DigiHealth-Asia

Deliverable D2.1: System Integration of Digital Health Care and the Remote Patient Monitoring System

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Executive Summary

This deliverable (Task 2.1 in the DigiHealth-Asia project) provides information about two key elements related to each pilot case study. The first element discusses the sensor types, whereas the second element discusses the model for system integration. Both of these elements are seen as the crucial first step in the development and implementation of the pilot cases. Following a thorough research carried out at each partner institution, a set of candidate sensors were selected. After a careful study of the technical parameters for each sensor and considering the requirements for each system, sensor choice was made. The proposed sensor and system integration will contribute to the implementation and realization of full system for each pilot case proposed in the WP2.

1. Introduction

This deliverable build upon the work in WP-1 (Task 1.1, 1.2 and 1.4) to report the most suitable components for development and integration of system components for three pilot cases. Based on the requirements and needs analysis for the proposed system, sensor hardware was selected for all three pilot cases. The following text introduces salient features for each pilot case study and technical details are provided in the subsequent sections.

NUST and CUST will develop system for the pilot case study that requires monitoring of cardiovascular patients. Considering the complexities of monitoring cardiovascular patients, a number of different sensor inputs are needed to monitor various physiological parameters. Both designs have adopted monitoring of Heart rate, Blood Oxygen saturation, Blood pressure, Electrocardiogram and Temperature. The communication architecture adopted for the two systems (developed at CUST and NUST) follows edge-based communication architecture [1]. For sensor types both systems adopted commercially available sensor hardware with standard outputs such as I2C and SPI are selected for interfacing with Wi-Fi/BLE based microcontrollers. Section 2 provides more details on sensor types, specifications, architecture and system components for both implementations.

MFU and CMU will jointly develop a system for monitoring mobility disorders in the elderly. The proposed systems will evaluate risk of fall detection through carefully planned mobility activities at home and in the health care settings. The overall system architecture consists of a sensors layers integrated with edge and cloud computing technologies for data collection and analysis. The application of estimating risk of fall detection in the elderly is a challenging task and requires fusing data from different sensors such as depth camera, images, accelerometer and other physiological parameters. The sensor layer in the proposed systems consists of two components; a depth camera and smart watch. The smart watch is chosen because several off the shelf models include several sensors (accelerometer, heart rate monitor etc.) that are already integrated in the device, thus, expected to reducing the prototyping and implementation phase. Section 3 provides more details on sensor types, specifications, architecture and system components for both implementations.

NUM and MNUMS will jointly develop a system for remote patient consultation. Based on the requirement analysis and skill's assessment carried in deliverables (1.1, 1.2 – 1.4), a diagnostic application of dental patients is chosen, which will allow capturing intraoral images, data processing and machine learning based model for analysis and diagnosis. This proposed system also makes use of cloud and edge technologies for facilitate the communication and storage of dental images. Section 4 provides more details on sensor types, specifications, architecture and system components for both implementations.

2. Pilot Case 1 - Cardiovascular monitoring

2.1 Cardiovascular Monitoring System implemented in National University of Sciences and Technology (NUST)

2.1.1 Sensor types

There are four types of sensors which will be used for cardiovascular monitoring by NUST for Pilot Case 1. Table 1 summarizes the output data type and the usage purposes for the four types of sensors.

S.No.	Sensor Name	Output data type	Specification/Usage
1	MLX90614 [2]	Digital (I^2C)	Infrared Thermometer https://www.melexis.com/en/product/MLX90614/Digital-Plug-Play-Infrared-Thermometer-TO-Can
2	MAX30101 [3]	Digital (I^2C)	High-Sensitivity Pulse Oximeter & Heart rate https://coolcomponents.co.uk/products/pulse-oximeter-and-heart-rate-sensor-max30101-max32664-qwiic
3	ADS1292R [4]	Digital (SPI)	Analog Front End IC for ECG measurement https://www.ti.com/product/ADS1292R
4	MAX86150 [5]	Digital (I2C)	ECG & PPG in-sync acquisition sensor for Blood Pressure estimation. https://www.maximintegrated.com/en/products/interface/signal-integrity/MAX86150.html

Table 1: Details of sensors to be used for cardiovascular monitoring by NUST.

In Pilot Case 1, there will be at least 10 x sensor nodes of each type implemented by NUST. The monitoring duration is planned to be around 2 to 3 hours per day for 6 weeks. Data will be collected continuously with a short interval of 1 min. The collected data will be uploaded to the cloud periodically (details mentioned in Figure. 1).

These sensors will be interfaced with a WIFI/BLE enabled microcontroller unit (MCU).

2.1.2 System integration

The NUST system architecture of Pilot Case 1 is shown in Figure 1. The details of each layer and component are described below:

