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Towards Ambient Assisted Living (AAL): Design of an IoT-based Elderly Activity Monitoring System

I.D.M.S Rupasinghe
Dept. of Computer Engineering, General Sir John Kotelawala Defence University, Sri Lanka
E-mail: 35-ce-0010@kdu.ac.lk

M.W.P Maduranga
Dept. of Computer Engineering, General Sir John Kotelawala Defence University, Sri Lanka
E-mail: pasanwellalage@kdu.ac.lk

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Abstract: This paper presents a design and development of an IoT-based system to real-time track elders' physical activities using accelerometer sensor data. The objective behind conducting such research is to overcome the lack of ability to monitor physical activities. Especially with the development of the socio-economic sector, the number of elders who live in isolated areas such as elderly homes have increased rapidly. In such a case with declining cognitive abilities, the healthcare of these elderly personalities becomes vulnerable. This research project fulfilled the necessity of a system to capture the vital details about those people. The Internet of Things (IoT) and cloud-based applications have become a significant part of the Information and Technology sector. Realtime monitoring is a concept tightly coupled with IoT cloud cloud-native application for this application is an excellent example of that.Further, the requirement of a low-cost system was fulfilled by using hardware components such as NodeMCU and accelerometer sensors. The designed and developed system is composed of a cost-effective wrist-worn device capable of capturing hand movement on three different arises. Hence, the detected signals are transmitted to a master node to process and recognize the activity according to the detected signal. Another significant aspect of the project is using machine learning techniques to recognize the four different activities such as walking, sitting, sleeping, and standing. The use of supervised machine learning techniques is evaluated to overcome the barriers of real-time activity recognition. Further different supervised machine learning algorithms were used and evaluated, which were extracted from existing literature. The project was conducted while accomplishing the machine learning life cycle stages, and it has significantly benefitted from generating highly accurate final results for the overall system. Further different supervised machine learning algorithms were used and evaluated, which were extracted from existing literature. The supervised machine learning algorithm Decision Tree Classifier used for this study. Using the Decision Classifier Tree algorithm succeeded in gaining more than 80% of model accuracy. Since the research topic comes under a classification type-oriented problem, the testing process of the model has been done using the confusion matrix for the trained model.

Index Terms: Ambient Assisted Living (AAL), Internet of Things (IoT), Supervised Learning

1. Introduction

In recent years the number of elderly people and elders who live independently and in isolated homes has been increased. Since elders are the most vulnerable party in terms of health, their health must be closely observed. Many developed and developing countries come across a situation where the population of elders becomes significantly high. As a result of that, it leads to an increase in the number of elderly homes. The underlying mechanisms of caretaking the elders suffer from various drawbacks such as less availability, high cost, high demand, and lack of sufficient resources. Since the health care of elderly persons is vulnerable, they require continuous consultations of medical professionals. But most countries don't have a sufficient medical sector with a solid capacity to cater to everyone.

Further, the bridge between the elders who live separately and their loved ones has become more expansive. Since this bridge between both parties doesn't seem to have any close enough connections necessity of an Information and Technology based solution was highly demanded. The initiative of this particular project was motivated by these facts, and the general idea of the project is to enhance the comfort of living of elderly persons [1-2].

There is a direct correlation between physical activities which elders perform with their physical and mental health. In such a scenario, especially when elders have declining cognitive abilities, it's essential to maintain appropriate physical activities in their daily life routine. These physical activities include movements including;

- Walking
- Standing
- Sleeping
- Sitting

It was a crucial factor to observe these activities to have an idea about their physical and mental health. The issue was there was no proper way of tracking the daily life actives of these elders closely and adequately. Since it is rather difficult to have individuals observe these elders through the day, the necessity of the Information and Technology-based tool has occurred. Further to make sure that real-time monitoring is enabled within this solution was an essential factor. The tern Internet of Things comes into play in this scenario. The problem statement can be defined as how to use IoT and Machine learning for elderly care.

