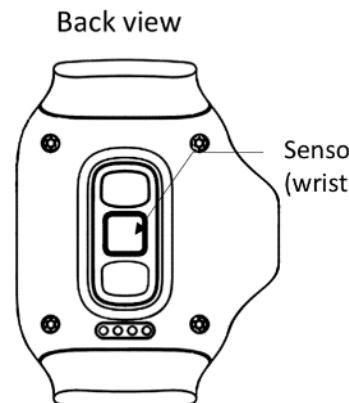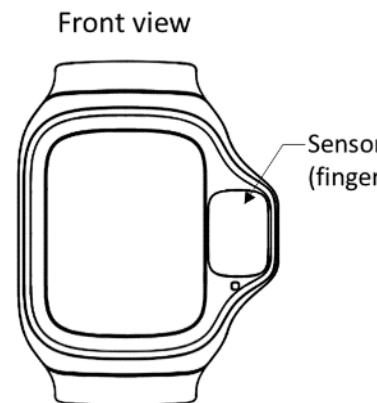
Invasive Approach – Processing Blood/Serum

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.
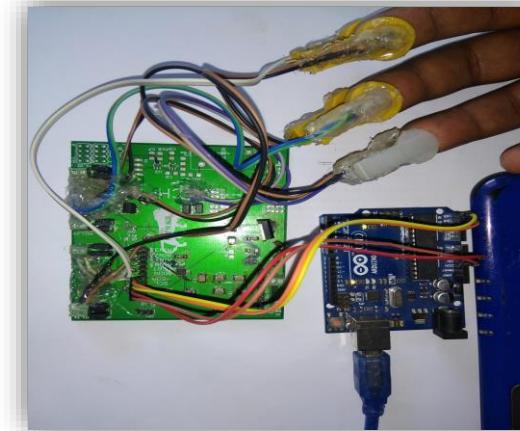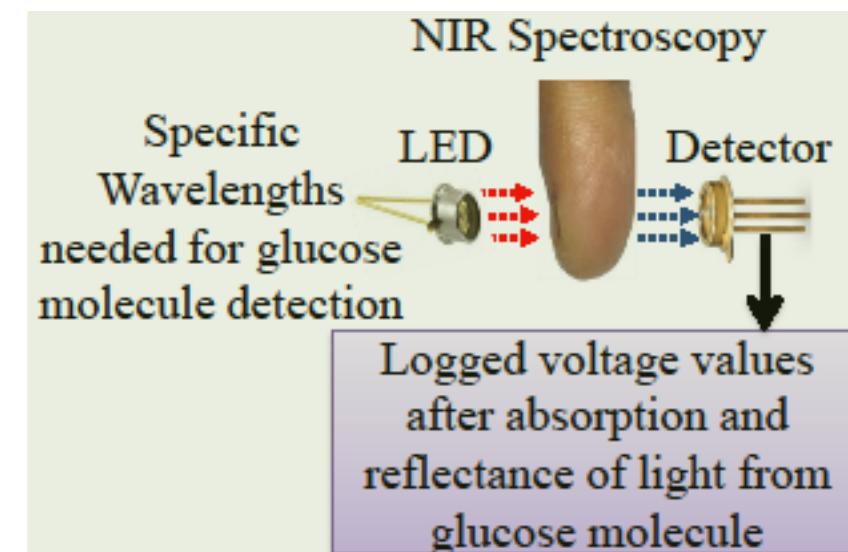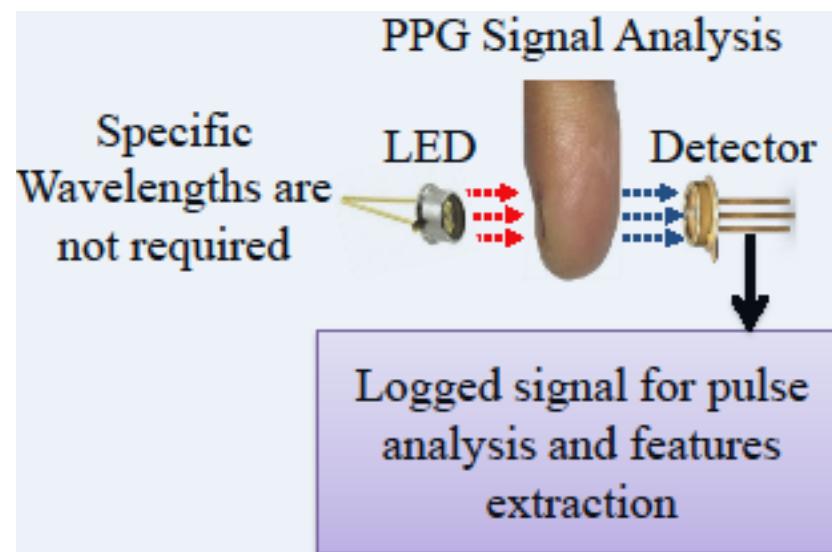
Noninvasive Glucose-Level Monitoring
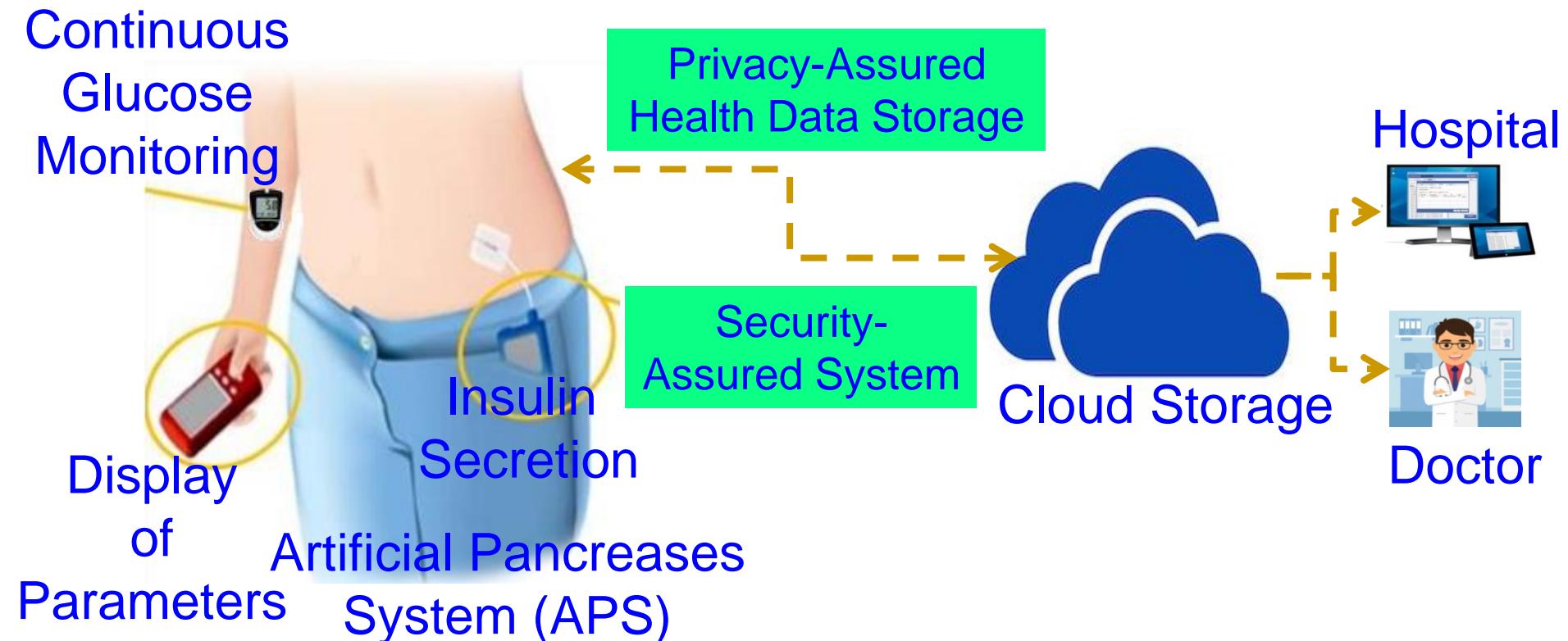
Photoplethysmogram (PPG)

Near Infrared (NIR)

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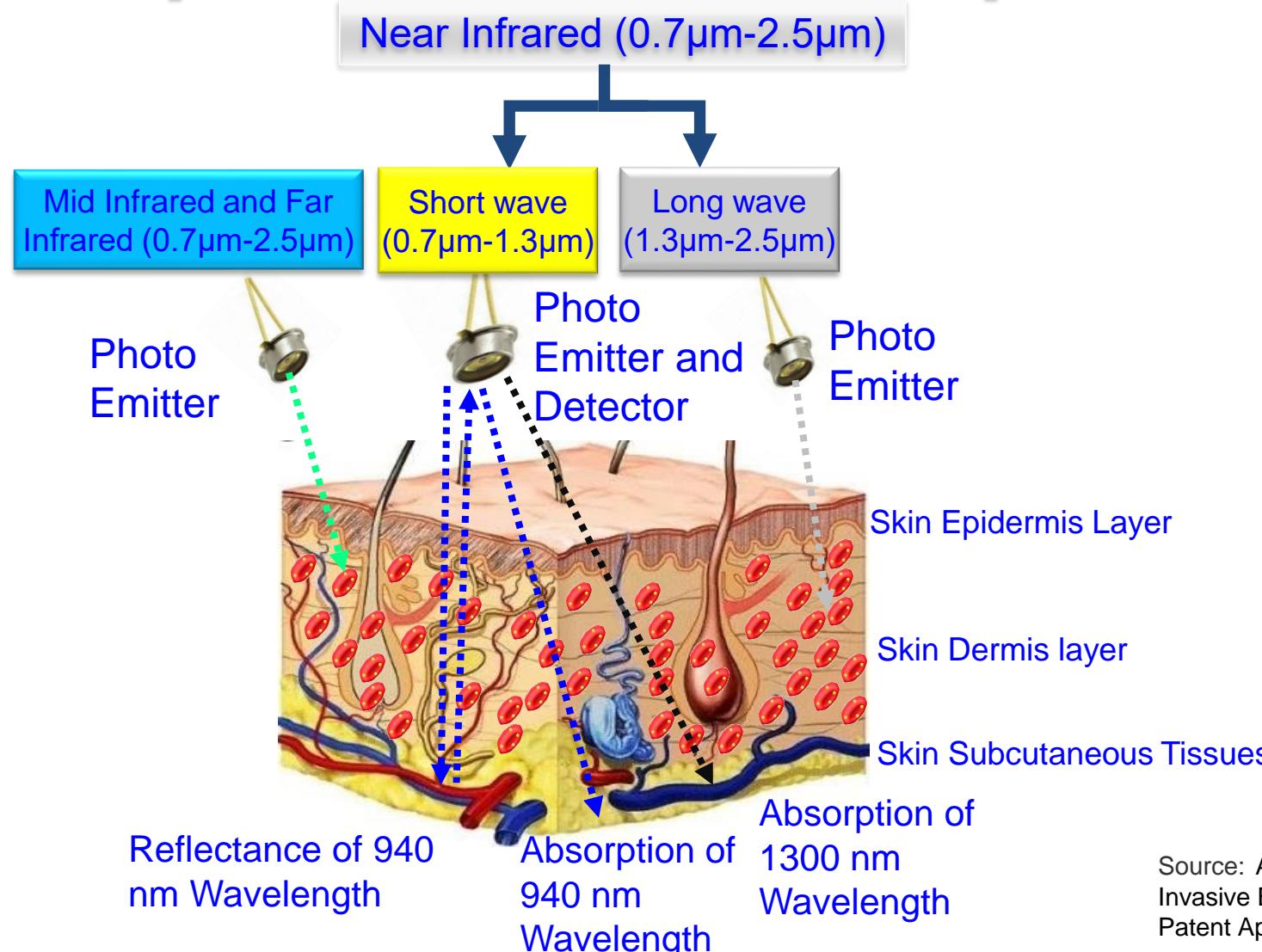
Automatic Glucose Monitoring and Control - Our Vision - iGLU (Intelligent Noninvasive)

Continuous Glucose Monitoring

Display of Parameters

Insulin Secretion

Artificial Pancreases System (APS)

Privacy-Assured Health Data Storage

Security-Assured System

Cloud Storage

Hospital

Doctor

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
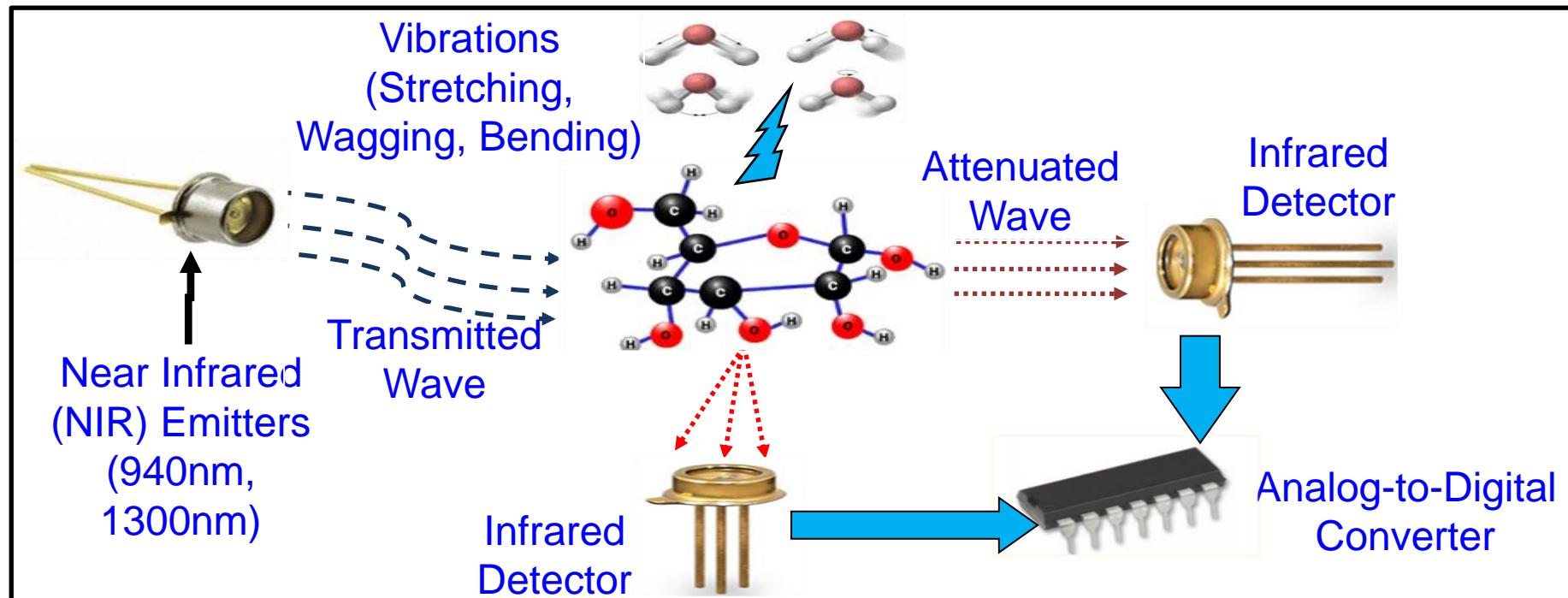
Unique Near Infrared Spectroscopy for iGLU

Near Infrared (0.7μm-2.5μm)

| Mid Infrared and Far Infrared (0.7μm-2.5μm) | Short wave (0.7μm-1.3μm) | Long wave (1.3μm-2.5μm) |

Photo Emitter

Photo Emitter and Detector

Photo Emitter

Skin Epidermis Layer

Skin Dermis layer

Skin Subcutaneous Tissues

Reflectance of 940 nm Wavelength

Absorption of 940 nm Wavelength

Absorption of 1300 nm Wavelength

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.