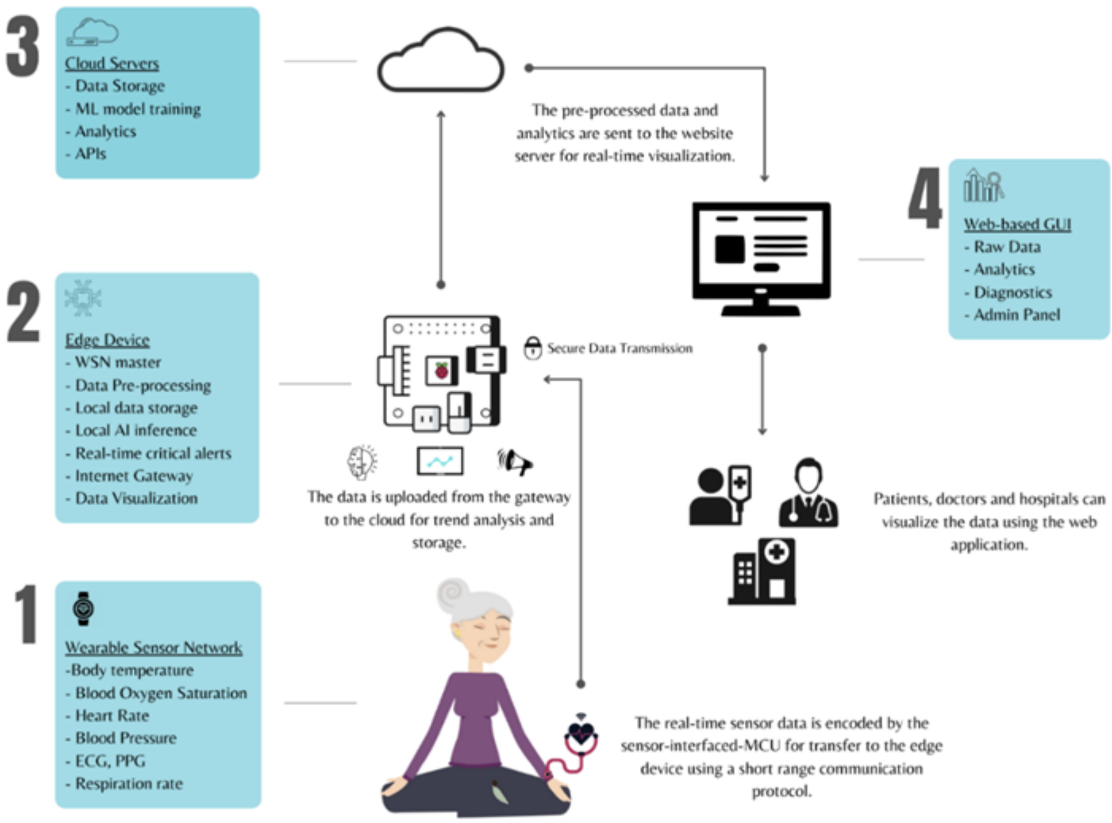

Figure 1: System Architecture of Pilot Case 1 by NUST

1) Wearable Sensor Network (WSN):

The WSN will comprise of various wearable sensors that will measure & monitor the vitals of the patient. For the cardiovascular pilot case, the following parameters will be measured:

- Body temperature
- Blood Oxygen Saturation (SpO2)
- Heart Rate
- Blood Pressure
- Electrocardiogram (ECG)
- Photoplethysmography (PPG)
- Respiration/Breathing Rate

The sensors (refer to Table 1 for details) will be connected to microcontroller(s) according to their designed wearable kit, and their data will be transferred to the edge node (WSN master) using Wi-Fi or BLE. Furthermore, we wish to explore other short range communication protocols, and select the most suitable based on the performance of battery life of sensor nodes.

2) Edge Device:

The edge device will act as the master node of the WSN. It will have multiple functionalities that will distinguish it from the traditional cloud-based architecture. Its main functionalities are described below:

- **Data Pre-processing**: The edge device performs pre-processing and cleaning of data received from the MCU. This includes the signal processing of ECG and PPG signals since the computational power and battery life of the wearable device will be limited. The garbage values are discarded, and the valid values are extracted from packets, processed, and arranged in a data table (JSON format).
- **Local Data Storage**: The edge device will provide a local data storage for the system. The data will be stored locally till it is time for it to be sent to the cloud. This is especially beneficial in case of unstable network connections.
- **Local AI (Artificial Intelligence)**: A major goal of this system is using modern technologies like AI and ML to derive inferences from patients' data and aid caregivers that include relatives, doctors, local hospitals, etc. Performing local decision-making using ML is helpful for anomaly detection in case of emergencies. This means that onset of any medical emergency the caregivers as well as the patient will be immediately notified and alerted. This architecture is advantageous because the edge device isolates the edge network from network dependencies and latency issues.
- **Internet Gateway**: The device will act as an internet gateway, i.e., it will send the processed data to the cloud over Wi-Fi. If we were to opt for a simple cloud-based architecture, the MCU would have to act as the gateway device to the cloud. This would have significantly affected the battery life of the wearable device since Wi-Fi is a very power-hungry communication protocol. It is important to clarify that for wireless data transmission with the cloud through the Internet, a Wi-Fi connection will be used.
- **Data Visualization**: The edge device will be interfaced with a screen for real-time visualization of the cleaned data through a GUI. The GUI will plot real-time health vitals as well as the local inference results, as seen in Fig. 2.

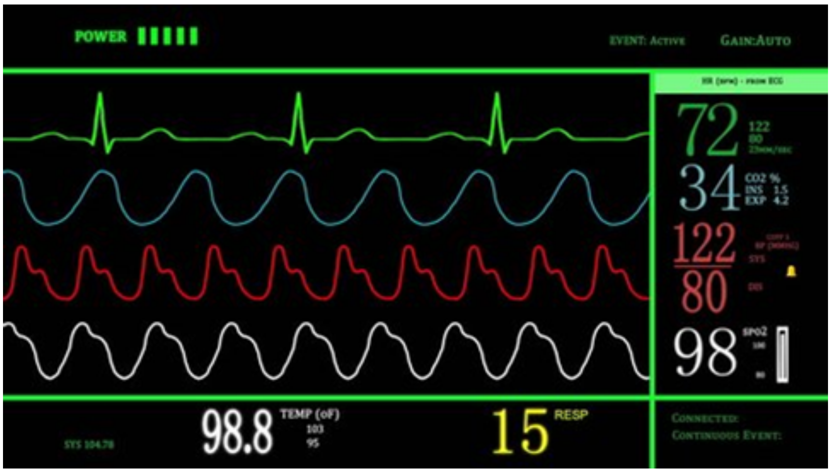

Figure 2: Data Visualization GUI

3) Cloud Server:

After the data is cleaned, it is sent to the main cloud server for storage and analysis. We plan to use **Amazon Web Services** (AWS**)** cloud services for this purpose. In this system architecture, the major computational load, i.e., training of the ML model, is handled by the cloud. The two main **functionalities** of the cloud in this system are described below:

- Data Storage: All patient data and archives will be saved and maintained by the cloud and will be available for viewing on the website.
- Model Training: As this is the most computationally expensive task, it has been assigned to the cloud server owing to their computational power. The trained model will be downloaded by the edge device so that it can start its prediction on real-time patient data.

4) Web-based GUI:

The data from the cloud including the ML inference is viewable on the website, as well as on the edge device, for real-time depiction of health status. Using the website, doctors can give their diagnosis based on patient data while the patients/caretakers can also view their vitals as well as the doctor's suggestions. The main **features** of the website are (tentative):

- Doctor/patient chat or video chat.
- Data analytics' visualization.
- A data repository
- Patient profile/ medical history
- Previous records
- Appointment scheduling

- Emergency alerts

For more information regarding the logical flow of the system, please refer to Figure. 3.