With the socio-economic development, the importance of the healthcare sector is also being enhanced. One of the primary focuses of healthcare was elderly care. The idea was to increase the comfort of the elderly or people above 60 years old and ensure that they won't face any barriers in accessing medical services and equipment. Further, the ability to closely monitor these senior citizens was a hot topic in the domain of the AAL (Ambient Assisted Living). Many researchers have pointed out the correlation between a particular person's physical activities and physical and mental well-being. In this particular research project, the overall aim is to construct a mechanism for addressing this particular problem [3-4].

This study mainly focuses on the use of modern-day emerging technologies such as IoT and machine learning, which can be used to build a robust system to monitor the physical activities of a particular person. With these technologies, this research work drastically enhanced the accessibility and availability of medical services to those above 60 years of age and who live in solitary environments. While conducting the project, a thorough analysis of the existing or related works has been done, and with that, the negativities of each of them are being identified. That process was crucial when it came to an understanding the scope of the project and identifying the technical and non-technical requirements under the scope of the project. Proposed systems is consisting a wearable sensor node and which includes a NodeMCU board and a accelerometer sensor. The acceleration values of x y and z axes are sent to the IoT cloud using MQTT broker. It will be applied machine learning techniques to train the accelerometer data and predict the current activity of the elder person.

2. Related Works

L. Mainetti et al. focus on designing a system to ensure the health of the elders is in a strong condition. Research more focuses on catering both indoors and outdoors for observing purposes. This particular research work is drastically focused on triggering a warning for predefined dangerous situations such as falls and collisions. The system's overall architecture comprises acquiring the data from sensors and passing those into the reasoning server via Bluetooth communication protocol. This particular reasoning server is responsible for notifying the related parties when a predefined set of hazardous situations has occurred.

P. Duarte et al. focus on researching a systematic mapping about the Ambient Assisted Living underlying platforms thatsters focus on researching a systematic mapping about the Ambient Assisted Living underlying platforms that cater to IoT concepts. Here, the authors have thoroughly analyzed the requirements that end users are expecting from the AAL system. So the paper emphasizes that the elders expect these AAL systems to be user-friendly, secure, scalable, adaptable, practical, cost-friendly, secure, scalable, adaptable, effectual, cost-effective, comfortable, etc. So, when designing an AAL system, it is crucial to make sure that the system caters to these requirements. Otherwise, the primary objective of such systems won't be fulfilled.

Works presented in [9] are primarily based on designing and developing an AAL system using Wireless Sensor Network (WSN). Initially, the authors describe the advantages and disadvantages of having WSN for designing an AAL system, and here using WSN has advantages such as cost-effectiveness and scalability. The overall system contains a wireless sensor network together with a cloud server. It suffers from drawbacks such as the system being vulnerableto being distorted from external parameters such as semimature. Also, it suffers from a lack of transmission speed. Most, notably in this particular project, the system suffers from high power consumption and it's a very significant drawback of this research.

Focus on a system specifically designed to observe the health conditions of senior citizens. The cloud computing architecture which is being incorporated in this project is Fog to Cloud (F2C). Here, it maintains a cloud server to log all the patients' health-related records and evaluate their health conditions. This particular system is moreover H. Saidi et al. focuses on health monitoring rather than activity monitoring. Ultimately the overall performance of the system is evaluated using the FogWorkflowSim toolkit. In [11], the intention is to design a wearable device that captures the

activities performed by the person who wears that particular device. The research is also extended to a phase where these sensors could be hung onto various clothes to capture the data and recognize the specific activity. These sensors are capable of responding to parameters such as field characteristics and sensor geometry. Here the science behind designing capacitive sensors is using the principles of electric flux simulation.

The system proposed in [12] is more focused on designing a system capable of recognizing ongoing activities. The primary technology is used here is image processing, and video surveillance is incorporated within the system. The activities are classified after analyzing the video footage collected from a video camera positioned within a specific place. These input data either might be the sequence of images (video) or still photographs. Afterward, these collected image data will be forwarded through a series of steps such as pre-processing, segmentation, feature extraction and retraction, and then detection. Further authors emphasize several obstacles or challenges when it comes to processing the image data. They're such as,

- Differences in recording settings such as resolution, frame rate, etc.
- Capturing images from different environments

However, this project is less recommended for healthcare as it severely breaches the privacy and security of the users. Also, the cost factor is a significant concern since the implementation of the infrastructure is quite costly.