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Smart Electronic Systems Laboratory (SESL)

UNT EST. 1890 DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING College of Engineering

iGLU 1.0: Capillary Glucose

Vibrations (Stretching, Wagging, Bending)

Transmitted Wave

Near Infrared (NIR) Emitters (940nm, 1300nm)

Attenuated Wave

Infrared Detector

Infrared Detector

Analog-to-Digital Converter
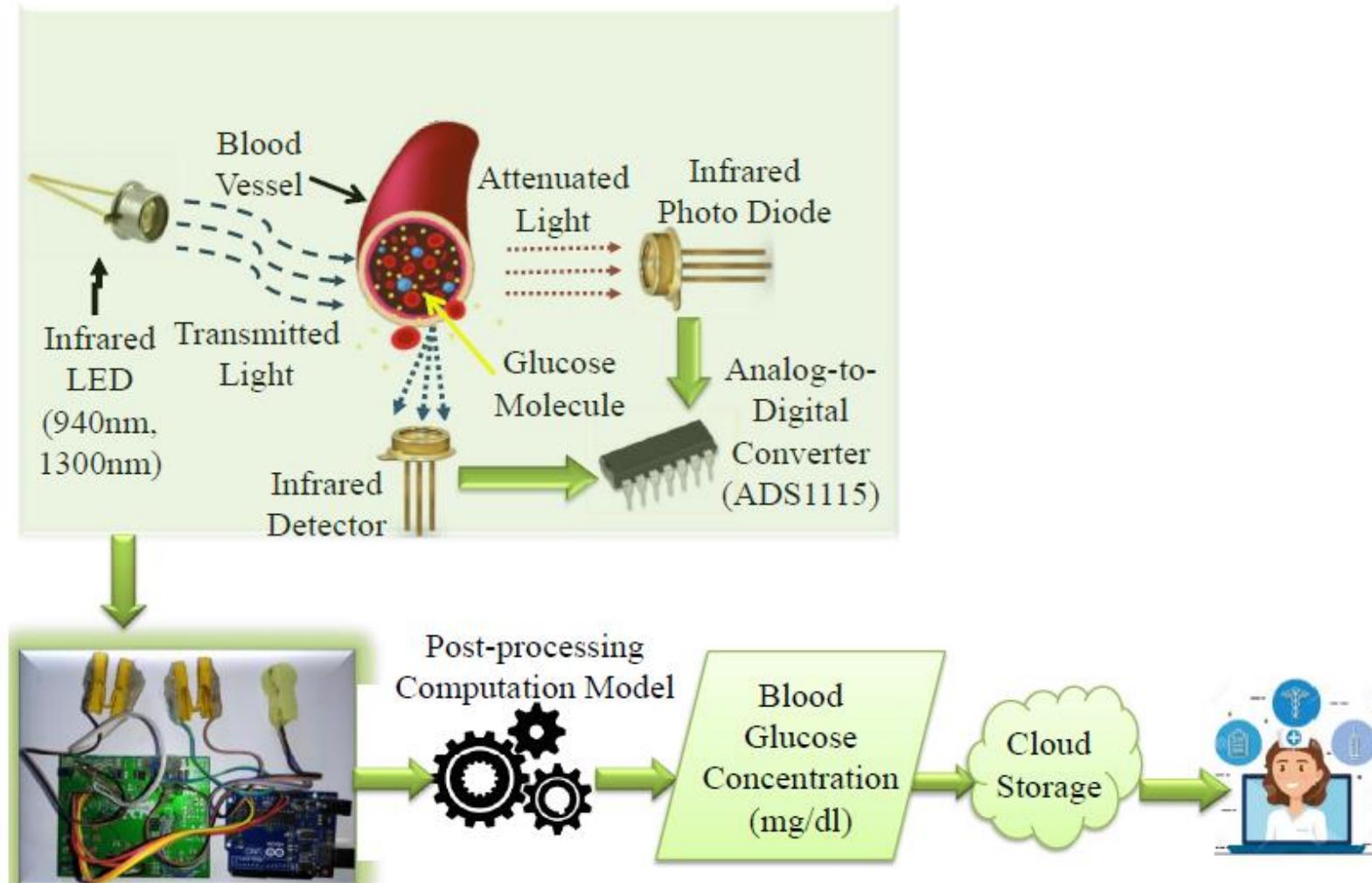
Clinically tested in an hospital.

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.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
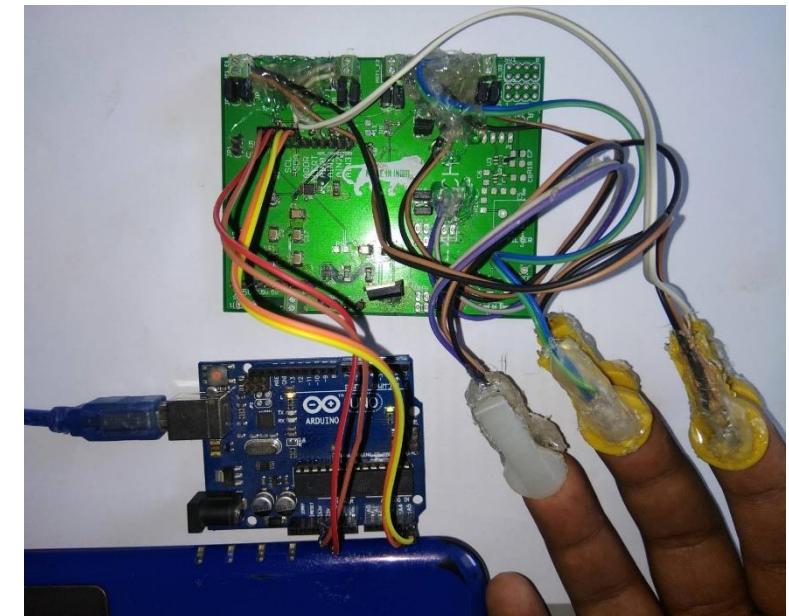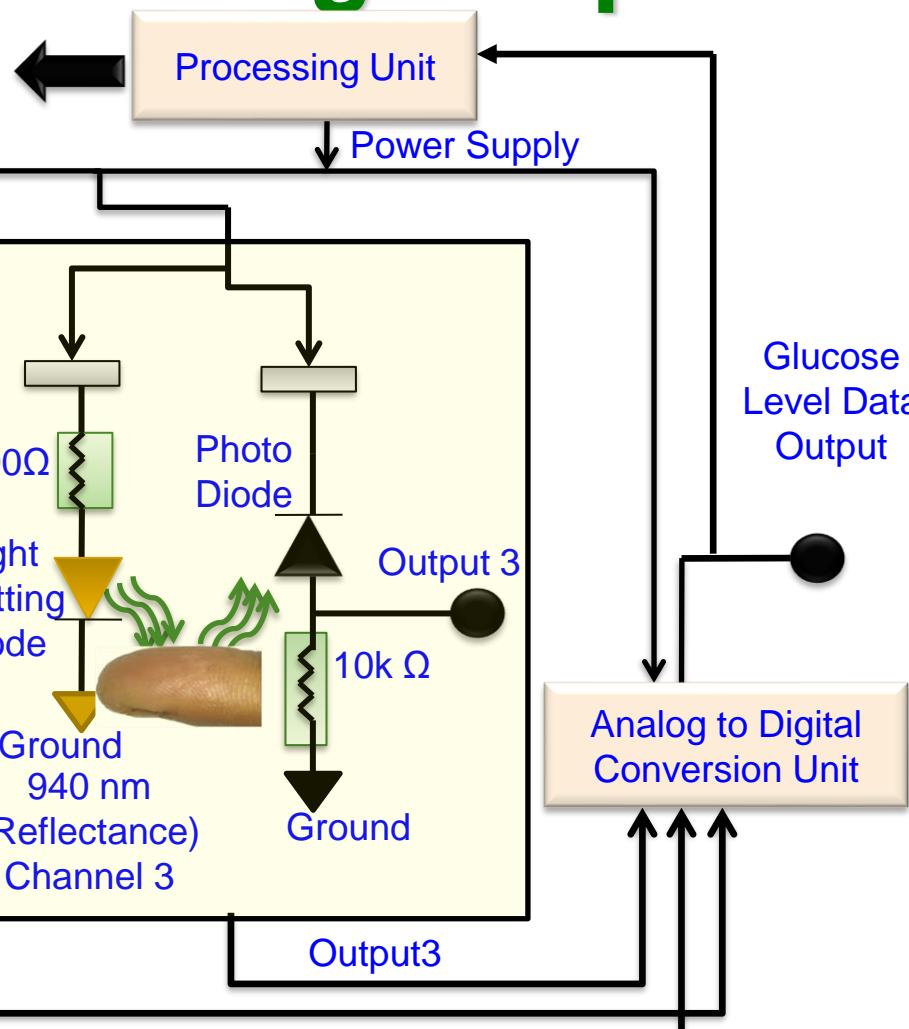
iGLU 2.0: Serum Glucose

Source A. M. Joshi, P. Jain, S. P. Mohanty, and N. Agrawal, "iGLU 2.0: A New Wearable for Accurate Non-Invasive Continuous Serum Glucose Measurement in IoMT Framework", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 66, No. 4, Nov 2020, pp. 327--335.

iGLU – Design Implementation

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

Elderly Fall Automatic Detection is Needed to Improve Quality of Life

➢ Elderly Fall: Approximately a third of elderly people 65 years or older fall each year.

➢ Fall Caused → Over 800,000 hospital admissions, 2.8 million injuries and 27,000 deaths have occurred in the last few years.

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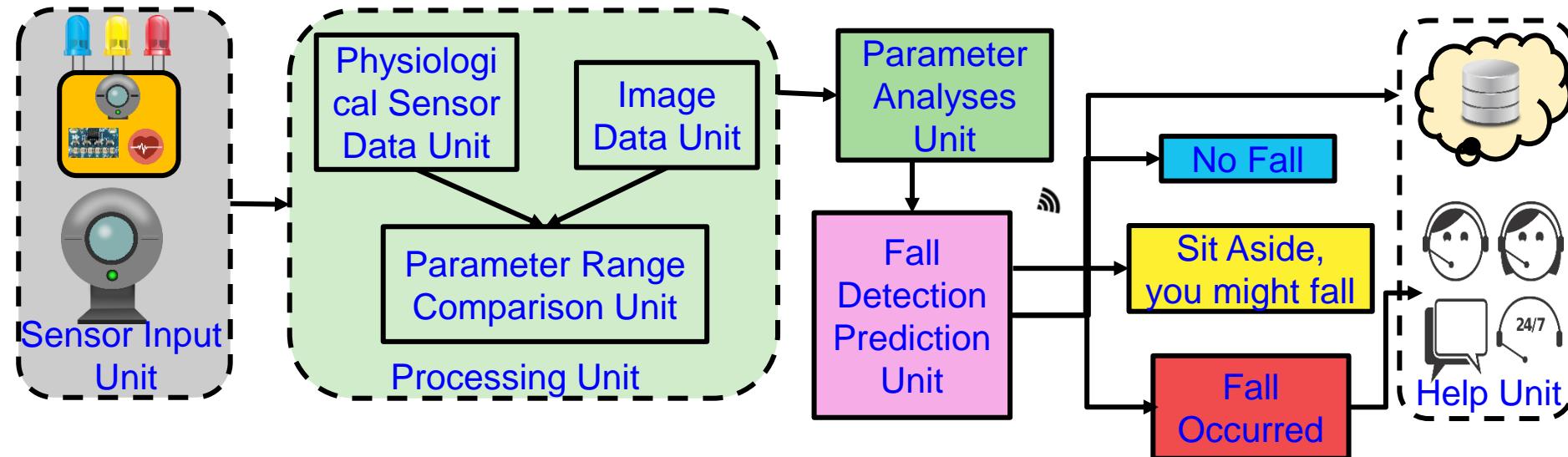
Consumer Electronics for Fall Detection

Wearables	Drawbacks
	Apple watch: uses only accelerometers, doesn't work on low thresholds like double carpet, bathroom, hardwood floors. The user must manually select the option SOS and as a reason it fails if the person is unconscious. Users may remain on the floor with no help for large hours.
	Philips Lifeline: Uses only accelerometers and barometric sensors for pressure changes. After the fall, the system waits for 30 sec and directly connects to help.
	Lively Mobile by greatcall and Sense4Care Angel4: Monitors fluctuations using only accelerometers.
	Bay Alarm Medical and Medical Guardian: Use only accelerometers. Have huge base stations limiting the usage and location access.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

Issues of Existing Research
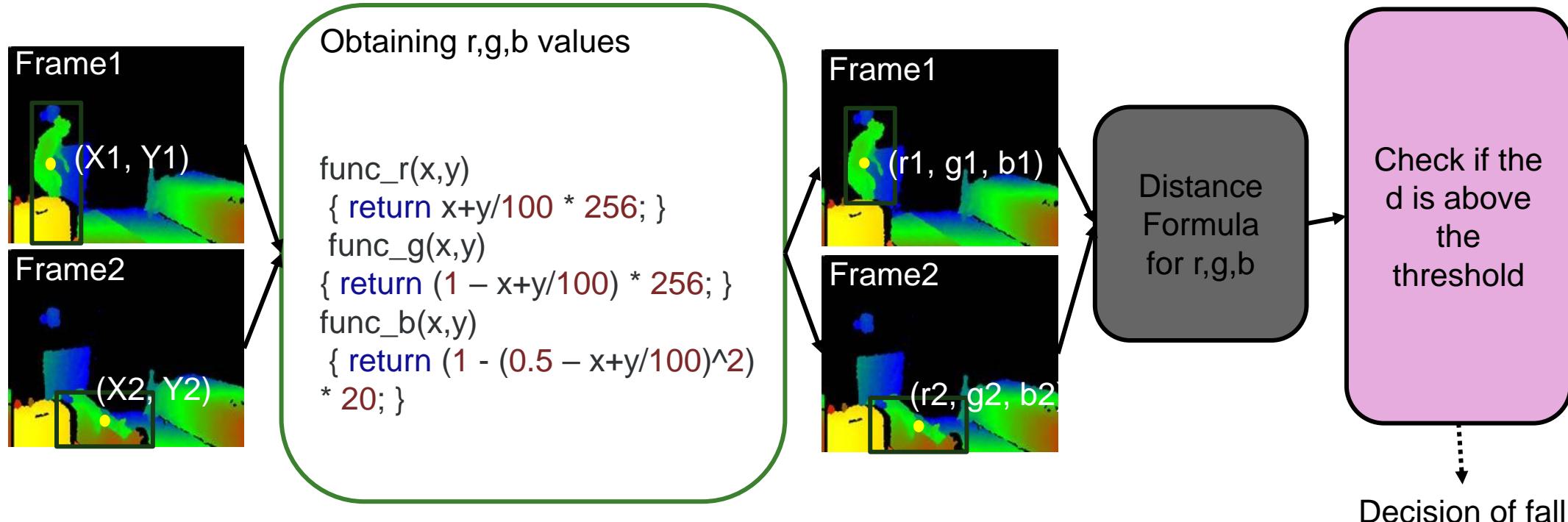
- Decisions of fall are dependent on the changes in accelerometer axes only.

- Some applications have user to give response after the fall and that can be time consuming as the user might not be conscious.

- Some applications are limited to a certain location and certain type of surroundings which add up the additional costs.