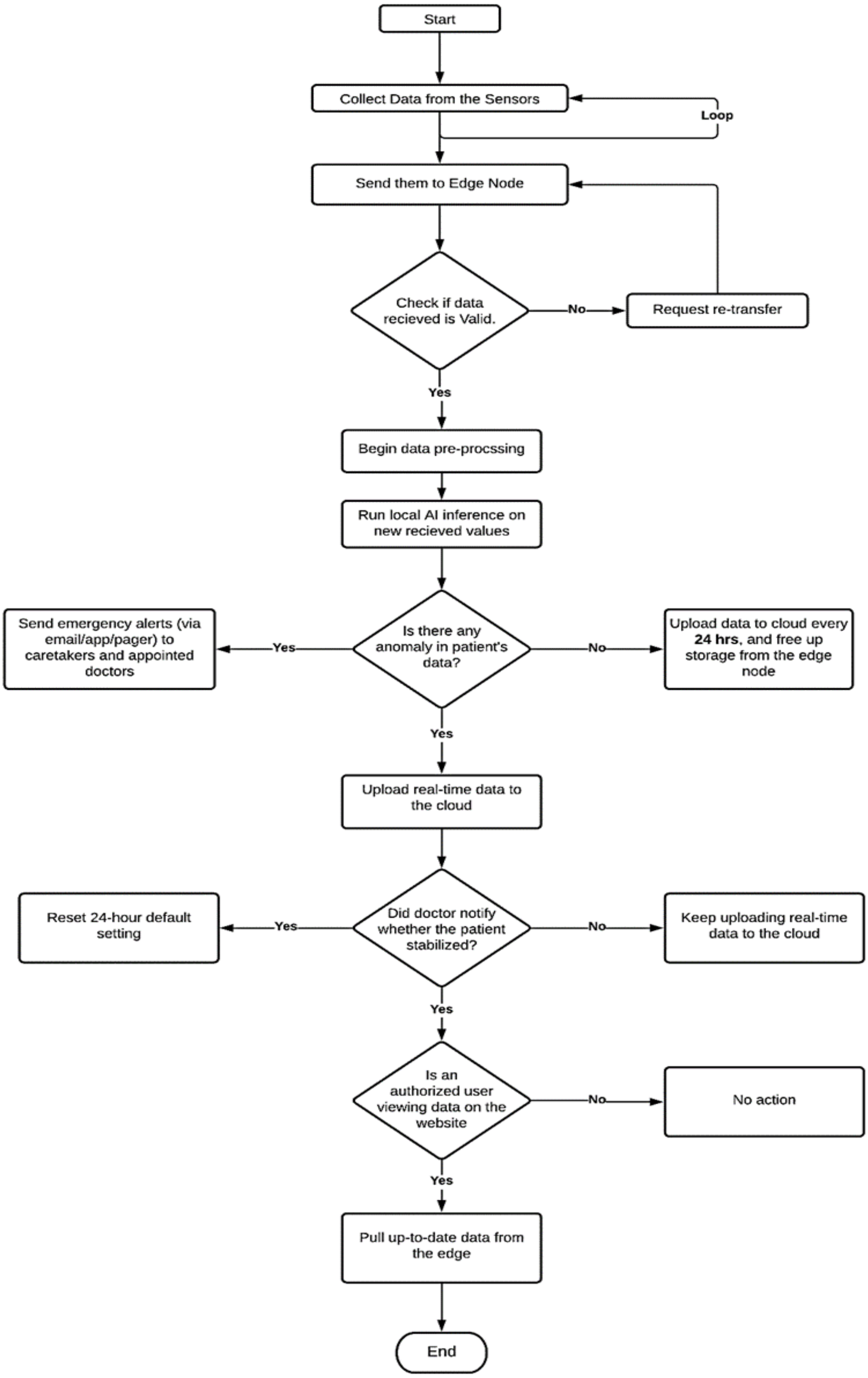

Figure 3: Logical flow diagram

2.2 Cardiovascular Monitoring System implemented in Capital University of Sciences and Technology (CUST)

2.2.1 Sensor types

The table below provides details of the sensors to be used for collecting data from the cardiovascular patients.

S No.	Sensor	Device Model	Output Data Type
1	Blood Pressure	Biosensor - AS7026GG Module https://ams.com/en/as7026gg [6]	Serial data transfer over I^2C Bus
2	Heart Rate		
3	Electrocardiogram (ECG)		
4	Oxygen Saturation in Blood (SPO2) [7]	Pulse Oximeter - MAX30102 https://www.mouser.co.uk/new/maxim-integrated/maxim-max30102efd-sensor/	Serial data transfer over I^2C Bus
5	Temperature [8]	MLX90614 https://www.melexis.com/en/documents/documentation/datasheets/datasheet-mlx90614	TWI interface through I^2C Bus

Table 2. Type of Sensors in the sensor network in Pilot Case 1 by CUST

For each patient, one biosensor (AS7026GG), one MAX30102 and one MLX90614 will be used. These devices will be enclosed in a hand wrap. Sensors will be directly interfaced with a microcontroller. A total of 20 prototypes will be developed for the pilot case. These sensors will continuously monitor patient's vital signs. The data from the sensors will be sent to the microcontroller. The microcontroller will send the data to the Edge device. Data collected at the edge device will be sent to the cloud server as per requirement.

2.2.2 System integration

The proposed architecture for remote monitoring cardiovascular patients is shown in Figure 4.

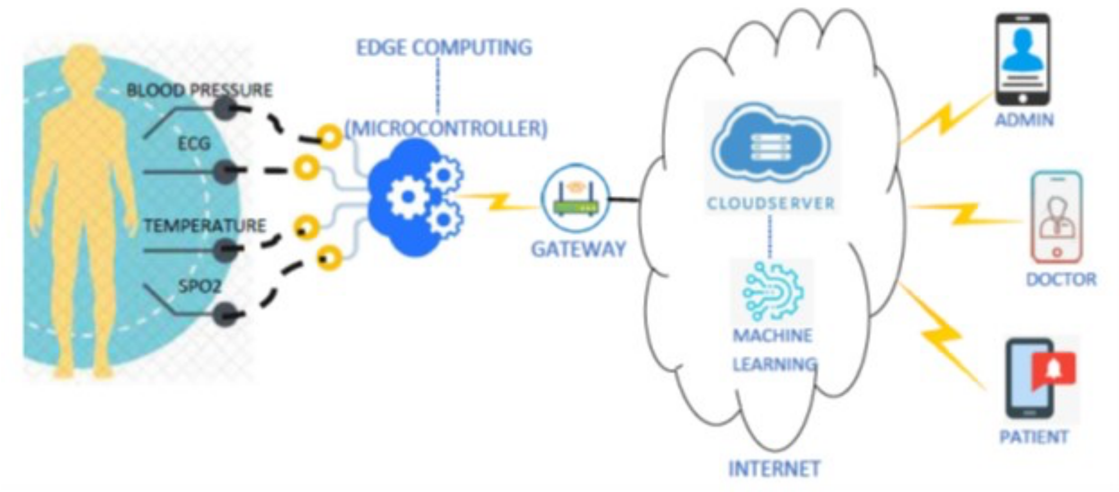

Figure 4: Proposed Remote Monitoring System for Cardiovascular Patients by CUST

A functional block diagram showing various functions being performed at different levels in the architecture is shown in Figure 5.