In[13] develops a human activity recognition system using the technology of an array of infrared sensors. The original work emphasizes the fact of making it cost-effective. Using these low low-resolution infrared sensors enables measuring the temperatures with an area of two dimensions. The benefits of using this system are that it's smaller in size, cost-effective, and has no privacy concerns. Also, it can operate in darkness. However, the accuracy of the sensor array is pretty minimal as it can distinguish between heat from the human body or something else (anima, hot water bottle, etc.) Using these characteristics, the project's authors came up with a solution to identify the heat generating from the human body (heat which dissipates to the environment) and recognize the ongoing activities.

Supervised learning has been investigated on activity recognition in [14]. This is also research that is relevant to human activity recognition. The basic methodology behind recognition in this study is to use the fact that if there is something available or not. The sensors are responsible for identifying the existence of persons, and afterward, the output will be generated as a sequence of binary values (1s and 0s). The authors used Support Vector Machine Classifier to distinguish between the activities succeeded in determining eight different activities. The primary issue of this research is that it requires a sufficient amount of data (binary information) to provide the outputs. T a sufficient amount of data (binary information) to provide the outputs, and this operation takes a significant amount of time. However, around 80% of accuracy has been achieved within this research work.

Q. Liang focuses on human activity recognition relying on the technologies of Thermopile Imaging Array Sensor. The system is composed of a 32*32 sensor array capable of viewing an area of 33in x 33in. The outputs generated by these sensor array sequential images, and each of the pixels on those images represents a temperature measurement. The activity recognition process will kick start even if the target element (a person in this scenario) is within the range. So, this is a limitation of using this technology. Therefore, these sensors are attached to a room wall and can only capture the data within that specific area.

The works in [16] mainly focus on using wearable devices to recognize activities performed by humans. The main idea is to make use of wearable devices to capture a person's moments. The researchers are seeking the best positioning of the wearable device in the human body. Areas such as waist, wrist, thigh, and ankle are being tested for this purpose. The data capturing mechanism is based on an accelerometer sensor, and a wearable device designed with an accelerometer sensor is used for that. Further, to classify the activities supervised machine learning techniques are being used. The model's training process uses ML algorithms such as Decision Table, SVM, and Bayes.

The works of [17] authors are experimenting with mobile phones to identify the activities performed by persons who carry them. The primary concern of this particular research is the use of a data set. The embedded accelerometer sensor in modern-day mobile devices are used for capturing the patterns of motions. Afterward use of the J48 classifier to classify the capture into a predefined set of activities is done. While evaluating the overall accuracy, the system provides less accuracy to activities such as sitting and standing. Since the accelerometer sensors within the mobile phones manufactured by various manufacturers do have considerable deviations from each other, it is a huge obstacle when it comes to preparing a training set. Further, the less practicality in cost and availability for this project using sophisticated mobile devices is also considerable concern about this research work.

By evaluating the findings from related works, quite a few matters or drawbacks should be addressed. Even though quite a few research works are done on this particular domain, most of them have many limitations. The ability to operate in real-time capability was lacking significantly. Further involvement of machine learning algorithms was also minimal. Further, most research hasn't provided maximum usability while providing the most efficient and accurate end users. Further, more usage of the Internet of Things for AAL systems hasn't been signed, and it's an area that should be addressed.

3. Background

3.1 Internet of Things

This describes a physical object network (IoT) embedded with sensors, software, and other technologies to connect and exchange data with other devices and systems through the Internet [2-3]. IoT is an extensive network of connected things and people collecting and sharing data about how they are used and their environment. IoT has become the most critical technology in the past few years. Now that we can connect everyday objects like baby monitors, cars. It means low cost of computing the cloud, mobile technologies physical things can share and collect data with minimal human intervention There is the number of technologies has possible for IoT including access to low cost, low power sensor technology, Connectivity, Cloud computing platforms, Machine learning, and analytics and Artificial intelligence.