- Prediction of fall or warning the user that there might be an occurrence of fall is not provided by most of the applications.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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

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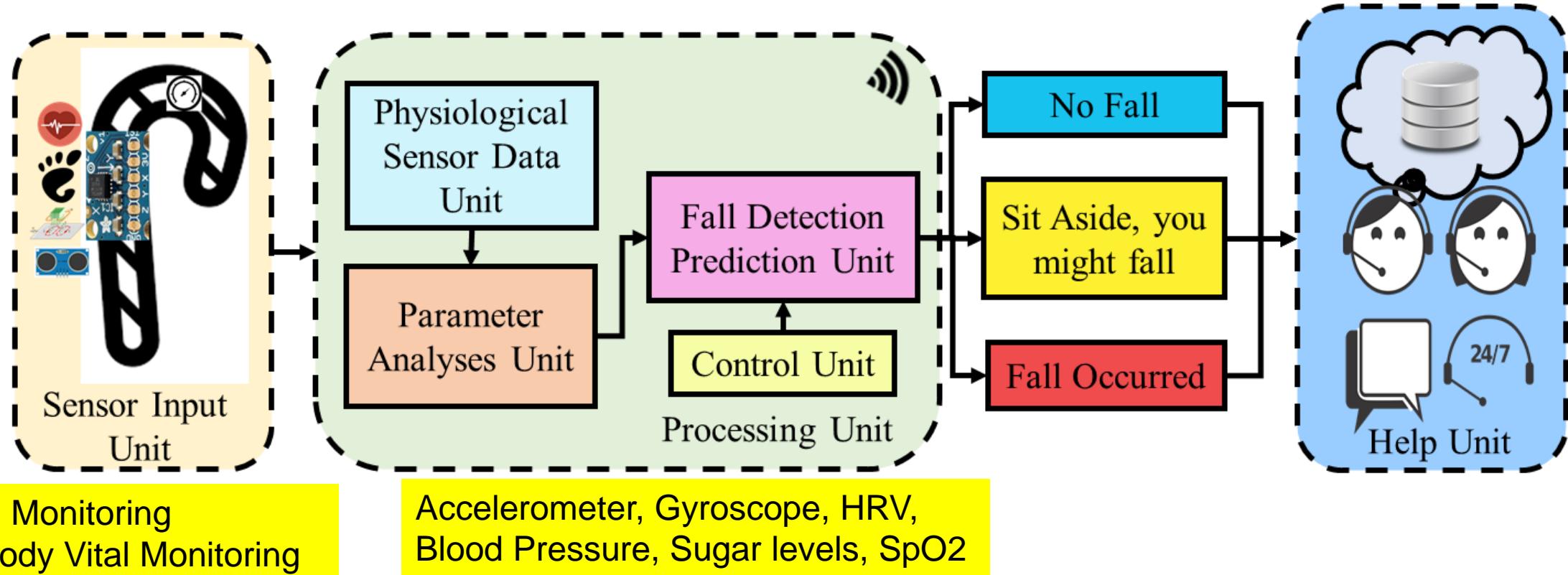
Good-Eye: Elderly Fall Detection

Frame1
(X1, Y1)

Frame2
(X2, Y2)

Obtaining r,g,b values

func_r(x,y)
 { return x+y/100 * 256; }
 func_g(x,y)
{ return (1 − x+y/100) * 256; }
func_b(x,y)
 { return (1 - (0.5 − x+y/100)^2)
* 20; }

Frame1
(r1, g1, b1)

Frame2
(r2, g2, b2)

Distance Formula for r,g,b

Check if the d is above the threshold

Decision of fall

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

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

# cStick: A Calm Stick for Fall Prediction, Detection and Control
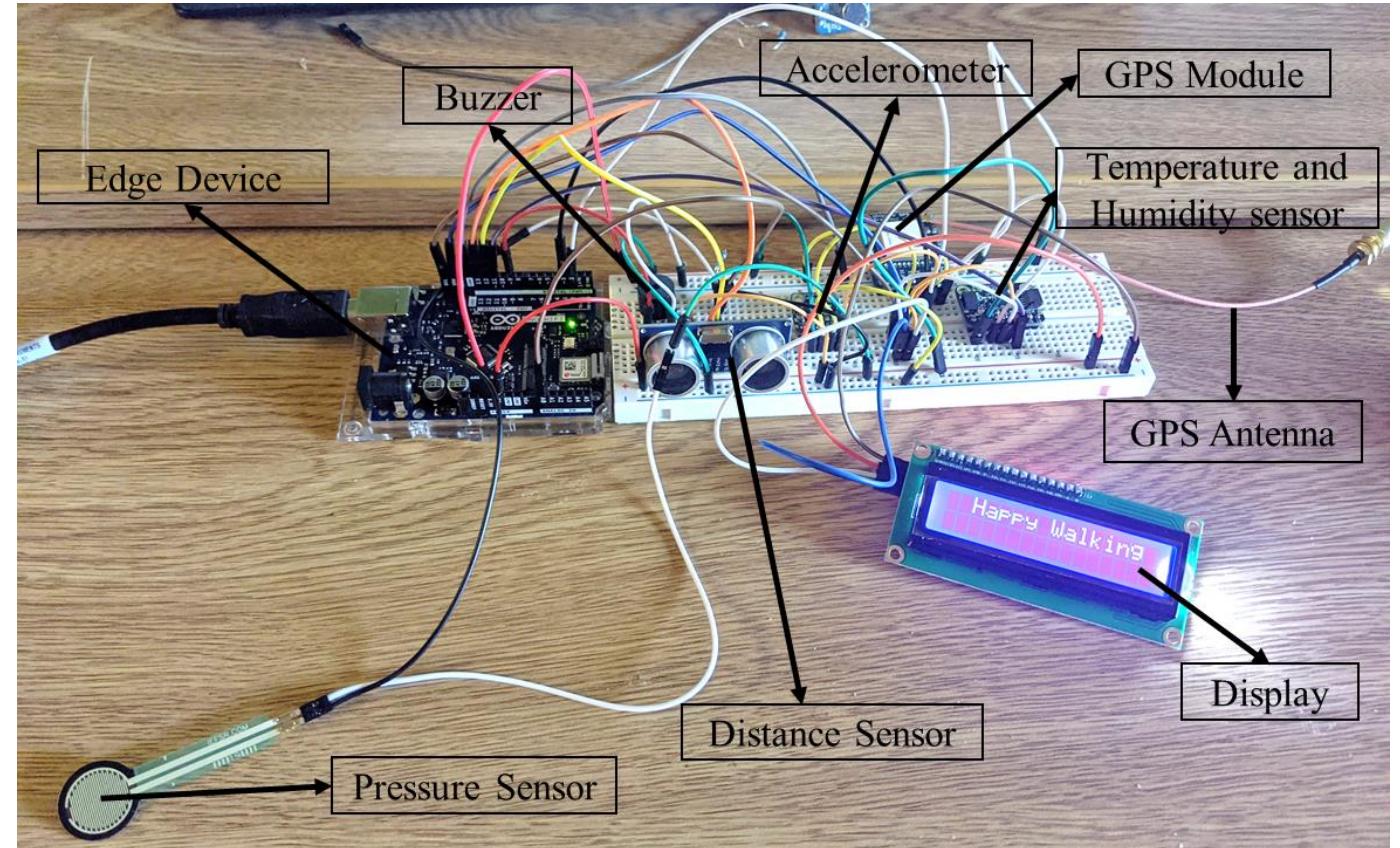
Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "cStick: A Calm Stick for Fall Prediction, Detection and Control in the IoMT Framework", in *Proceedings of the 4th IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2021.

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cStick - Prototyping
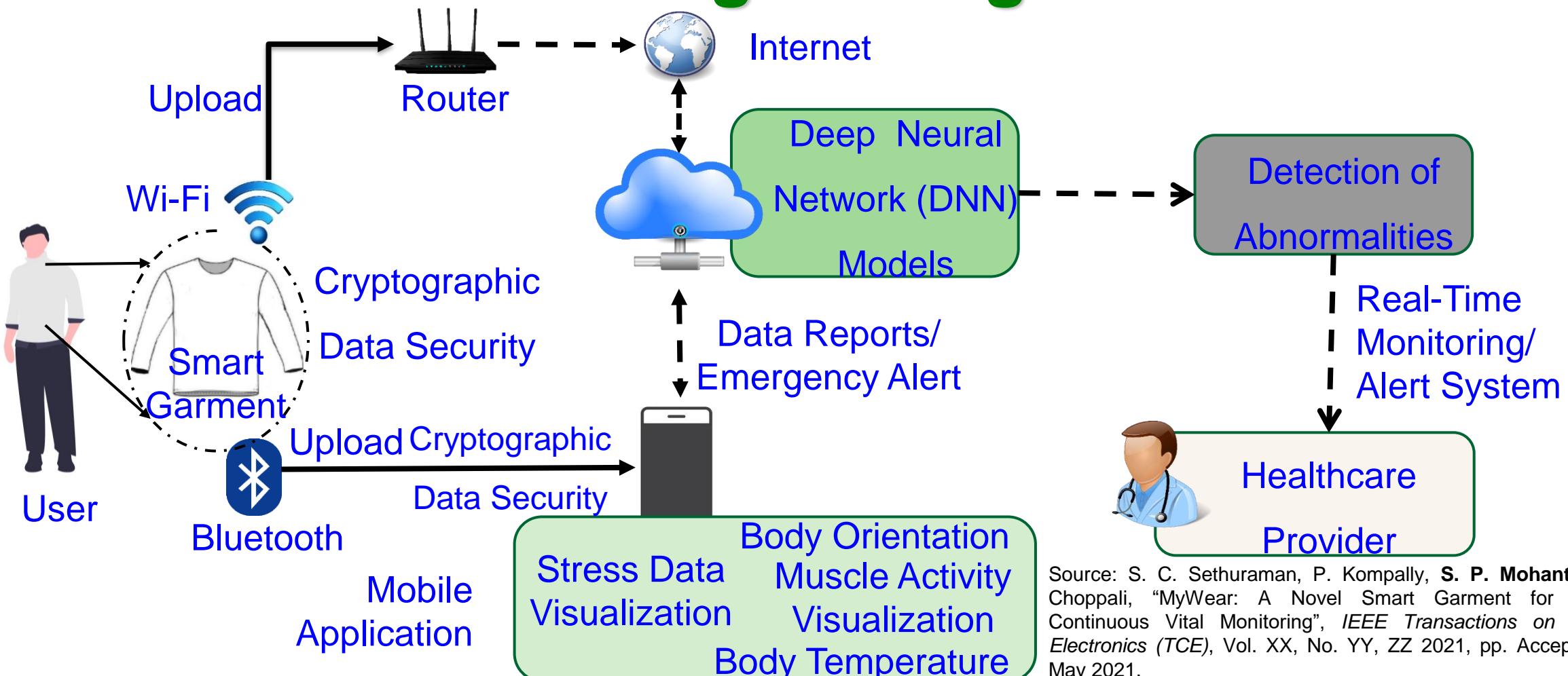
- For the IoMT-Edge computing, a controller has been chosen with real time sensor data from various sensors which monitor the required parameters.

cStick: Fall detection and prediction Accuracy – 96.7%.
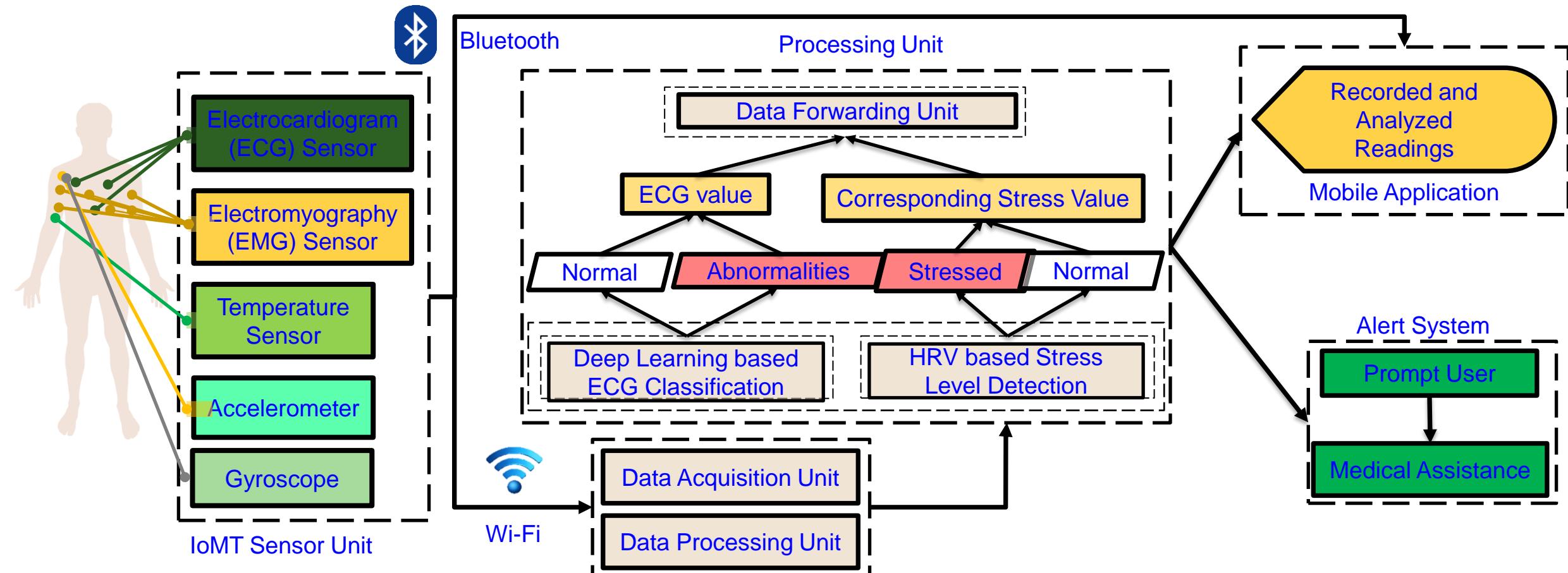
Source: L. Rachakonda, S. P. Mohanty, and E. Kougianos, "cStick: A Calm Stick for Fall Prediction, Detection and Control in the IoMT Framework", in *Proceedings of the 4th IFIP International Internet of Things (IoT) Conference (IFIP-IoT)*, 2021.

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

Internet

Upload   Router

Wi-Fi

Cryptographic

Data Security

Deep Neural Network (DNN) Models

Detection of Abnormalities

Smart Garment

Real-Time Monitoring/ Alert System

User

Upload Cryptographic

Data Reports/ Emergency Alert

Bluetooth

Data Security

Healthcare Provider

Mobile Application

Stress Data Visualization

Body Orientation

Muscle Activity Visualization

Body Temperature

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 Electronic Systems Laboratory (SESL)

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

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
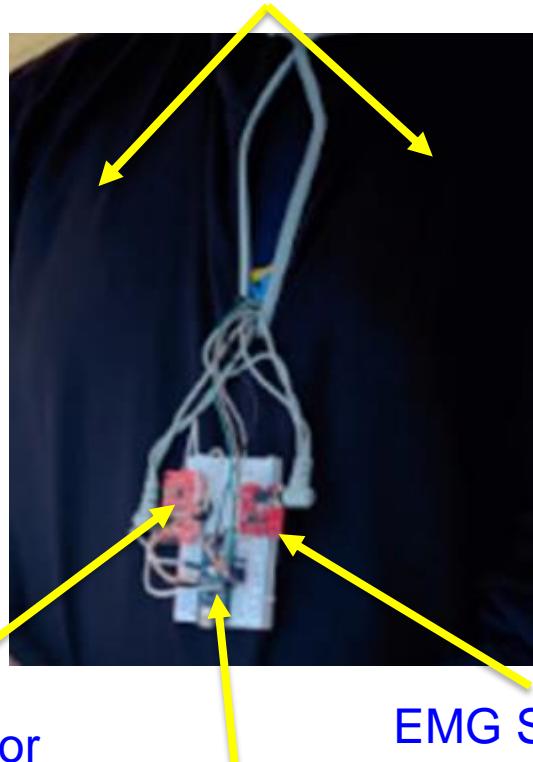
MyWear – A Smart Wear for Continuous Body Vital Monitoring – using ECG & EMG

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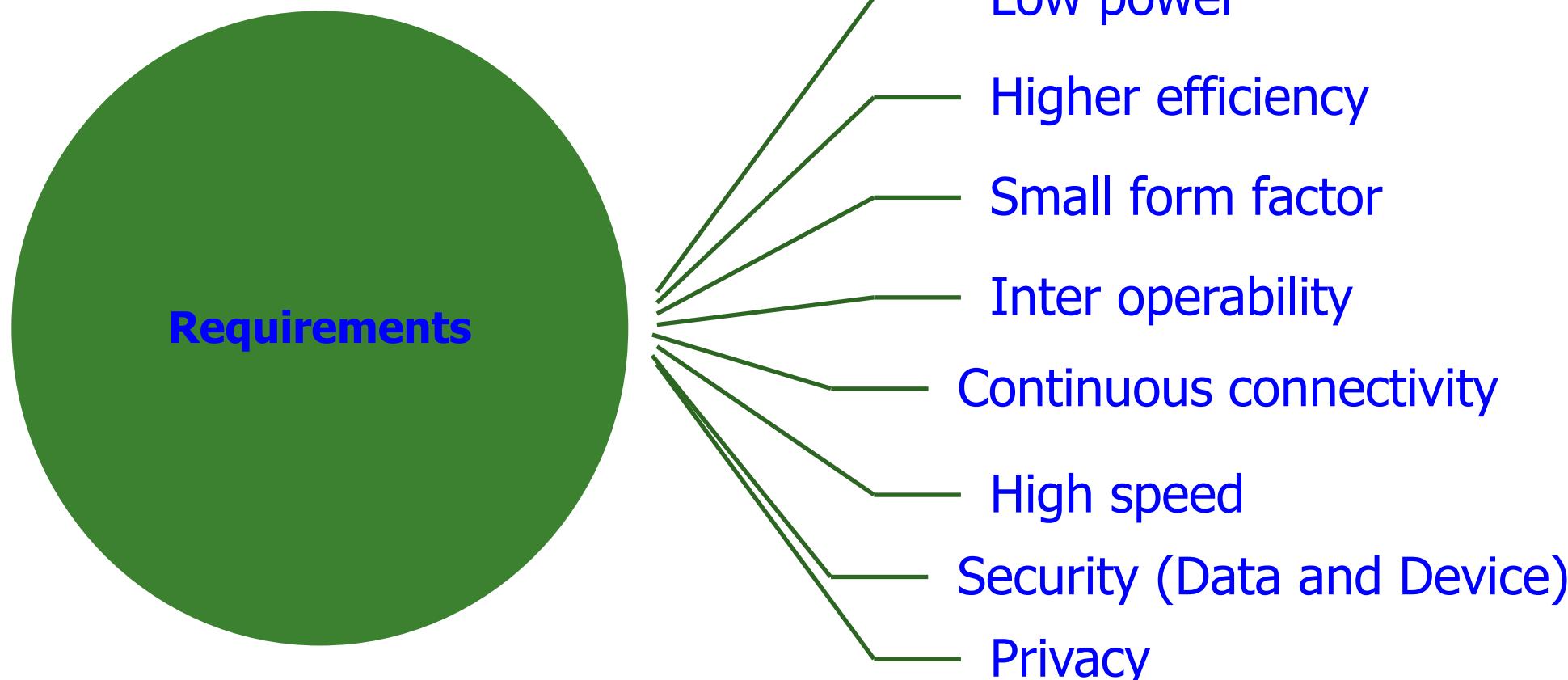
Source: S. C. Sethuraman, P. Kompally, **S. P. Mohanty**, and U. Choppali, "MyWear: A Novel Smart Garment for Automatic Continuous Vital Monitoring", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. XX, No. YY, ZZ 2021, pp. Accepted on 30 May 2021.