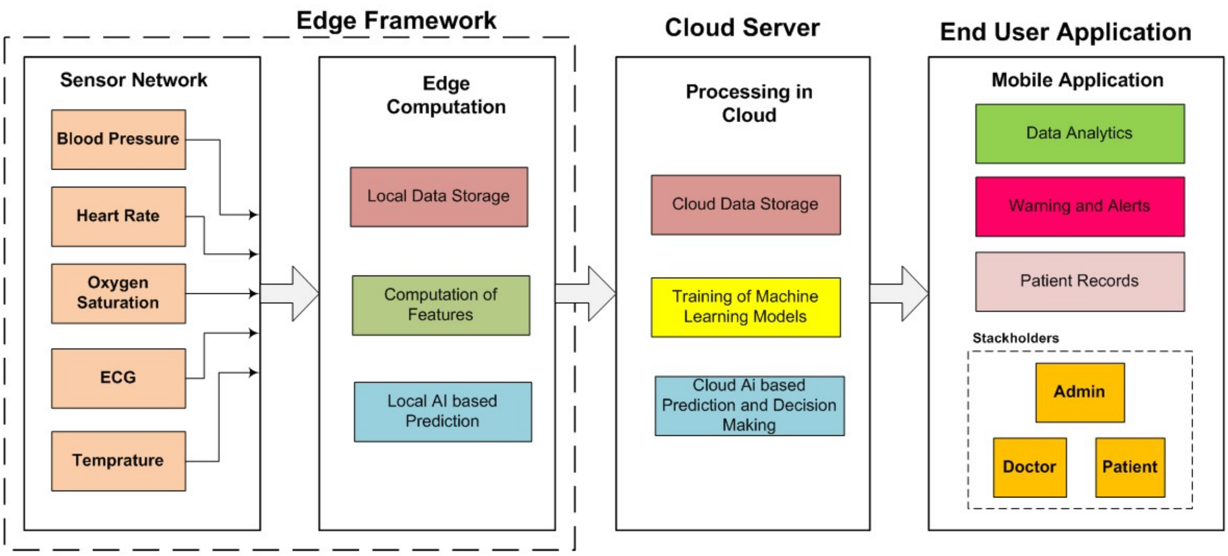

Figure 5: Functional block diagram for the Proposed Cardiovascular Patients Remote Monitoring System by CUST

The system consists of 4 major layers i.e., Sensor Network, Edge Computation, Cloud Server and End user application. The details of each layer are described as below:

1. Sensor Data Acquisition

A network of sensors will be used to acquire the medical vital data of the cardiovascular patients. These sensors will be interfaced to a microcontroller. Table 2 above shows vital signals being acquired and corresponding sensor device modules. Acquired data will be transmitted wirelessly to the edge device for further processing and storage at regular intervals.

2. Edge Computing

Edge device will receive data from the sensor network. It will perform the following tasks as shown in the functional block diagram.

- Local Data Storage
- Machine Learning based inference
- Generation of alert messages
- Transmission of preprocessed data to the cloud

Data from the edge device will be wirelessly transmitted over Wi-Fi to the next layer i.e., Cloud server.

3. Cloud Data Processing

Main purpose of the cloud server is following:

- Storage of Patient Data
- Training of Machine Learning Models
- Long-term Machine Learning based inference

Data in the cloud will be used for long term inference based upon machine learning. Outcome of this inference will be available to patients and the caregivers through the final layer of the system.

4. End User Mobile Application

At the user end, a mobile application will be used to perform the following tasks:

- View patient records and history
- Visualize data analytics
- Receiving warning and alerts

Using the mobile application, doctors can view the patient record and history. Mobile application will also be used to share the alerts and critical decisions from the edge device or from the cloud based upon long-term machine learning predictions. These alerts and warning messages are conveyed to different stakeholders. These stakeholders include patients and care givers including doctors, nurses and paramedics.

3. Pilot Case 2 - Mobility Disorder Monitoring

3.1 Mobility Disorder Monitoring System implemented by Mae Fah Luang University (MFU)

3.1.1 Sensor types

Table 3 summarizes the sensors used by MFU in Pilot Case 2 for fall risk assessment.

S. No.	Sensor Name	Output data type	Specification/Usage
1	FSR402 [9]	Analog output as a voltage 0-5 V	Force sensitive resistor 0.5 inch Actuation Force 0.1 Newton Force Sensitivity Range 0.1 - 10.0^2 Newtons  Ref: https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr This sensor is for measuring changes of subjects' weights during Balance test, Chair stand test and Time up and go test.
2	LiDAR Benewake TF-Luna [10]	Analog output convertible to a range of 0-800 cm	LiDAR Distance Sensor 0-800 cm  Ref: https://www.mouser.com/ProductDetail/Benewake/TF-Luna-I2C?qs=DPoM0jnrROUWvdDwJYVpzw%3D%3D This sensor supports the Gait speed test.

Table 3: Sensors to be used by MFU for fall risk assessment.

In Pilot Case 2, 2 to 4 FSR 402 sensors will be used for each fall risk assessment except the Gait speed test. For the Gait speed test, a LiDAR TF-Luna will be used. Each fall risk test will consume 10-15 seconds. Data sampling is every 0.2 second. Data is transmitted to the edge device after the assessment. All collected data will be uploaded to the private server periodically. These sensors will be interfaced with a WIFI/BLE enabled microcontroller unit (MCU).

3.1.2 System integration

MFU and CMU collaborate to develop a sustainable system to prevent mobility disorder in the elderly due to fall. The entire system architecture of Thai partners is illustrated in Fig. 6. MFU focuses on fall-risk assessment at healthcare centers while CMU intends to monitor the elderly's activities and exercises at home. The system architecture for MFU is shown in Fig. 7.