Moreover, IoT devices are part of this concept. As an example, we can consider a Smart home. We can automate our homes by using IoT. We can control lighting, security systems, and air condition by using IoT. Then we consider how IoT applies to health care services. We can use it for different purposes like data collection of patients and data analyzing, and also we can use it for remote health condition monitoring etc. Some hospitals are using smart beds, so we can notify when the patient is getup. These are a few examples of applying IoT for healthcare purposes [6].

3.2 Supervised Learning

The underlying objective of using supervised machine learning is to use a trained machine learning model to produce the results/outputs by relying on inputs. In this particular scenario, inputs are the sensor readings coming from IoT wearable devices. These inputs are the measurements of accelerometer sensors.

In the modern era, the usage of machine learning has been increased to many industrial and non-industrial applications. The emerging technologies such as AI (Artificial Intelligence) and smart homes, smart cities, etc. These are being motivated and developed on the foundation of the concepts of machine learning. The ability of machine learning-related technologies to act accordingly by considering the previous learnings is a considerable benefit. Supervised machine learning is a sub category of machine learning disciplines capable of predicting the behavior or the fate of future instances by using a set of previous instances that are labeled [20].

While comparing static programming, supervised machine learning doesn't require a program. The only thing is to supply the learning materials in the form of a dataset. In relevance to this research project, supervised machine learning is used to predict the current activity and generate accurate enough results. Under the scope of this project, few machine learning algorithms based on supervised learning have been used. These algorithms typically rely on the input dataset to generate predictions. Those algorithms include the Decision Classifier Tree algorithm K-Nearest Neighbor algorithm and Random Forest Algorithm.

4. Design and Implementation

4.1 Wearable Device Design and Implementation

The particular system's design was based on a design architecture that empowers the system to cater to the primary and required functionalities of the system. The system contains several hardware and software-related components, connected, and interacting flow is elaborate in Fig.1.

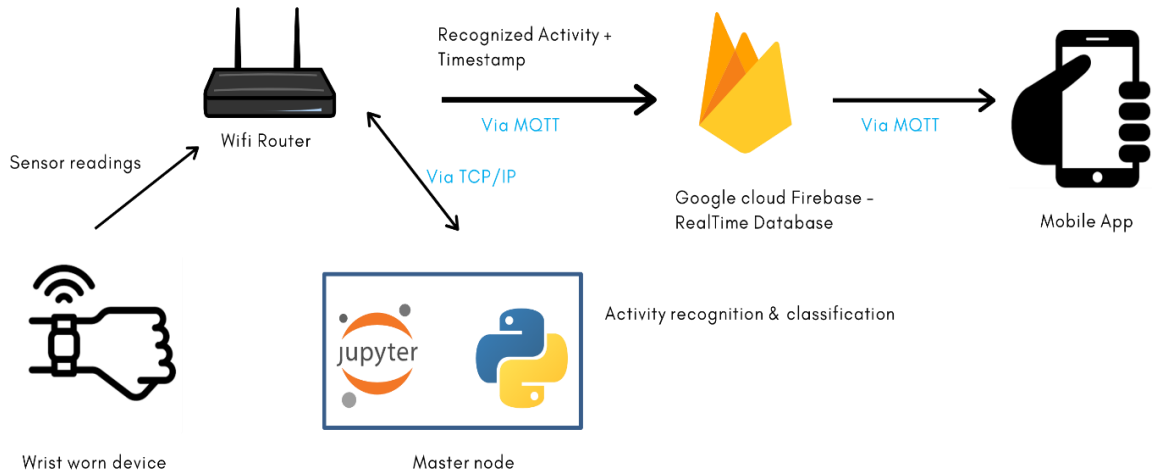

Fig.1.The System Overview

The design of the wearable device should cater to all of these requirements while fulfilling the primary requirements. In this scenario, the Node MCU (esp -8266) board is the perfect solution. The WiFi SoC module provides specifications such as operating voltage 3.3V, clock speed 80MHz, the flash memory 4MB, includes a PCB WiFi antenna [18]. One of the main advantages of using Node MCU board is that it is smaller, so it perfectly suits designing such a wearable device.