Smart Healthcare – Some Challenges

Smart Healthcare Architecture – Requirements

Requirements

- Low power
- Higher efficiency
- Small form factor
- Inter operability
- Continuous connectivity
- High speed
- Security (Data and Device)
- Privacy

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

Smart Healthcare – Data Quality

Validity

Integrity

Reliability

Relevance

Data Quality

Objectivity

Completeness

Generalizability

Utility

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 -- Prof./Dr. Saraju P. Mohanty

Machine Learning Challenges
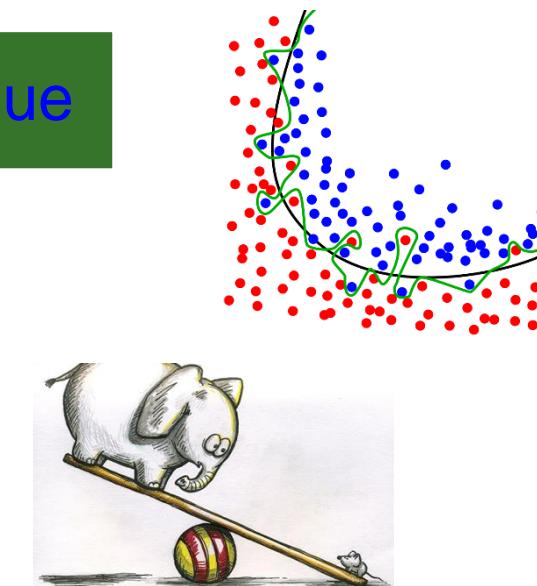
Machine Learning Issues

- 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 -- Prof./Dr. Saraju P. Mohanty
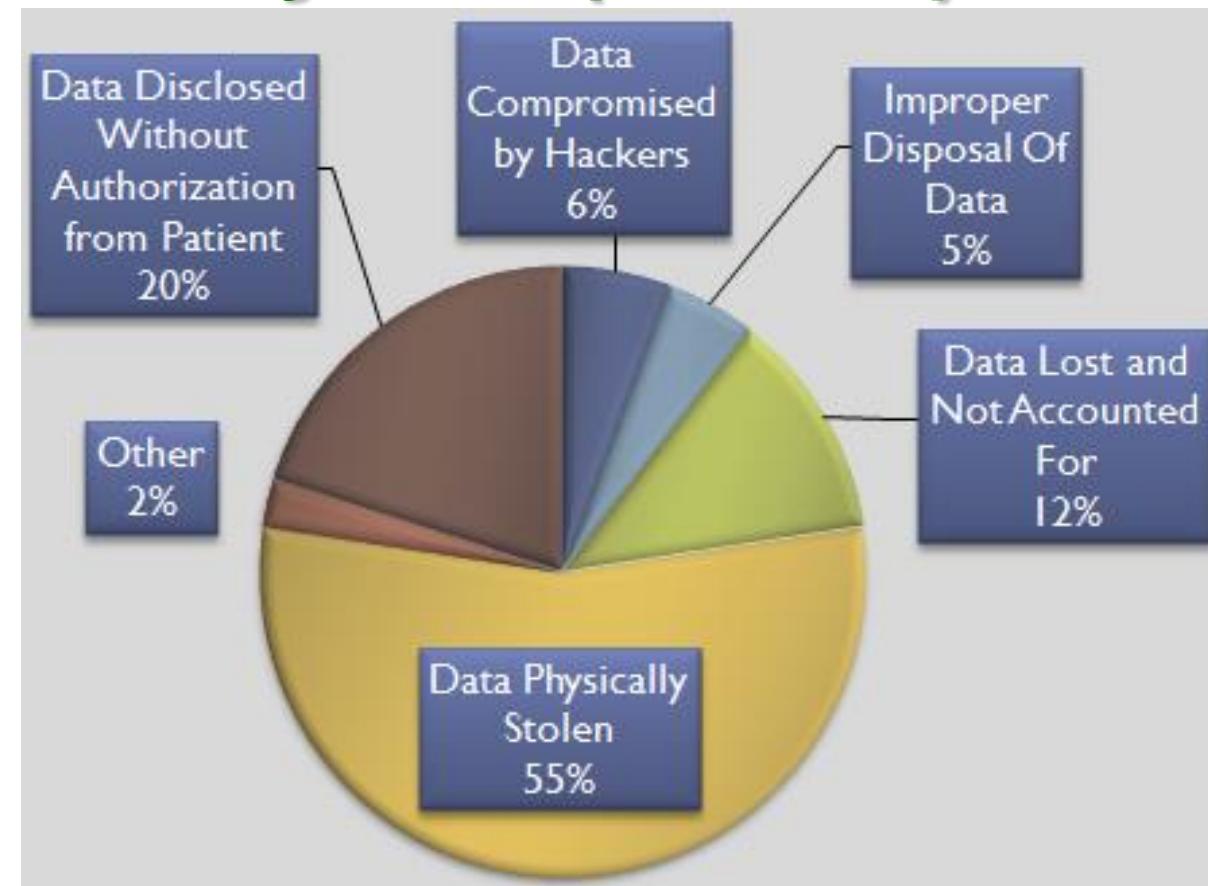
Smart Healthcare - Security Challenges

Selected Smart Healthcare Security/Privacy Challenges

- Data Eavesdropping
- Data Confidentiality
- Data Privacy
- Location Privacy
- Identity Threats
- Access Control
- Unique Identification
- Data Integrity
- Device Security

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

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

IoMT Device Security Issue is Scary
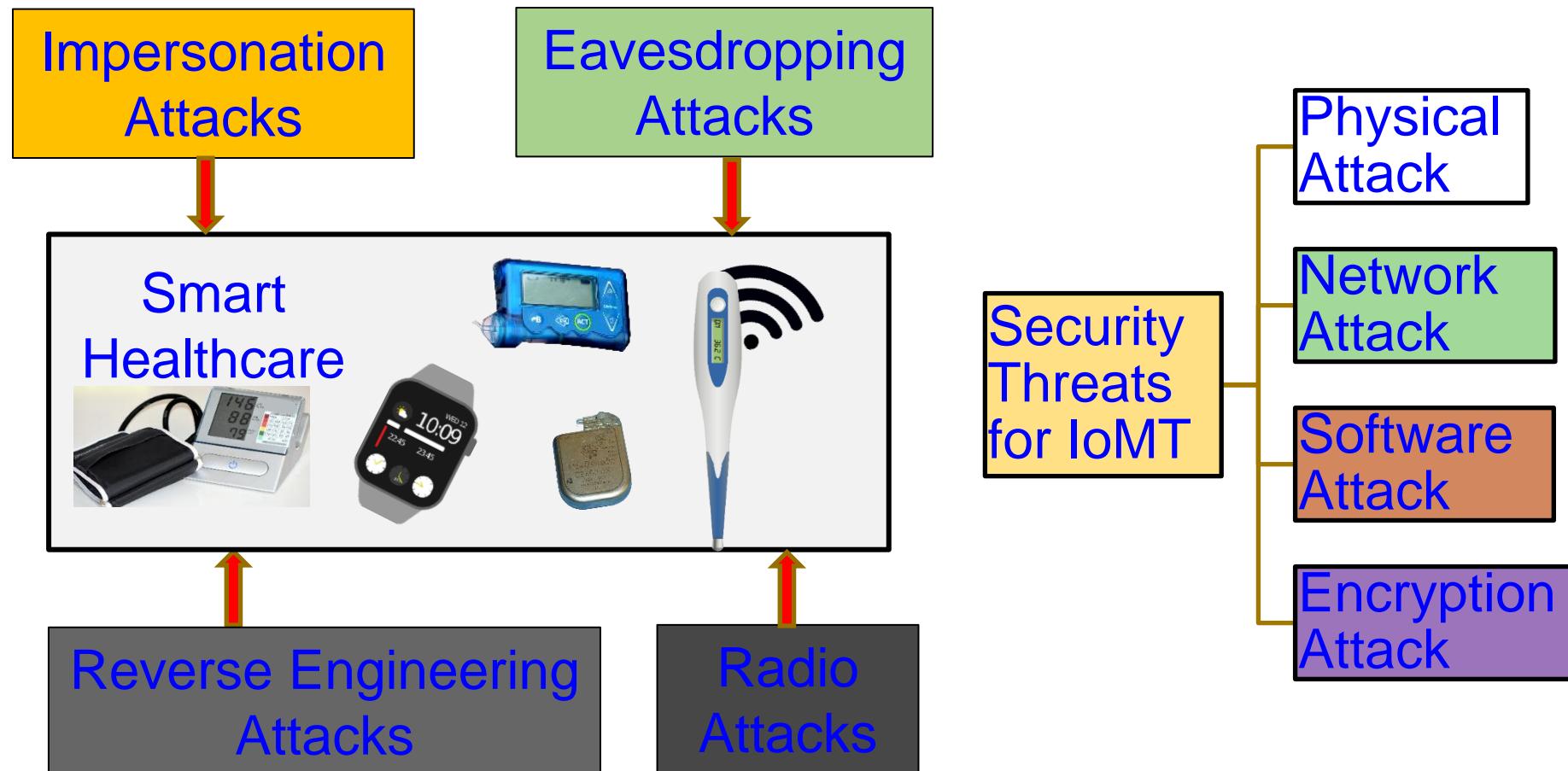
- Insulin pumps are vulnerable to hacking, FDA warns amid recall:

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

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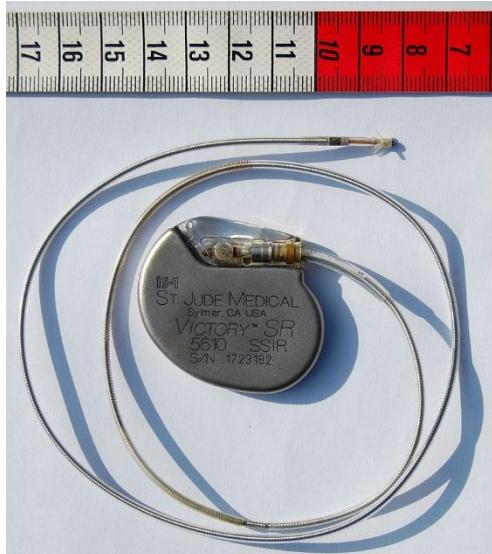
IoMT Security – Selected Attacks

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 – Energy Constrained

Pacemaker
Battery Life
- 10 years
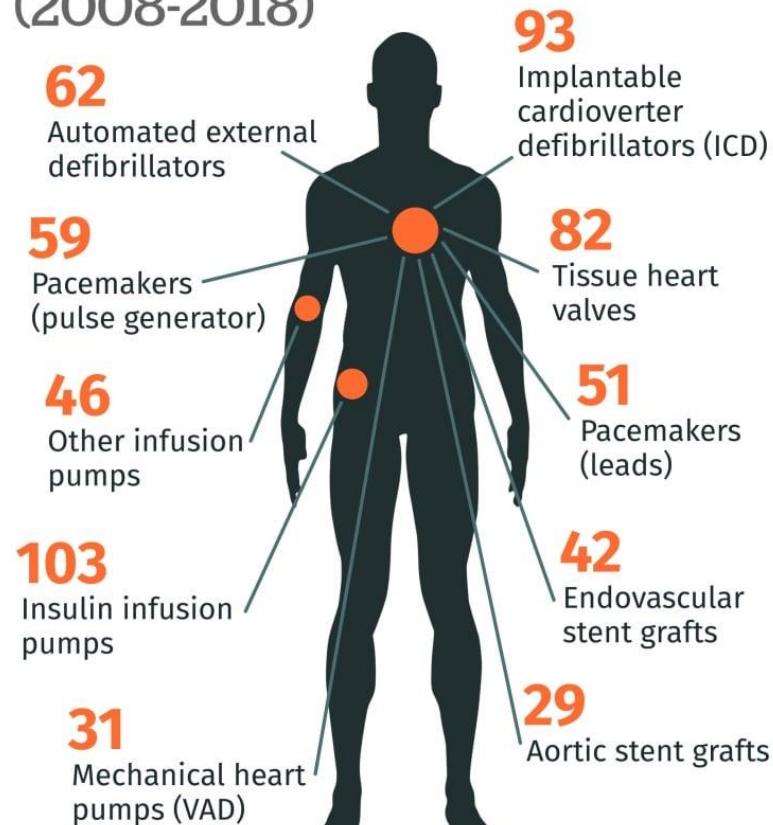
Neurostimulator
Battery Life
- 8 years

> 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

10 devices tied to the most reports involving death
(2008-2018)

62 Automated external defibrillators

59 Pacemakers (pulse generator)

46 Other infusion pumps

103 Insulin infusion pumps

31 Mechanical heart pumps (VAD)

93 Implantable cardioverter defibrillators (ICD)

82 Tissue heart valves

51 Pacemakers (leads)

42 Endovascular stent grafts

29 Aortic stent grafts

CBC NEWS

Source: Health Canada & ICIJ

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

CENTRAL ILLUSTRATION: Cardiac-Implantable Electronic Devices: Technical and Safety Considerations

FACTORS INFLUENCING SAFETY	SMALL POTENTIAL RISKS
MR magnet: • Magnet strength • Radiofrequency power • Magnet position	**Heating effects:** Tissue injury (Mainly theoretical) **Strategy to minimize risk:** Lead designed to limit current induction
Cardiac implantable device: • Ferromagnetic material • Presence of reed switch • Device programming	**Mechanical effects:** Device movement (Mainly theoretical) **Strategy to minimize risk:** Limitation of ferromagnetic materials
Leads: • Ferromagnetic material • Lead stability	**Electromagnetic effects:** • Altered sensing/capture • Inhibited therapies • Inappropriate therapies (No significant adverse patient outcomes) **Strategy to minimize risk:** Lead designed to limit current induction, replacement of reed switch with Hall sensor, temporary device reprogramming
Patient: • Patient position • Patient size	

Indication to scan: If the benefits outweigh the very small potential risks, MRI is acceptable
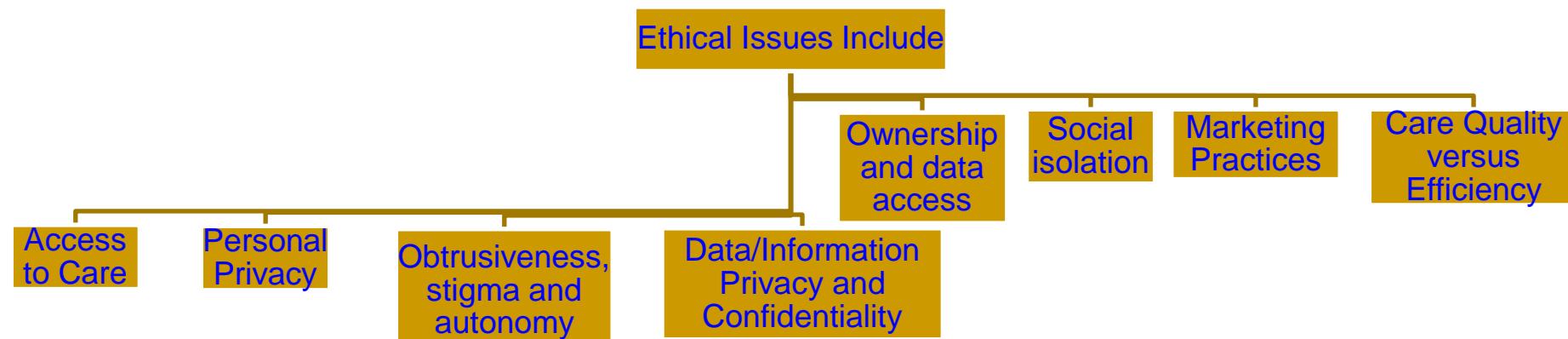
Miller, J.D. et al. J Am Coll Cardiol. 2016;68(14):1590-8.