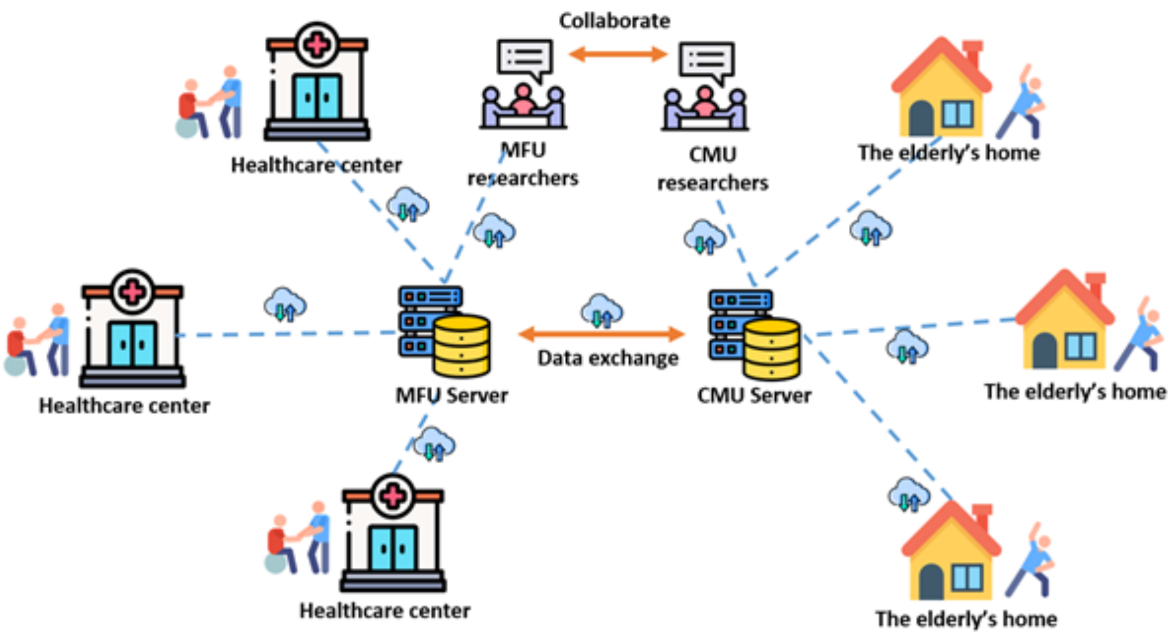

Figure 6. Mobility disorder monitoring system architecture in Pilot Case 2 by MFU and CMU

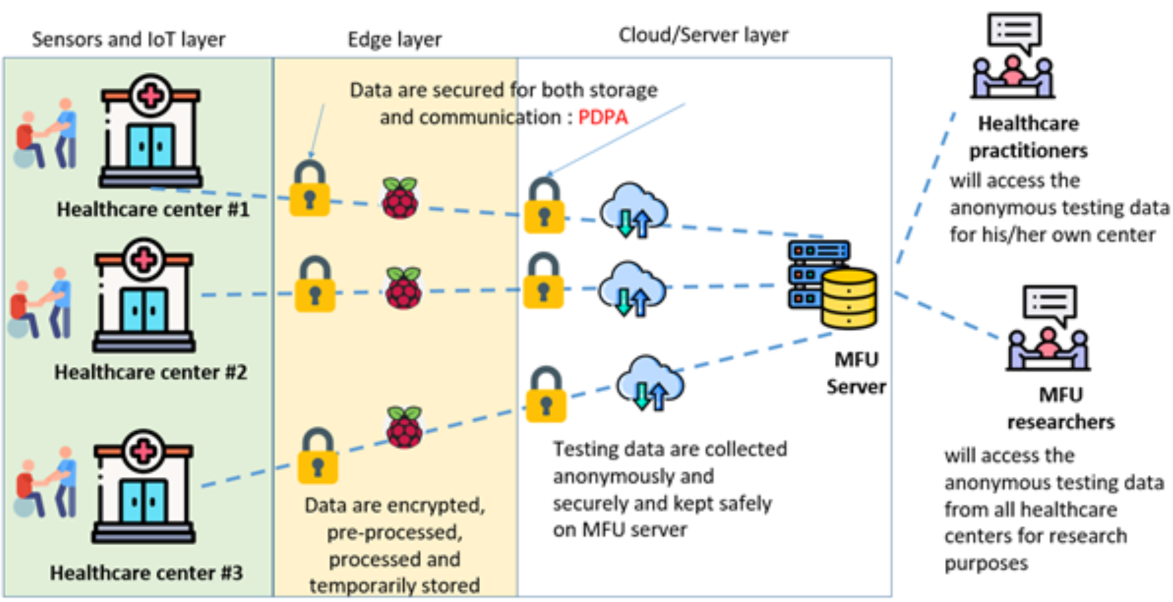

Figure 7. The system architecture implemented by MFU in pilot case 2

For MFU, the system comprises of three main layers as follows:

1) Sensor and IoT layer

This primary layer focuses on developing end-user equipment for fall-risk assessment based on sensors and IoT devices as demonstrated in Fig. 8. Testing data from sensors is collected anonymously, kept temporarily in a local storage of MCU.

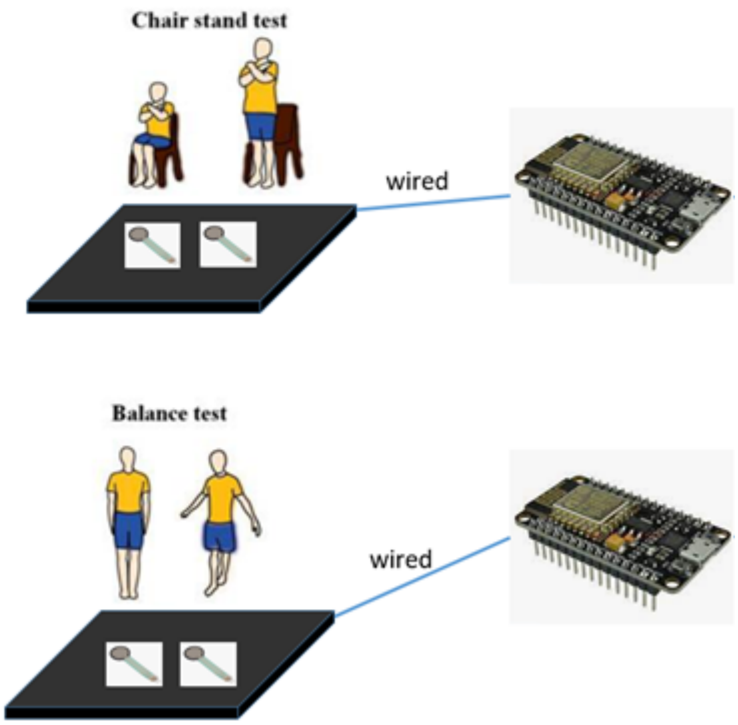

Figure 8. Example of sensors and IoT devices for fall-risk assessment

2) Edge layer

This intermediate layer comprises of more powerful equipment such as single-board computers to communicate with the IoT devices and to store testing data. At the same time this layer acts as a network gateway as well as an edge computing node for local data processing through machine learning techniques. The edge layer also connects to the cloud/server layer to transmit the anonymous testing data for MFU researchers.