Next, the problem was to determine a sensor that could capture the motions accurately. The perfect sensor should be able to provide sensor reading with high precision all the time. Also, the sensing rate is a crucial factor, and the sensor should have lesser latency to cope with the system's real-time operation. This requirement is fulfilled by using a mu 6050ngyroscope and accelerometer sensor. Which exhibits specifications such as [19]

Then the necessity of a master node has been raised since the system requires a central processing unit to provide results relying on incoming sensor readings and supervised machine learning techniques. To run the trained set using ML algorithms, a computer/ laptop which runs on Windows operating system is being used. The computational power that a computer has is considered in this case, and it is fully capable of matching the requirement of an IoT-based system. Afterward, the problem was about the connectivity between IoT wearable device and the master node. To resolve that, a WiFi router that operates in IEEE 802.11b/g/n is being used. This WiFi router is capable of taking 12v, 1A while maintaining a power consumption of 5W. To transmit data, HTTP communication protocol; has been used.

The system comprises IoT wearable device, master node, cloud server, and a mobile application. The designed and developed IoT wearable device is responsible for measuring the fluctuations in the acceleration of the person wearing the device and transmitting it to the master node in real-time. The WiFi router between the IoT wearable device and the master node will transmit the data via TCP/IP protocol. Next, the master node sits in between the IoT wearable device and acts as the system's brain. This master node will process the incoming signals and provide predictions or results according to them. Afterward, the predictions will be transmitted to a cloud server. The designing process of the master node was done by considering the required computational power. This master node is a PC/laptop which runs Windows 10 OS. The master node directly connects to a cloud server which accepts incoming data from the master node.

As the IoT cloud, Google Firebase is used. Firebase is a mobile platform from Google that offers several different cloud-related features. The service allows users to save and retrieve data from any device or browser. It is a lagging platform for web, Android, and iOS applications. Firebase offers a real-time database, different APIs, multiple authentication types, and a hosting platform. Since this is an introductory practical session that covers the basics of Real-Time DatabaseWhen our users are offline, and the real-time database uses the device's local cache for SDK modification services and storage. Local data is synced automatically when the device arrives online—store and sync data with NoSQL cloud database. Data is stored as JSON and synchronized in real-time to every connected client and remains available when your App goes offline. This has some pros and cons.

The cloud server acts as the central database of the system. It directly connects to the master node and the mobile application. The server relies on sub-pub architecture and stores the incoming data in the collections (tables in No SQL databases). The cloud server will act as a middleman for accepting data from the master node and then transmit to the mobile application. The mobile device which runs the Android OS platform is being installed with the designed and developed mobile application that will provide features such as authentication, real-time monitoring, and a detailed report about records to the end-user.

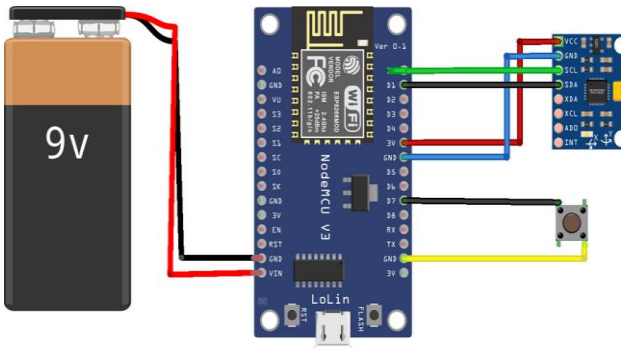

Fig.2. Circuit diagram of the wearable device

Fig.3. Actual image of the device

Fig.2 elaborates on the connectivity between the following components, NodeMCU -esp 8266 MPU 6050 accelerometer sensor, 9V power source, and Switch (push down).

The connection with each component is established using circuit wires, and then all the components have been soldered into a dot board. An HTTP communication protocol is being used when programming the Node MCU to send the sensor readings towards the master node vial WiFi router. By using restful web API, this task was succeeded.