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/

Ethical Issues Include
- Access to Care
- Personal Privacy
- Obtrusiveness, stigma and autonomy
- Data/Information Privacy and Confidentiality
- Ownership and data access
- Social isolation
- Marketing Practices
- Care Quality versus Efficiency
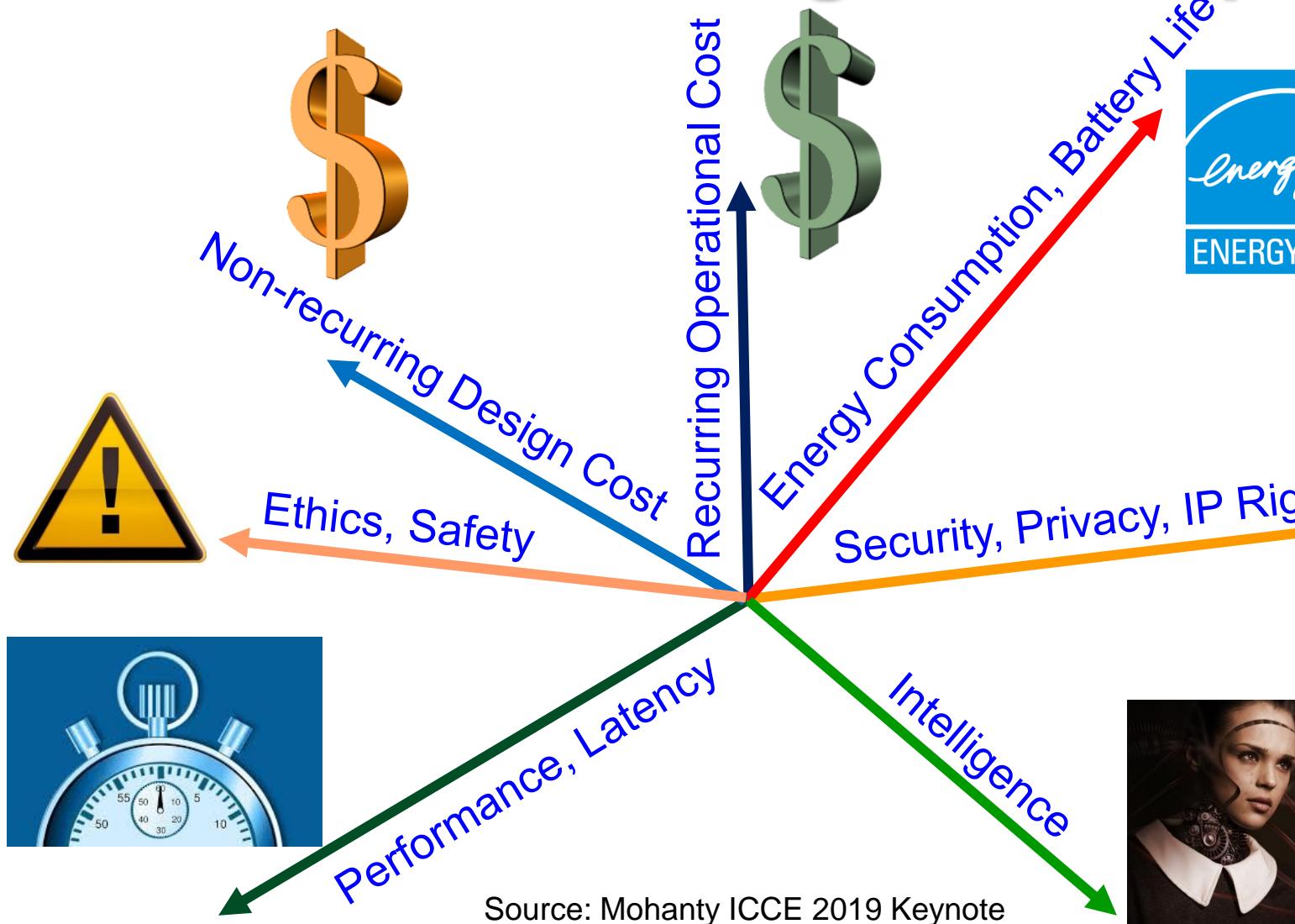
Source: B. Mittelstadt, "Ethics of the health-related internet of things: a narrative review", *Ethics Inf Technol* **19,** 157–175 (2017), DOI: https://doi.org/10.1007/s10676-017-9426-4.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

Smart Healthcare –
Some Solutions

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
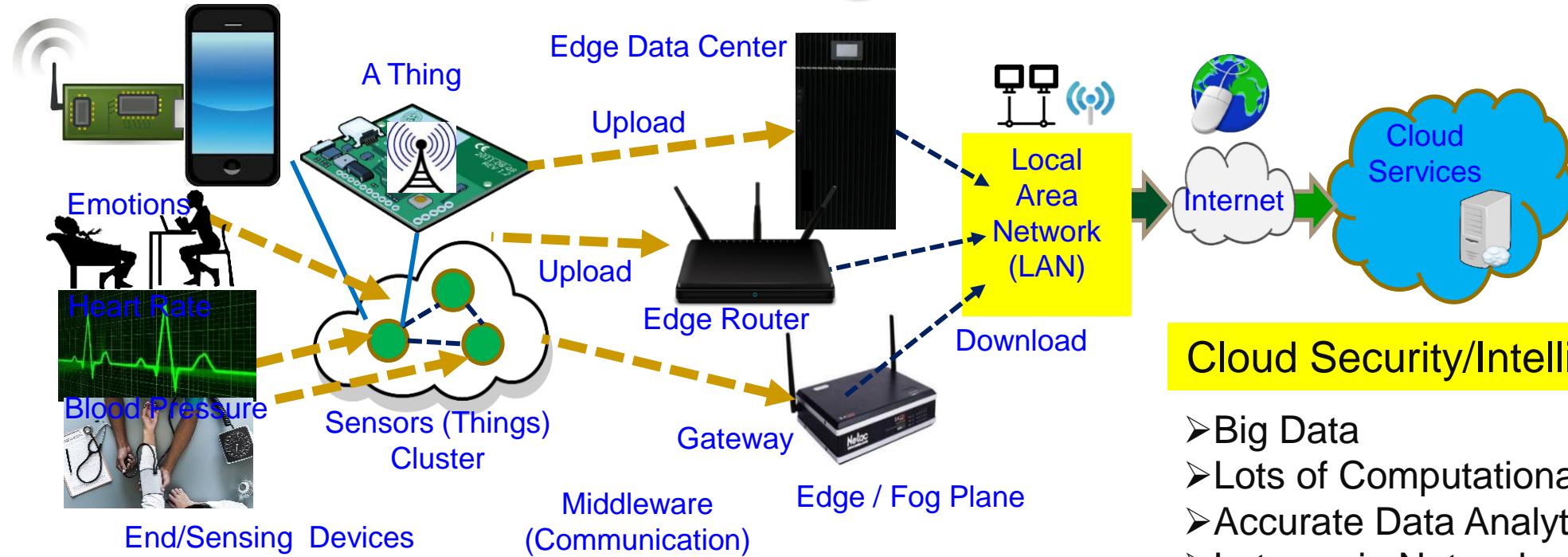
IoT/CPS Design – Multiple Objectives

Non-recurring Design Cost

Recurring Operational Cost

Energy Consumption, Battery Life

ENERGY STAR

Ethics, Safety

Security, Privacy, IP Rights

Performance, Latency

Intelligence

Smart Cities Vs Smart Villages

Source: Mohanty ICCE 2019 Keynote

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UNT

CPS – IoT-Edge Vs IoT-Cloud

A Thing

Edge Data Center

Upload

Local Area Network (LAN)

Internet

Cloud Services

Emotions

Upload

Edge Router

Download

Heart Rate

Blood Pressure

Sensors (Things) Cluster

Gateway

Edge / Fog Plane

End/Sensing Devices

Middleware (Communication)

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

Heavy-Duty ML is more suitable for smart cities

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

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Smart Electronic Systems Laboratory (SESL)
UNT EST. 1890 DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING College of Engineering
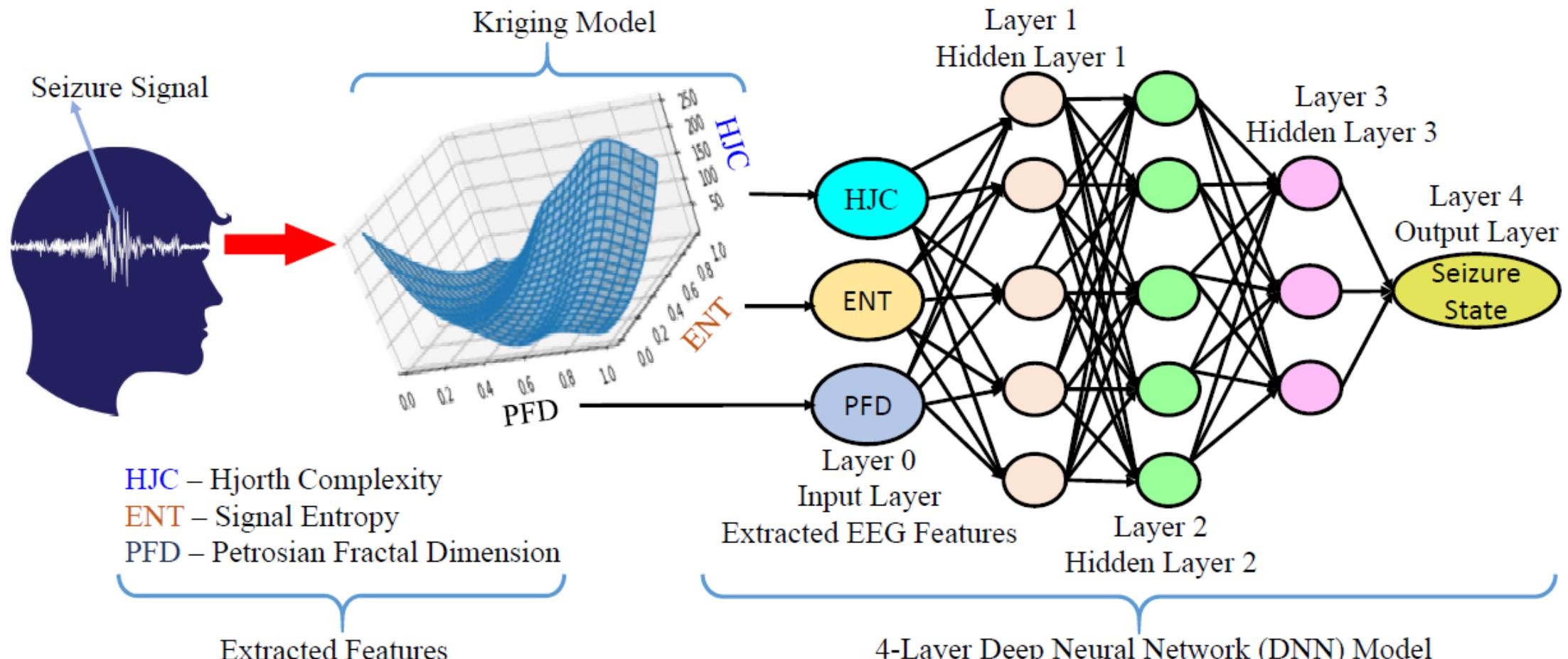
Hierarchical ML to Reduce Training Time - Bootstrapping

- A Bootstrap helps in pulling on a boot.

- It means solving a problem without external resources
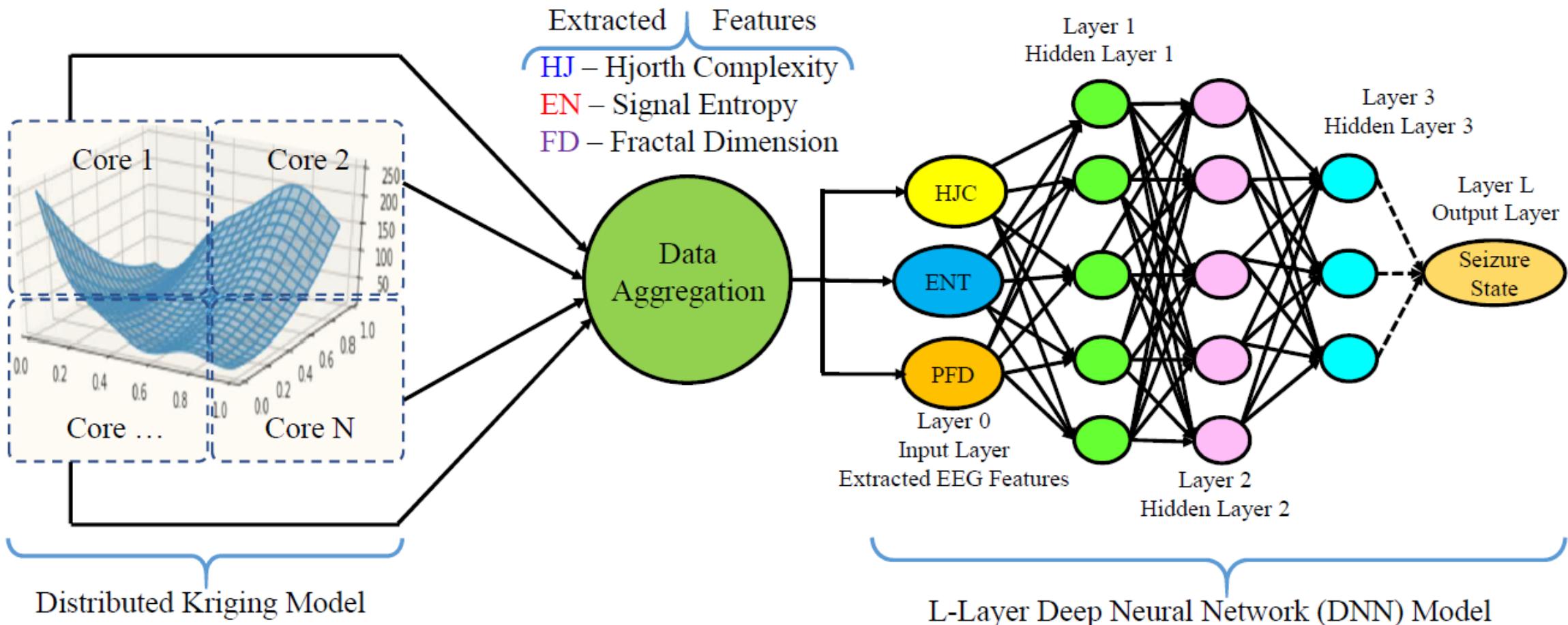
Bootstraps

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

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Smart Electronic Systems Laboratory (SESL)

UNT DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING College of Engineering

EST. 1890

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

Extracted Features
HJ – Hjorth Complexity
EN – Signal Entropy
FD – Fractal Dimension

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.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty
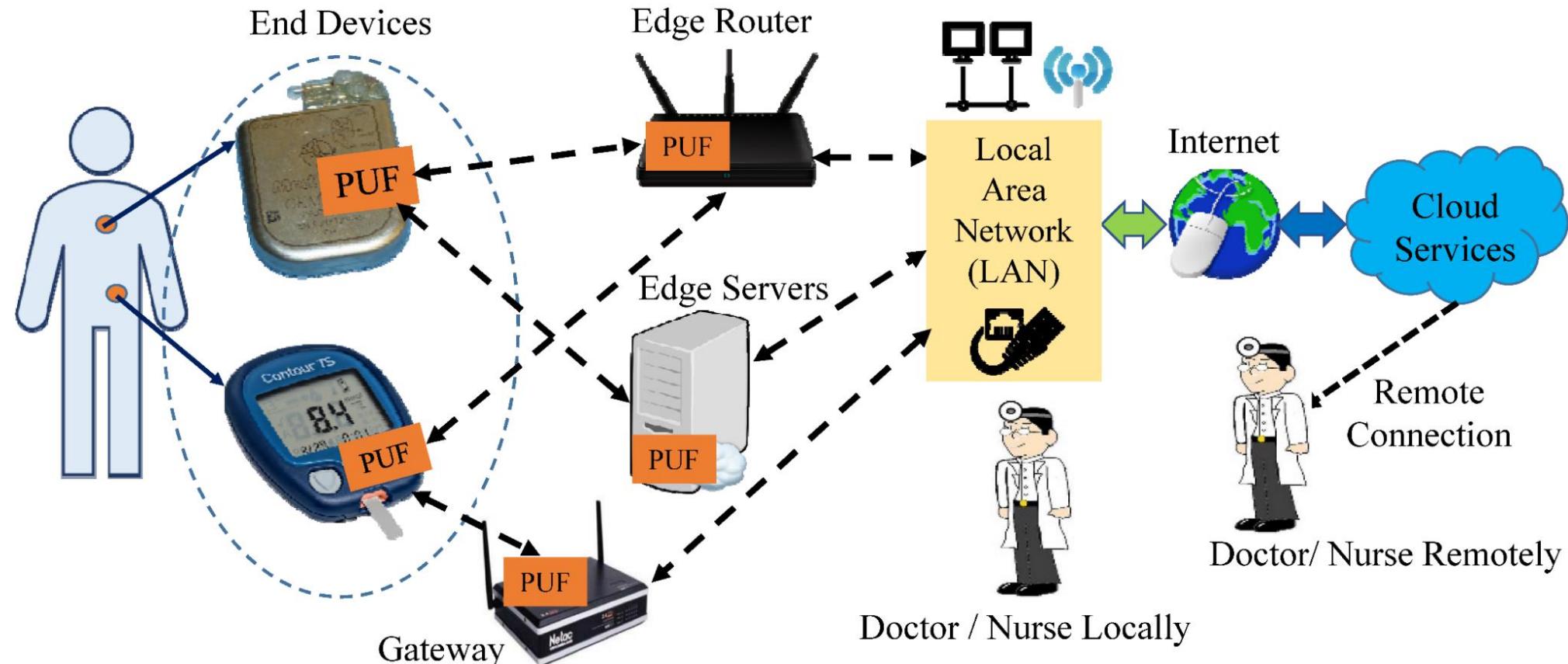
Experimental Results: Dataset A