3) Cloud/Server layer

The final layer is the cloud/server layer which will be hosted at MFU. This layer receives testing data from the edge layer and stores it in database, visualizes the data to the healthcare practitioners and allows the researchers to analyze the data and develop machine learning models for feeding back to the edge layer.

3.2 Mobility Disorder Monitoring System implemented by Chiang Mai University (CMU)

3.2.1 Sensor types

Table 4 summarizes the sensors used by CMU in Pilot Case 2.

No.	Sensor Type	Output Data type	Specification/Usage
1.	Depth Camera	USB 2.0	GymBot Model 1.2 Basic parameters - Module size: 127.5*19*24mm - Interface: USB 2.0 - Working distance: 0.8~4m - Measurement accuracy: ± 2mm@1m - Power supply mode: USB Output data - Raw Data: 16bit - Color data format: YUV Depth image Resolution @frame rate 640×480@30fps / 320×240@30fps - FOV H60°×V47° Color image resolution @frame rate - 1920x1080 @30fps / 1280x720 @30fps / 640x480 @30fps / 320x240 @30fps - FOV H60°×V47 Development platform Windows support Android / Linux
2.	Smart watch	3G/WIFI/ Bluetooth	Apple Watch Model Series 6 and/or Xiaomi Band Model Series 7 Basic parameters - Module size: 127.5*19*24mm - Interface: USB 2.0 - Working distance: 0.8~4m - Measurement accuracy: ± 2mm@1m - Power supply mode: USB Output data - Raw Data: 16bit - Color data format: YUV Depth image Resolution @frame rate 640×480@30fps / 320×240@30fps - FOV H60°×V47° Color image resolution @frame rate - 1920x1080 @30fps / 1280x720 @30fps / 640x480 @30fps / 320x240 @30fps - FOV H60°×V47° Development platform Windows support Android / Linux

Table 4: Sensors to be used by CMU for activity monitoring

3.2.2 System integration

The proposed architecture for mobility disorder from CMU side is shown below in Fig. 9.

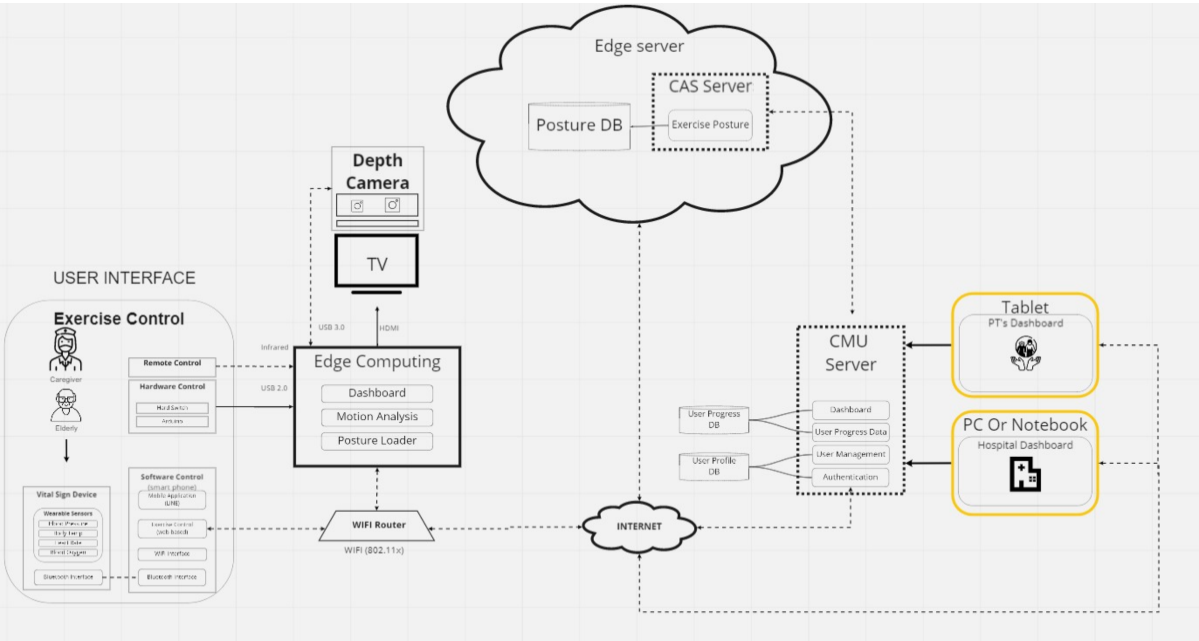

Figure 9. The mobility disorder monitoring system architecture implemented by CMU in Pilot Case 2

The functionalities and the digital data flow are displayed in Figure 10.