4.2 Accelerometer Data Collection and Pre-Processing

The dataset was collected using the above device. The data instances are being collected for this scenario, and the complete data set contains 220 instances. All of those instances are classified under activities that are intended to be recognized as the final output of the system. The dataset acquisition process was done within a controlled environment by adhering to the primary principles of the scientific process [19]. For this process, both male and female test subjects were being used and considered having senior citizens (above 60 years of age) as the test subjects. The data collection process was done at a sampling rate of 1500ms, and this was set by the use of delay keyword embedded with Arduino C language. The pseudo-code elaborates the steps which are involved to classifying the sensor readings.

```
Start
                Input: Sensor readings (in a single string)
                Output: X-axis measuring, Y-axis measuring, Z-axis measuring, Date & Timestamp

DECLARE arrayOfSensorReadings: ARRAY OF STRING

Begin Loop :
                X axis measuring = arrayOfSensorReadings[0]
Y axis measuring = arrayOfSensorReadings[1]
Z axis measuring = arrayOfSensorReadings[2]
Date & Time stamp = Current date & Time in milliseconds

END LOOP
```

Hence the application will recognize the incoming sensor readings in terms of accelerometer sensor readings concerning X, Y and Z arises, and store/save them in three different columns in a Google sheet. In addition, there is an autogenerated column for adding and time stamp for each of the data instances. This is mainly because of the necessity of validating the sampling rate of the data collection process. Also, a separate column is dedicated to inserting the label or the class of a particular data instance.

5. Model Training

After the dataset has been successfully collected and these are raw data instances that are being labeled. Then the dataset must be appropriately processed and analyzed. To provide accurate enough predictions from the model, there should be a sequence of operations performed on the dataset. First of all, the dataset is needed to be pre-processed. Data pre-processing is a significant aspect of machine learning-based projects [18]. The impact of the data pre-processing phase is on enhancing the machine learning model's overall accuracy and making the model consistent enough to provide online real-time predictions. Data pre-processing typically involves operations such as.

The cleaning process for this particular dataset was done by checking for duplicates and null or empty values. Also, the incorrect data are being removed by categorizing them as unclassified data instances. Further, the missing values in between data instances are being checked, and in case of such missing values, the data instance is being removed.

Data integration emphasizes the idea of merging several sub-datasets. In this scenario, the data instances which are beign collected using different individuals in different periods are being combined to make a sufficient dataset. The training process of the dataset is incorporated with the use of supervised machine learning techniques. The idea was to provide predictions relying on previous learnings. The relevant machine learning algorithms used to train the model are being emphasized in the previous chapter by referring to their characteristics.

The training process is started by importing the collected and pre-processed dataset to the machine learning project. Pandas library, a popular data analysis-based library in Python, is also used for this particular case. The real-time monitoring module offers the application's core functionality, which is to observe the data instances in a cloud server. The application will provide a graphical representation of a particular activity depending on the incoming server readings. For example, if the current ongoing activity is sitting, the App will show the user a graphical representation of a sitting person.