Models	Detection Latency
DNN	0.80s
Ordinary Kriging	0.86s
Krig-DNN	0.80s
Dist-Krig-DNN	0.80s
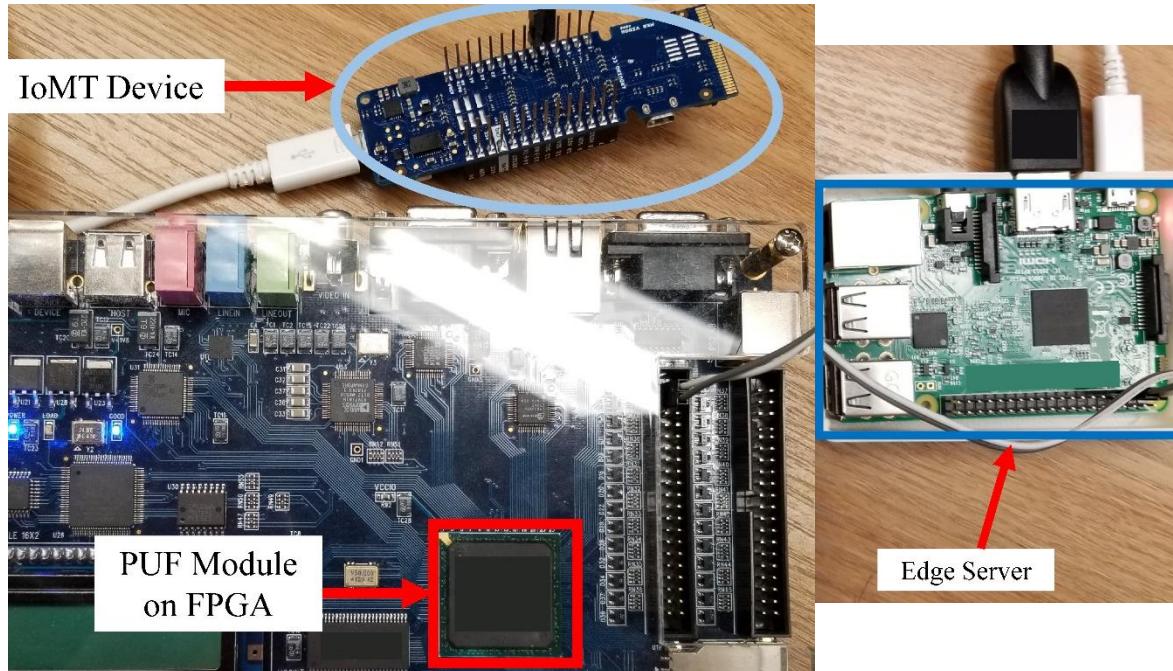
Source: I. L. Olokodana, S. P. Mohanty, and E. Kougianos, "Distributed Kriging-Bootstrapped DNN Model for Fast, Accurate Seizure Detection from EEG Signals", *Proceedings of the 19th IEEE Computer Society Annual Symposium on VLSI (ISVLSI)*, 2020.

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.

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IoMT Security – Our Proposed PMsec

IoMT Device

PUF Module on FPGA

Edge Server
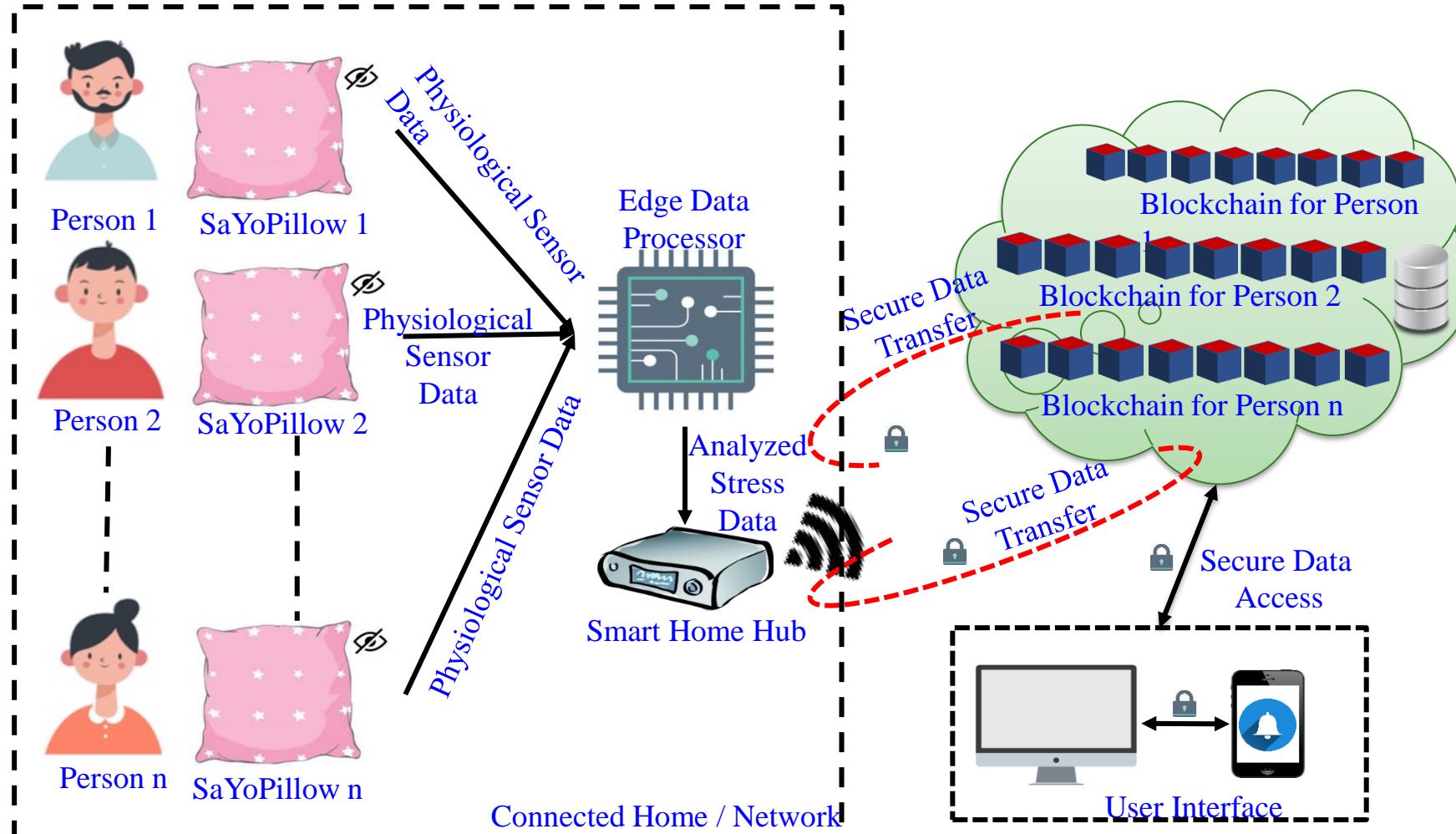
Average Power Overhead –
~ 200 µW or 0.2 mW

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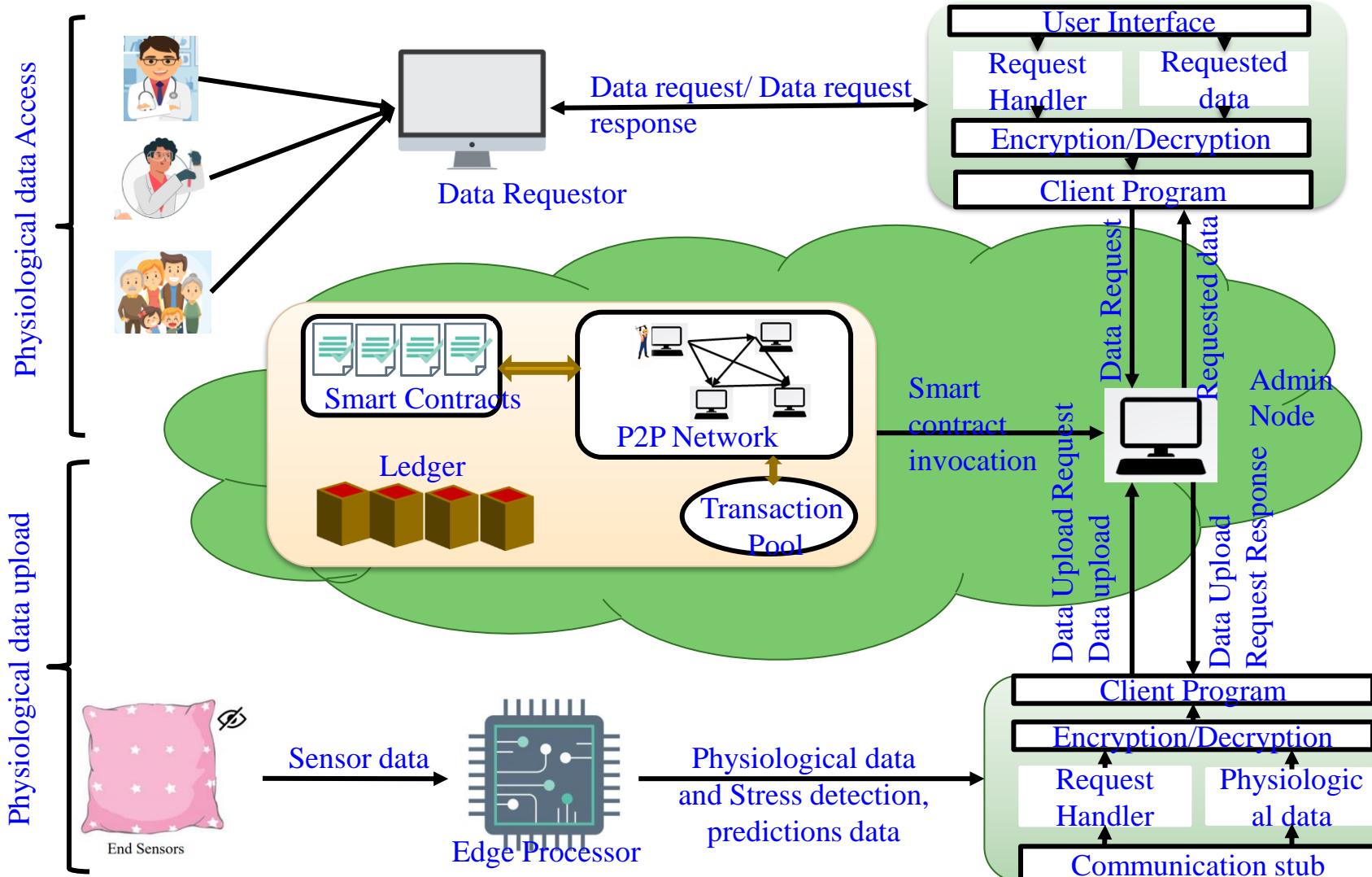
Source: V. P. Yanambaka, S. P. Mohanty, E. Kougianos, and D. Puthal, "PMsec: Physical Unclonable Function-Based Robust and Lightweight Authentication in the Internet of Medical Things", *IEEE Transactions on Consumer Electronics (TCE)*, Volume 65, Issue 3, August 2019, pp. 388--397.

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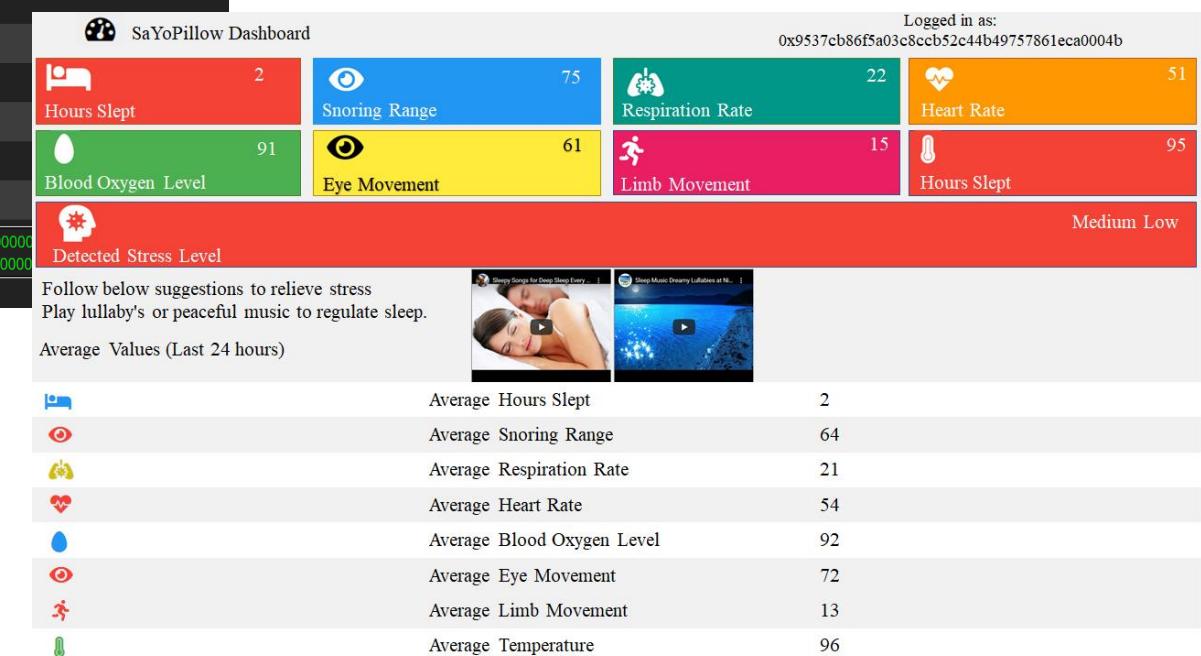
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

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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.