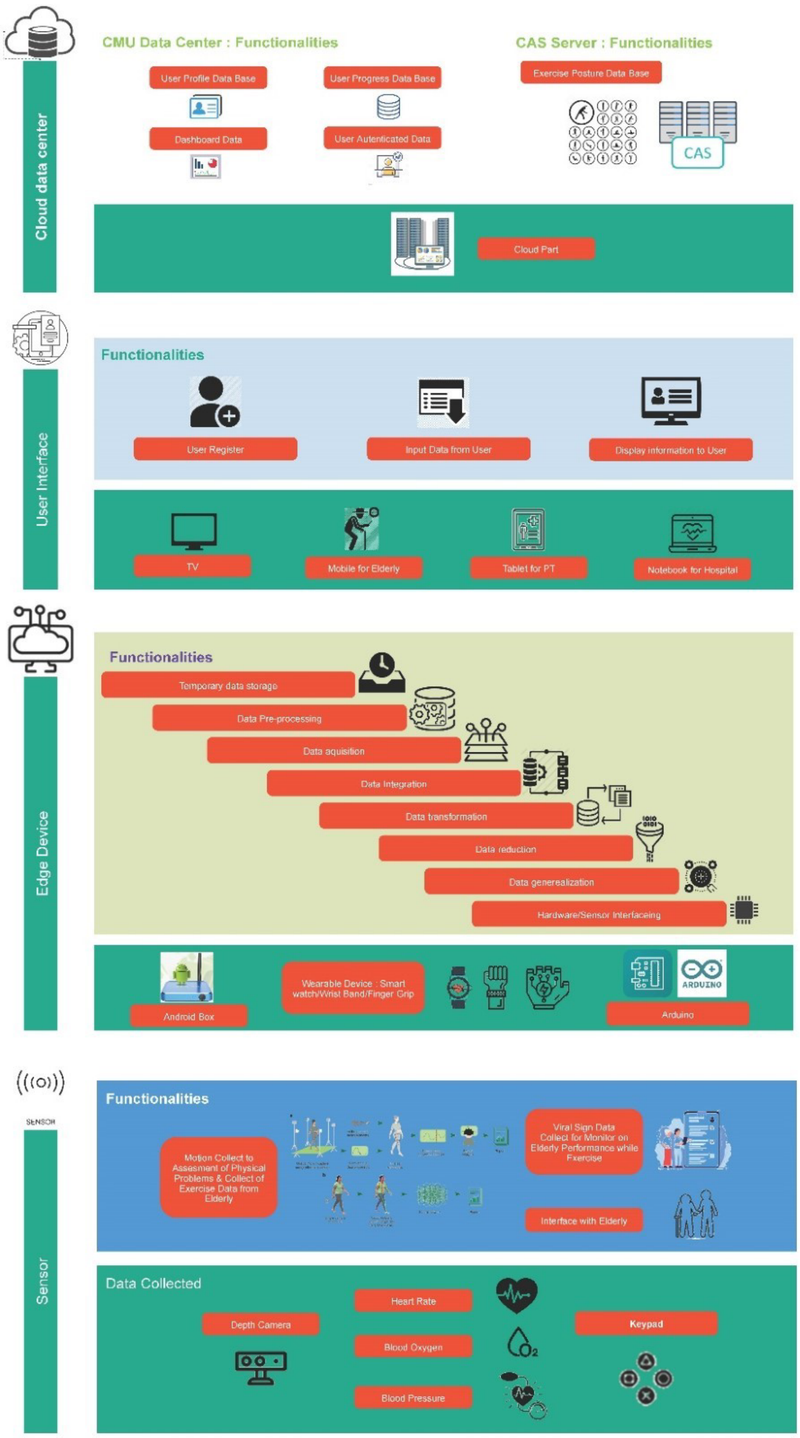

Figure 10. Functionalities and Data Flow for the CMU Mobility Disorder Architecture

The CMU system consists of 4 layers as seen in Figure 10. The description of each layer is given as below:

1) Sensor Layer

- Depth camera

The depth camera has an internal component that consists of a sensor (VGA Camera and IR Sensor) that communicates with the edge device via a USB 3.0 cable. The main function of this layer is to receive image data - a picture of an elderly person. The depth of the image will be processed in order to continue using the information obtained from this. As shown in Figure 11, this can be changed to Skeleton Tracking.

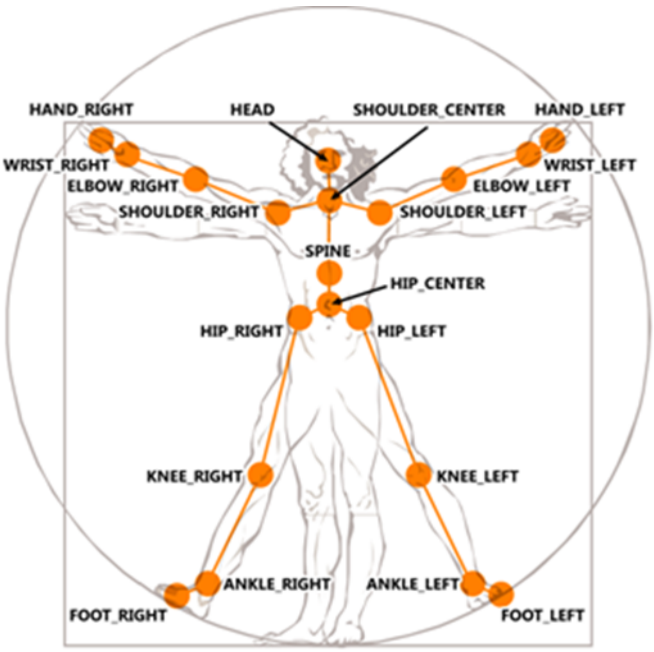

Figure 11. Skeletal Tracking (From: Kinect SDK API Reference, Microsoft) [11]

The driver for the Depth Camera can be used to communicate with the Camera Sensor and to pass data from the Depth Camera to other layers. The type of data received from the sensors include:

- Object color
- Depth in each part of the image (Depth) which will be used to transform data together with colors.
- Skeleton i.e., the location of each part of the body, which is received from the camera and used in the edge system.

- Smart watch

The elderly target group's performance is monitored using a Smart watch equipped with a heart rate and pulse oxygen sensor. The smart watch helps with target group assessment and monitoring of fatigue conditions during exercise.

2) Edge Device

The edge device is connected to the sensor and will perform the following functions:

- Temporary data storage from sensor and commands from other layers.
- Data pre-processing
- Acquisition of data
- Data Integration and generalization
- Transformation of data
- Reducing the large image of data
- Interfacing with the sensor part.

– User Interface

User Interface will allow the user to interact with the system. There are 3 interfaces in the system:

- Connect with an elderly user via a mobile app and a television in order to assist them with system exercise.
- Connect with a Practitioner: The practitioners can see the progress or problems, and the statistics.
- Connect with a hospital or an elderly care center via a notebook or a PC: data can be displayed as statistics to the care center or hospital in order to adapt or redesign the appropriate system to assist the elderly in preventing falls.

3) Cloud Data Center

The cloud data center in this system has two parts:

- The CMU Server, used to collect:
  - User profile data
  - User progress data
  - Dashboard of every user data especially with PT and Hospital

- User authenticated data

- CAS Server

  This server will be the developer server, where they will design the software in this system. In the beginning, they may collect exercise posture data, but in the future, we may collect other data as needed.

4. Pilot Case 3 - Remote patient consultation

4.1 Remote Patient Consultation System implemented by National University of Mongolia (NUM) and Mongolian National University of Medical Sciences (MNUMS)

In this pilot case, instead of monitoring 20 patients as suggested in the project proposal, our team will provide 10 dentists with intraoral cameras and collect digital intraoral images of dental patients with doctor's descriptions for the first 6-8 weeks. Each dentist's office will be asked to provide quality data of at least 100 patients. A machine learning model will be developed for the collected, labeled (doctor's description as a label) image data to build a diagnostic system API. A small mobile or web application for preliminary diagnosis based on patients' digital intraoral images will then be created for dentistry.

4.1.1 Sensor types

The intraoral cameras will transfer the digital images (JPEG imaging format) using a USB cable, Bluetooth or Wi-Fi to a mobile phone or a desktop computer, and mobile or web-based application will be used to upload the images (jpeg files) and diagnosis (CSV files) to a hosting cloud platform like AWS.