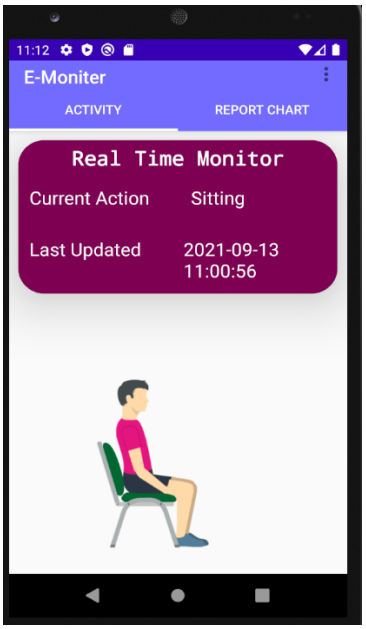

Fig.4. Mobile App. Developed for real-time monitoring

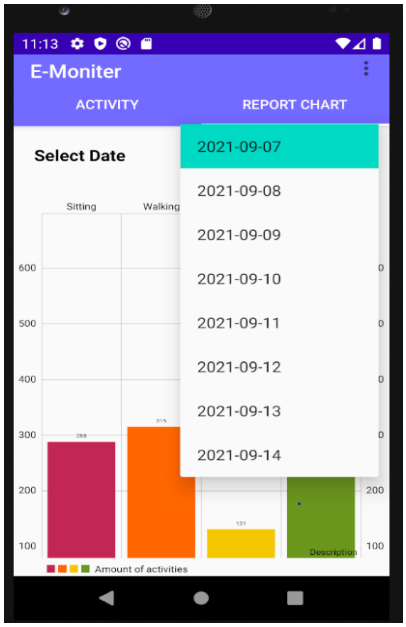

Fig.5. Report generating function of the Appc

Fig.6. Real-time testing of the activity

6. Testing and Evaluation

This particular project is typically based on machine learning techniques, and there are two different problem types available in conventional machine learning-based projects. Namely classification type problems and regression type problems. This particular research work comes under a classification type problem [21-22]. In classification type problems, the evaluation process typically done by creating the confusion matrix to measure the model's performance. A confusion matrix is a detailed summary of the predictions made out of the trained model. It emphasizes how the model is behaving when giving predictions for new data instances.

Table 1. Confusion Matrix

	SLEEPING	STANDING	WALKING	SITTING
Sleeping	**4**	**0**	**0**	**0**
Standing	**1**	**10**	**0**	**0**
Walking	**0**	**0**	**8**	**3**
Sitting	**0**	**0**	**1**	**7**

Table 2. Accuracy of activity recognition using Decision Tree Classifier

Activity	Accuracy
Sleeping	100%
Standing	89%
Walking	70%
Sitting	80%

The above confusion matrix was created by using Python programing language and using the test set divided in the training process of the dataset. Observing the above confusion matrix can come across the accuracy of the trained model's precision is sufficient. Especially the model can successfully recognize sleeping activity and provide almost 97% accuracy in such cases. This is mainly because the sleeping activity doesn't involve more extraordinary moments, and thus the algorithm or the model won't confuse much in detecting such occasions. Further, the two sitting and standing activities also provide enough accuracy (80% or more than 80%). But the walking activity is showing an accuracy under 80%, mainly because of the greater moment of the activity that leads to confusing the model much more. After the model was tested and evaluated with statistical parameters, the functioning of the overall system was being evaluated whether to identify that the statistical analysis and real-world testing provide the same results.

7. Discussion

The ultimate goal of the research work is to enhance the comfort of the life of the elderly society of the senior citizens by designing and developing a monitoring system to evaluate the vital physical activities of their day-to-day life. The entire system was empowered with the Internet of Things and machine learning techniques to enable remote monitoring. The overall system design incorporated a wearable device designed using a NodeMCU board and an accelerometer sensor. The particular wearable device did fulfill the primary aims and objectives of the project. To proceed with the implementation of the project, several technologies were used. The reasons for selecting such a technology stack have been discussed. This research project also focuses on the supervised machine learning techniques which can be incorporated for human activity recognition. Three of the most commonly used machine learning algorithms were being discussed under the scope of the project. This paper mainly focused on elderly activity recognition and, at the end of the project, recognized four different activities successfully: sleeping, walking, standing, and sitting. As for future work, the project's scope can be enhanced to allow the system to recognize more activities such as climbing a staircase up or down, reading a book, and exercising. Also, it can add a new feature to detect any collisions or falls of the person wearing the IoT device and trigger a warning to their caretakers in case of such a situation.

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Authors' Profiles

IDMS Rupasinghe is a final year undergraduate in BSc. (Hons.) in Computer Engineering at the General Sir John Kotelawala Defence University, Sri Lanka. He is currently persuing a internship in software engineering in the Information and technology industry. Also, hs is a student member of the Computer Society of Sri Lanka (CSSL) from 2019 onwards. He is intrested in research areas such as Internet of Things based home automation, machine learning in IoT applications and IoT security.

MWP Maduranga obtained his BSc.Eng. in Electronic Engineering degree in 2013 from the Asian Institute of Technology(AIT), Thailand, and MS.c.Eng in Electrical and Electronic Engineering degree from the University of Peradeniya, Sri Lanka, in 2017. He received Engineering Charter in Electronics and Telecommunication Engineering from the Engineering Council, the UK in 2020. Also, he is a senior member of the IEEE. He is currently a lecturer in Computer Engineering at General Sir John Kotelawala Defence University, Sri Lanka. His current research interests include Machine Learning-based indoor localization, AI/ML in IoT Applications , and wireless communication

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