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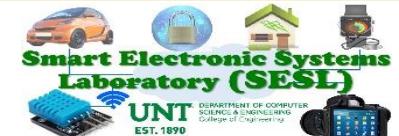
SaYoPillow: Prototyping
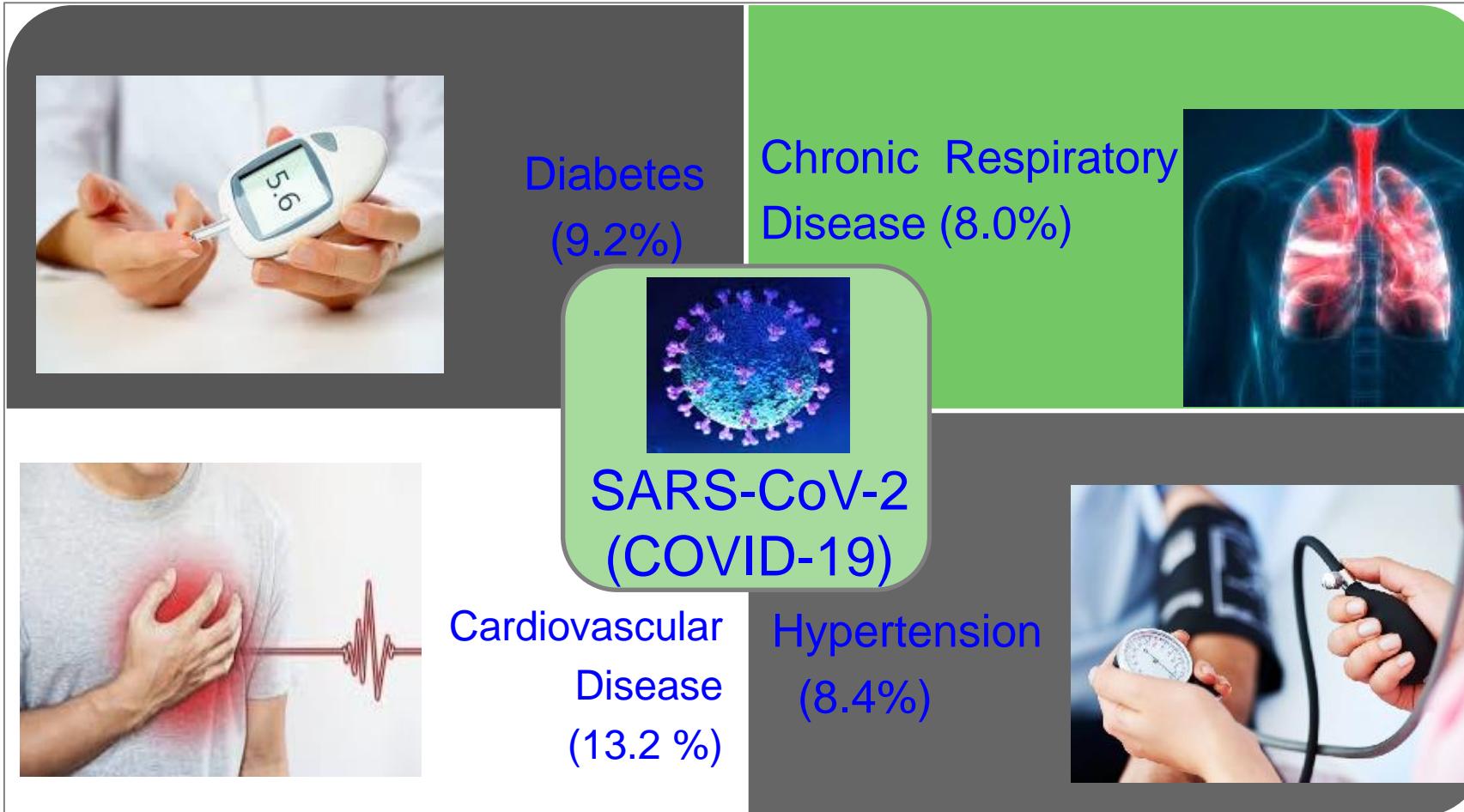
Source: L. Rachakonda, A. K. Bapatla, S. P. Mohanty, and E. Kougianos, "SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits", *IEEE Transactions on Consumer Electronics (TCE)*, Vol. 67, No. 1, Feb 2021, pp. 20-29.

Smart Healthcare – COVID-19 Perspectives

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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.

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Impact of COVID-19 on Diabetes Patients

Unbalance Glucose Insulin	Increases the level of Diabetic Ketoacidosis (DKA)	SARS-CoV-2 Connects with Angiotensin-Converting Enzyme 2 (ACE2)	High Blood Sugar
Body is not generating enough insulin to burn excess amount of generated ketones	Cellular receptor (ACE2) binds easily with the virus SARS-CoV-2	ACE2 → damage of pancreas islets → insufficient insulin secretion	
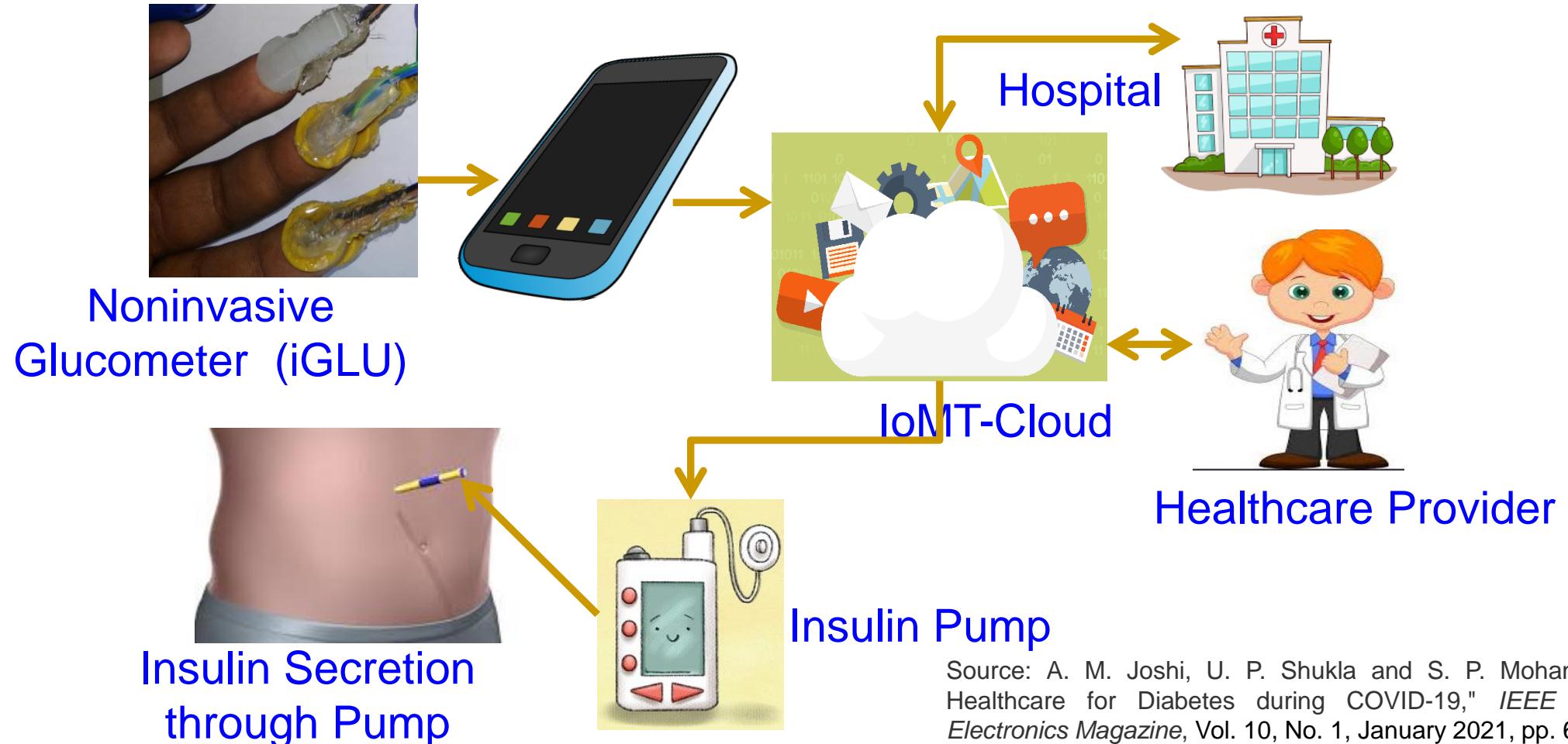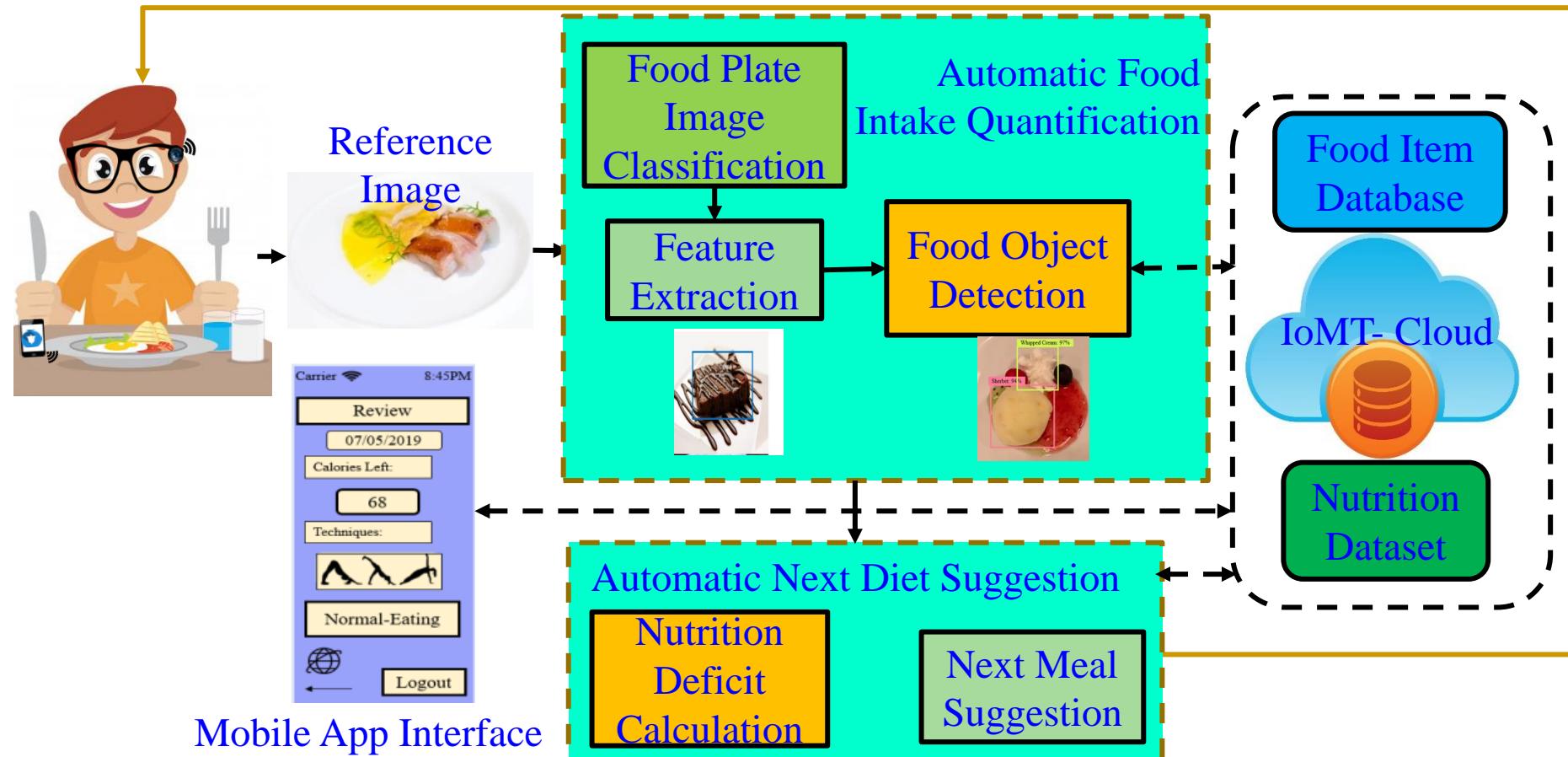
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

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

Noninvasive Glucometer (iGLU)

Hospital

IoMT-Cloud

Healthcare Provider

Insulin Pump

Insulin Secretion through 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.

Smart Electronic Systems Laboratory (SESL)
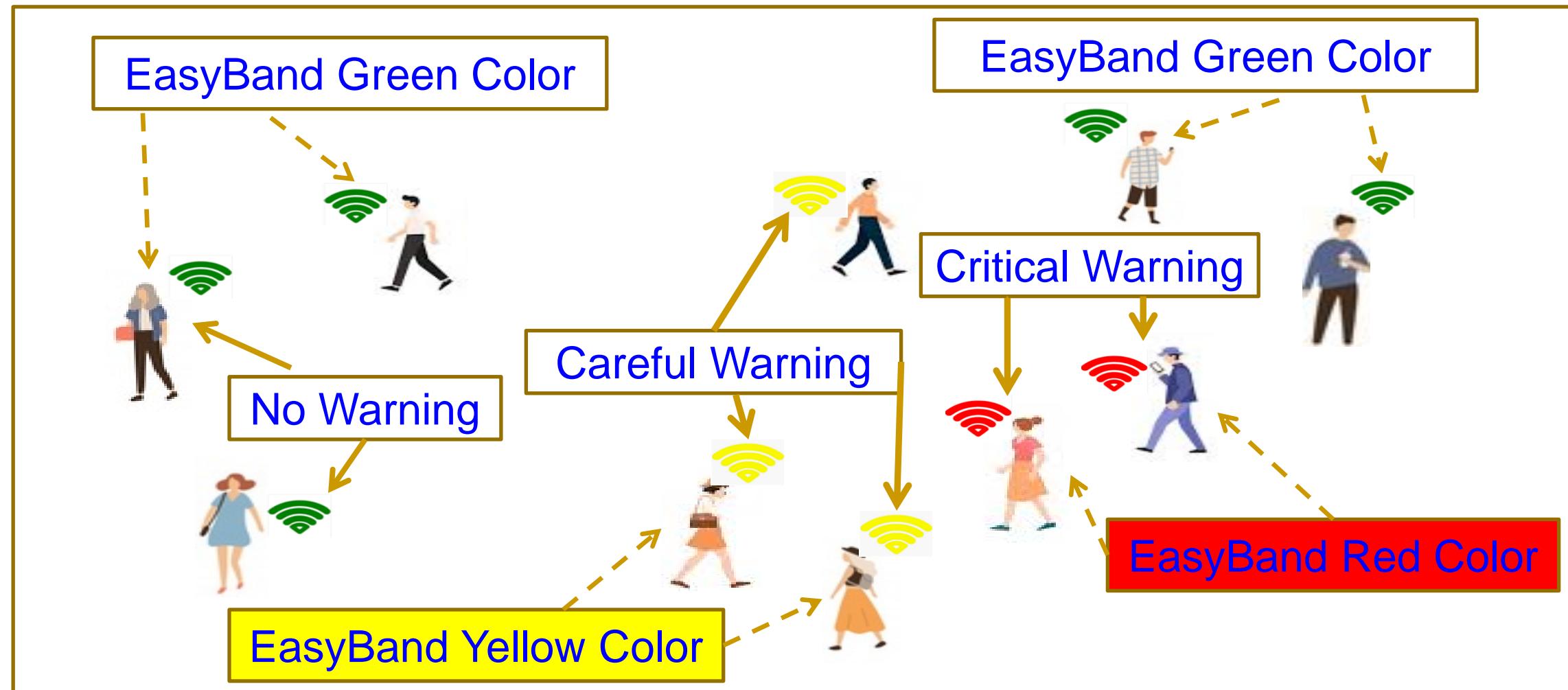
iLog + iGLU - Our Diet Automatic Monitoring and Control for Blood Glucose Level
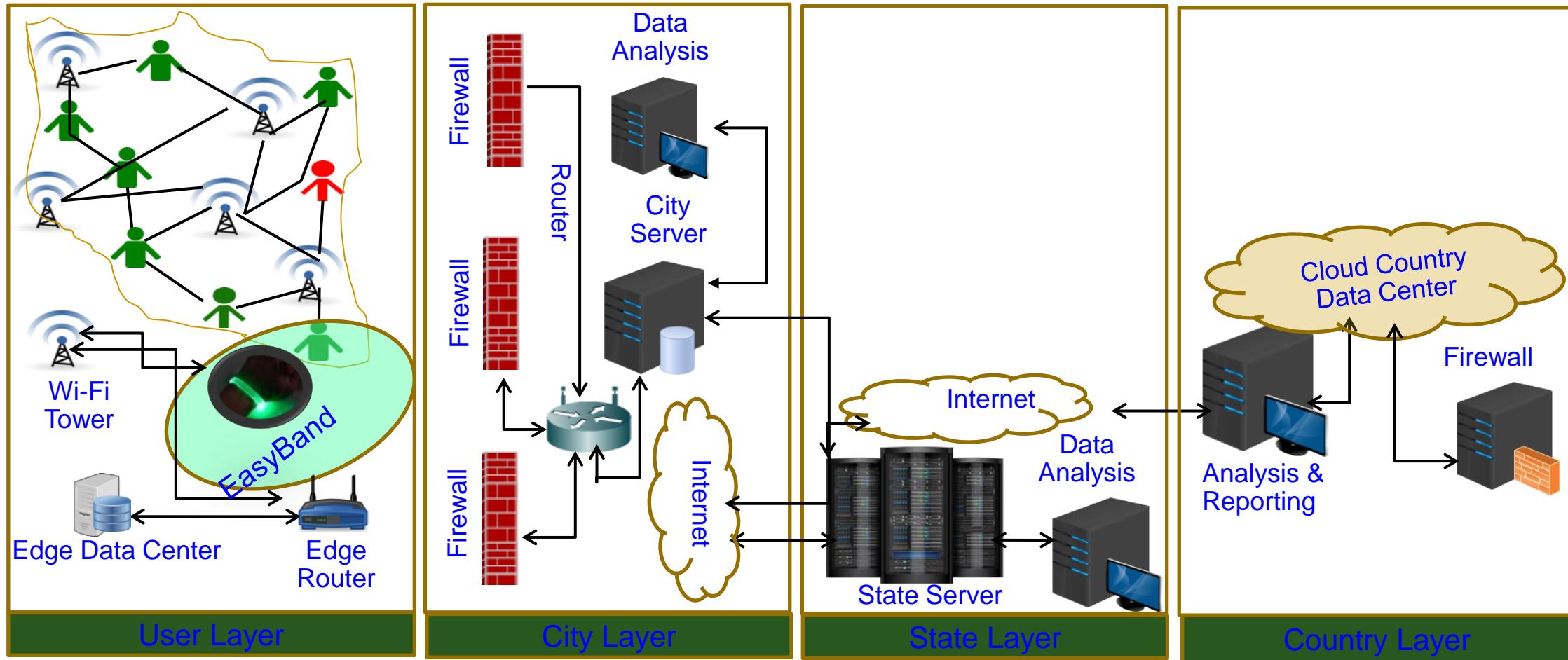
Source: A. M. Joshi, U. P. Shukla and S. P. Mohanty, "Smart Healthcare for Diabetes during COVID-19," *IEEE Consumer Electronics Magazine*, Vol. 10, No. 1, January 2021, pp. 66--71.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

EasyBand – Safety-Aware Mobility during Pandemic

EasyBand Green Color

EasyBand Green Color

Critical Warning

No Warning

Careful Warning

EasyBand Yellow Color

EasyBand Red Color

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.