Table 5 shows the intraoral cameras alternatively (the supply is very much limited at the moment in Mongolia due to Covid-19 situation) to be used by NUM&MNUMS in Pilot Case 3 for early childhood dental caries detection and assessment.

S. No.	Sensor Name	Output data type	Specification/Usage
1	Daryou DY-50 Intraoral Camera [12]	Universal jpeg imaging format	Power: DC 5V+/-0.5V(1.5A) by USB Type of Focus: Auto-focus of AF Picture: 4.8 million pixels (static) Viedo:640x480 Scope of Focus: 5mm-50mm Camera Length: 20 cm Cable Length: 2 m Connection port: 5 pinholes Handset Weight: 38 g

			 Ref: https://www.daryoudental.com/product-page/daryou-intraoral-usb-camera-5mp This camera will be used to take pictures of patients and be uploaded to our server with doctor's diagnosis.
2	ProDENT Dental Intraoral Camera PD740 [13]	JPEG	Anti-fog, non-spherical lens, Super-wide automatic adjusting-focus lens Type of focus: Auto-focus of AF Picture: max--3.8 million pixels,1.3 million pixels (dynamic) and 3.8 million pixels (static) Picture Pixels:640*480 Scope of focus: 5mm ~50mm Length of handset: 200mm Connect port:5 pinhole  https://www.prodentshop.com/products/prodent-dental-intraoral-camera-usb-pd740-blue This camera will be used to take pictures of patients and be uploaded to our server with doctor's diagnosis.

Table 5: Intraoral cameras to be used by NUM&MNUMS for dental caries monitoring.

4.1.2 System integration

The system diagram for the pilot use case 3 – remote consultation of patients is shown in Figure 12. The pilot study will consist of two research stages: data collection and model creation. In the first stage of data collection, dentists will take the digital images of patients with an intraoral camera and upload them with professional diagnosis (the date template will be defined beforehand) to the cloud server using a mobile or web application. This application shall have data filtering and data pre-processing functions on the edge side so that only quality data will be sent to the cloud server for further processing. In the second stage, after the amount of data collected is sufficient for a decent machine learning model, the IT team will build a machine learning algorithm based on the uploaded data and deploy the model to the cloud server (or using MATLAB Production server). The system data flow will have a cyclic direction such as intraoral camera images – upload with a mobile or web application - cloud server – machine learning model – patient-doctor consultation terminal, which can be online through the to-be-built application or face to face, depending on the severity of diagnosis and treatment plan.

To protect patient's privacy, no user identification information except age and gender will be collected. Every dentist office in Ulaanbaatar (where the pilot study will be conducted) has a good internet connection, so uploading images with a mobile or web application will have no issues. The mobile application will have a data filtering function that will warn and stop the uploading whenever the data trying to upload is not aligned with the data criteria pre-defined by the project experts. During the data collection period, the IT team will conduct extensive research on the existing open databases for various sources of teeth images to enrich the data used for our machine learning model. But we would be careful with the orientation of the cameras used in different scenarios for avoiding any bad impact to machine learning model.

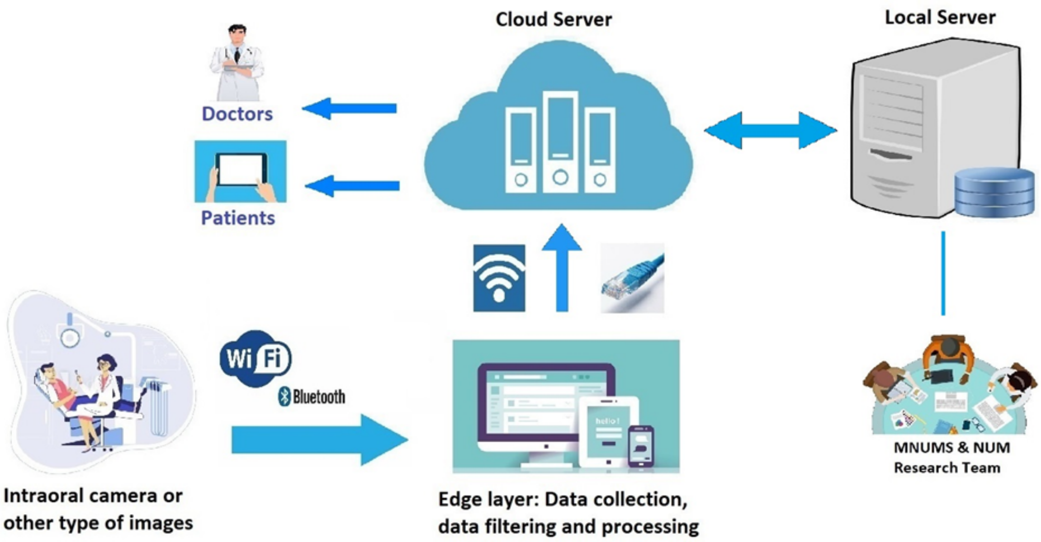

Figure 12. System diagram for the pilot use case 3 - Machine learning for dental caries detection

The NUM&MNUMS remote consultation system consists of four layers as seen in Figure 12. The description of each layer is given as below:

1. **Sensor, Data Acquisition**

This layer focuses on receiving image data from

- Intraoral camera
- Other type of medical image producing devices

for further processing. Images are transferred to the next layer through a Wi-Fi or USB cable connection.

2. **Edge Device**

The edge device (a mobile or personal computer) will have several functionalities:

- Interfacing with the sensor and cloud part
- Data acquisition
- Data filtering and pre-processing
- Local data storage
- Transformation of data
- Transferring data to the cloud server

3. **Cloud Server**

The pre-processed and cleaned data in the edge part will be sent to the main cloud server for storage and data processing. In this layer, we plan to use Amazon Web Services or MATLAB Production Server and the server will be used for two main functions:

- Data Storage
- AI model Training

4. **Local Server**

The local server will be used similarly to the cloud server, only it is for further long-term development and maintenance purpose with cost effectively.

5. Conclusion

This deliverable outlined selection of sensor types and model for system integration for the three digital health monitoring applications namely; cardiovascular, mobility disorder (fall detection) and remote consultation for dental patients. This deliverable reports the sensor hardware chosen for each pilot case and details on how these will be integrated with proposed system for end-to-end data collections and analysis. A salient feature common to all three systems is use of cloud and edge technologies for data communication, storage and analysis. The proposed sensor and system integration will serve as a building block to the implementation and realization of full system proposed in the WP2 (Tasks 2.1 – 2.6).

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