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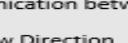
EasyBand in Healthcare CPS (H-CPS)
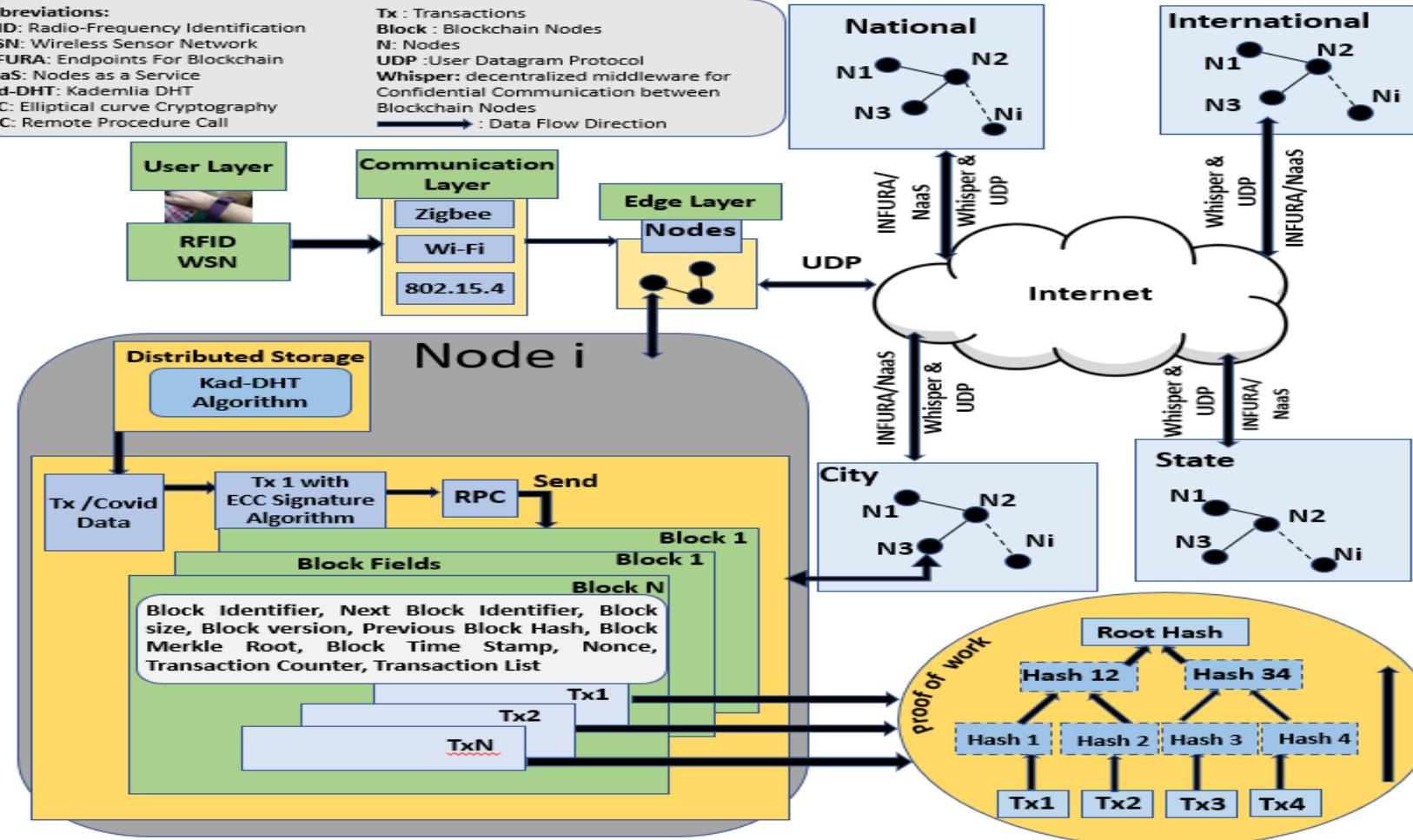
Source: A. K. Tripathy, A. G. Mohapatra, S. P. Mohanty, E. Kougianos, A. M. Joshi and G. Das, "EasyBand: A Wearable for Safety-Aware Mobility During Pandemic Outbreak," *IEEE Consumer Electronics Magazine*, vol. 9, no. 5, pp. 57-61, 1 Sept. 2020, doi: 10.1109/MCE.2020.2992034..

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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.

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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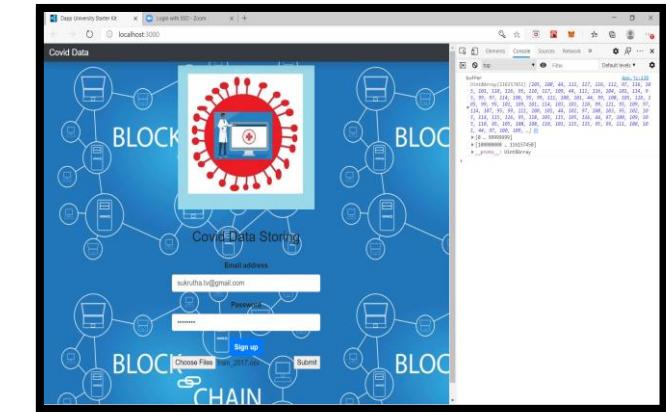
CoviChain: A Blockchain based Framework for Nonrepudiable Contact Tracing in H-CPS

- 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.
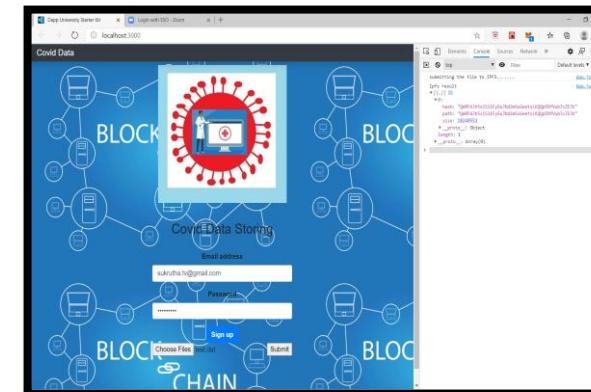
1. User Interface
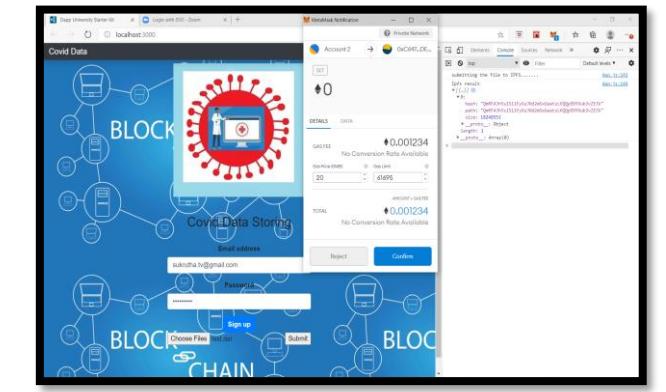


2. File Converted to Buffer

3. IPFS returning Hash

4. Confirming Metamask

Smart Healthcare -- Prof./Dr. Saraju P. Mohanty

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

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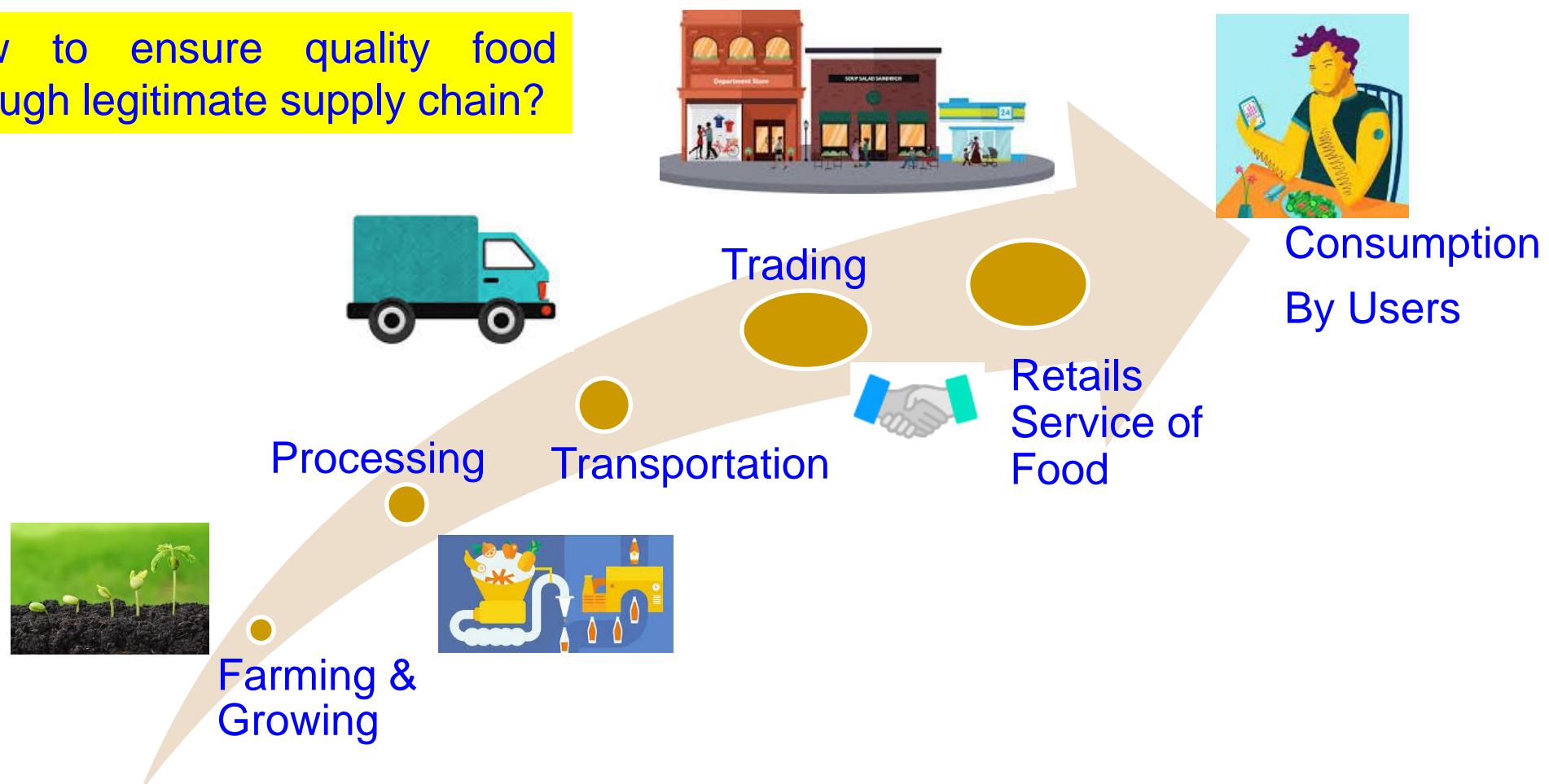
The times for data in MedRec are calculated assuming the mining time of the conventional Ethereum blockchain to be 13 Seconds for 1MB Data.

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.

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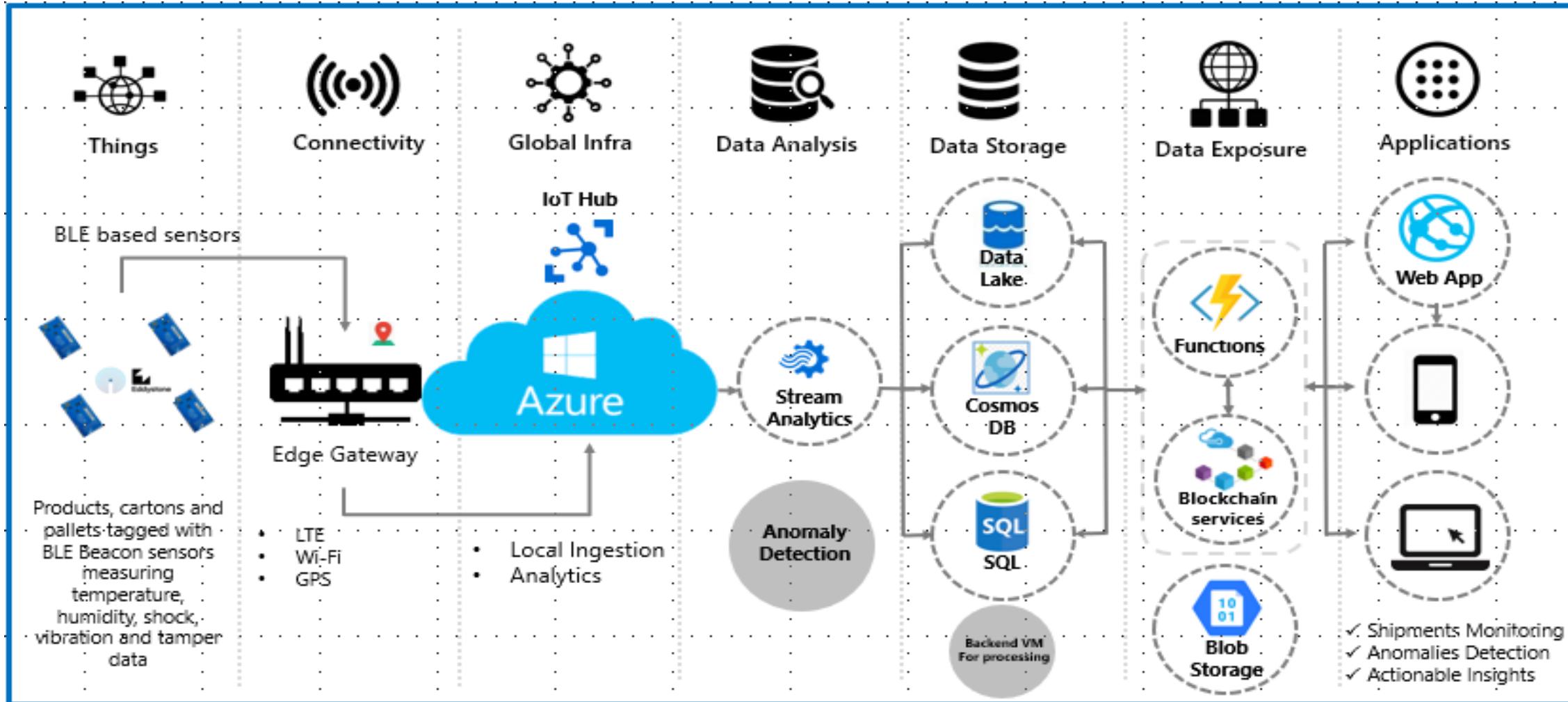
Pandemic – Trusted Food Supply Chain

How to ensure quality food through legitimate supply chain?

Consumption By Users

Trading

Retails Service of Food

Processing

Transportation

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/

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Conclusions and Future Research

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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 cybersecurity and privacy.

- Smart Healthcare can be effective during stay-at-home scenario during pandemic.

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Future Research

- Machine learning (ML) models for smart healthcare needs research.

- Internet-of-Everything (IoE) with Human as active part as crowdsourcing need research.

- Smart Healthcare will need robust data, device, and H-CPS security need more research.

- Cybersecurity 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.

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Smart Electronic Systems Laboratory (SESL)

UNT EST. 1890 DEPARTMENT OF COMPUTER SCIENCE & ENGINEERING College of Engineering

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