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(Research Article)

# Implementation of multi-agent AI voice-controlled smart home systems supporting mobility-impaired aged users for inclusivity and sustainability

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## Abstract

This paper is presents a comprehensive framework for transforming legacy home buildings into fully inclusive, intelligent and sustainable environments through the deployment of smart infrastructure. It utilized cutting-edge technologies including Internet of Things (IoT), Artificial Intelligence (AI), and adaptive architectural systems, to dismantle physical and digital barriers faced by mobility-impaired aged and disabled persons in their residential homes. The work introduced a smart home system designed for mobility-impaired aged persons using sensor-based technologies to create Internet of Things (IoT) of home area networks (HAN). The IoT network has home appliances and security devices to meet increasing infrastructure demands driven by the growing elderly population in developing countries. This work designs, models and implements the Multi-agent AI and IoT HANs for mobility-impaired aged users in a proteus environment. The system lets users control home technologies and environments through sensors and mobile devices by utilizing natural voice commands and IoT networked microcontrollers. Experimental results from a three-room apartment implementation show that the system can manage home appliances and assistive devices. While the system exhibits lower performance in noisy environments, it enhances independence for mobility-impaired aged individuals. Machine training of specific older adults is used to enhance the security of the proposed model. When tested, the IoT HAN system correctly rejected untrained persons.

**Keywords:** Mobility-Impaired Aged Person; Internet of Things; Proteus Environment; Smart Home; Home Area Network.

## 1. Introduction

The World Health Organization (WHO) showed that 1 billion persons aged 60 or older live worldwide (WHO, 2022). This number will double to 2.1 billion by 2050. The shift in ageing population distribution started in high-income countries, but now the low- and middle-income countries are experiencing the most significant change (WHO, 2022). The demographic shift towards an ageing population, particularly pronounced in developing countries, has brought to the forefront the pressing need for infrastructure that caters to the unique requirements of older persons with disabilities. This demographic trend is accompanied by a surge in impairments resulting from diverse factors such as accidents, traditional delivery practices, poverty, poliomyelitis, stroke, tribal wars, acts of terrorism, physical or mental trauma, and societal challenges, which limit the autonomy of seniors in performing daily tasks.

To overcome these challenges, this work implements a comprehensive framework for transforming legacy home buildings into fully inclusive, intelligent and sustainable environments through the deployment of smart infrastructure. The initiative, titled "Intelligent Homes for Inclusivity," aims at utilizing cutting-edge technologies including: Internet of Things (IoT), Artificial Intelligence (AI), and adaptive architectural systems to dismantle physical and digital barriers

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faced by mobility impaired aged persons in their residential homes. This system introduces a multi-agent AI and IoT-based smart home system supporting mobility-impaired aged persons to overcome the current traditional accessibility measures that often focus on static compliance, which have failed to address the dynamic, real-time needs of mobility-impaired aged persons' population. By harnessing the power of natural voice commands, networked microcontrollers, multi-agent AI and IoT-based technologies, the envisioned smart home system that revolutionize the living experience of mobility-impaired aged individuals was realized. The objective is to empower this group of individuals with the tools and resources to navigate their living spaces with ease, comfort, and independence. The social impact of this approach encompasses a fundamental shift in how mobility-impaired aged persons interact with their living spaces. This smart home system fosters inclusive empowerment and autonomy by enabling individuals to control their home environments through voice commands and mobile devices, which is essential for maintaining inclusivity, dignity and independence in the later stages of life.

The main contributions of this paper are that it:

- models, designs and implements a multi-agent AI and IoT-based HAN for mobility-impaired aged persons;
- uses voice command to harness the advantages of a multi-agent AI and IoT supporting assistive living for mobility-impaired aged and persons;
- creates an inclusive platform that supports mobility-impaired elderly persons;
- presents machine training as AI method of securing the multi-agent and IoT HANs for mobility-impaired aged persons from intrusive network control by untrained persons.

## 2. Review of Related Works

According to (Aqeel-ur-Rehman & Khursheed, 2014), the home automation industry is among the most rapidly growing industries with the capacity to change people's living standards. The authors developed a hand-held voice-controlled automation system for homes, enabling users to speak their commands to perform specific tasks at home without walking over to the microphone to speak. Authors (Helo, et al., 2021) combine multiple functions and computerized devices for various domestic uses in a single system. It utilizes a computer/smartphone through the Internet to monitor, measure, and control home conditions, appliances, and home access.

It is vital to achieve mixed initiative when designing the algorithms for smart home systems (Wu & Fu, 2011). The study integrated smart home system into an existing home environment without changes in the infrastructure to suit aged and physically impaired persons, especially those living alone in their homes, and it involved recognition of voice and security (Aliet al., 2017). The system automation comprises two modules focusing on voice command recognition, low-power RF wireless transmission modules, and a microcontroller. (Baldonado, 2024) combines detection of objects, distance evaluation, and auditory feedback capabilities to enhance awareness of the environment and navigation, aiming to improve the mobility and independence of visually impaired persons.

(Yeole, Bramhankar, Gaikwad, Bansod, & Borade, 2015) I designed and implemented a secure home automation system using ATMEGA; electrical appliances and sensors are connected to the ATMEGA board through the input/output ports. A real-time security system was proposed to monitor both doors and windows and remotely detect smoke, gas leaks, and water flooding in a home (Hou et al., 2008). A system regulator, such as a valve, monitors and sends information to the security network incorporated with this application, constrained mainly by operating range. Such constraints may be overcome by using multi-hop communication systems. Home control systems use three interfaces: ZigBee, Bluetooth, and GPRS. Energy-saving techniques are presented in the work to increase the battery life and reduce network failures. Another study (Kuriakose et al., 2022) showed that, assistive technologies have become integral to the daily lives of people with disabilities.

## 3. Methodology

The methodology involves a systematic top-down design and implementation of a multi-agent AI and IoT-based smart home system for mobility-impaired aged users. It integrates hardware subsystems—electrical controls, voice-activated interfaces, and robotic wheelchair—with sensors connected in a Home Area Network (HAN). Sensor data are processed in time windows via a central controller using a binary event model to predict actions. The system is modeled and simulated in the Proteus environment. Machine training techniques enhance voice command recognition for secure system interaction, ensuring only trained users can control home devices and assistive technologies.

### 3.1. System Model

This study uses a systematic approach to design and implement a multi-agent AI based smart home system for mobility-impaired aged persons. Its framework is a top-down design modularized and integration of various subsystems within the smart home environment. By delineating the step-by-step processes involved in system design, modelling, machine training, construction, and evaluation, this methodology ensures the seamless development and deployment of a secure, user-friendly multi-agent AI and IoT-based smart home system. The hardware model of the proposed secure multi-agent AI and IoT-based system is shown in Figure 1. It involves electrical control, voice-activated, and robotic wheelchair subsystems.

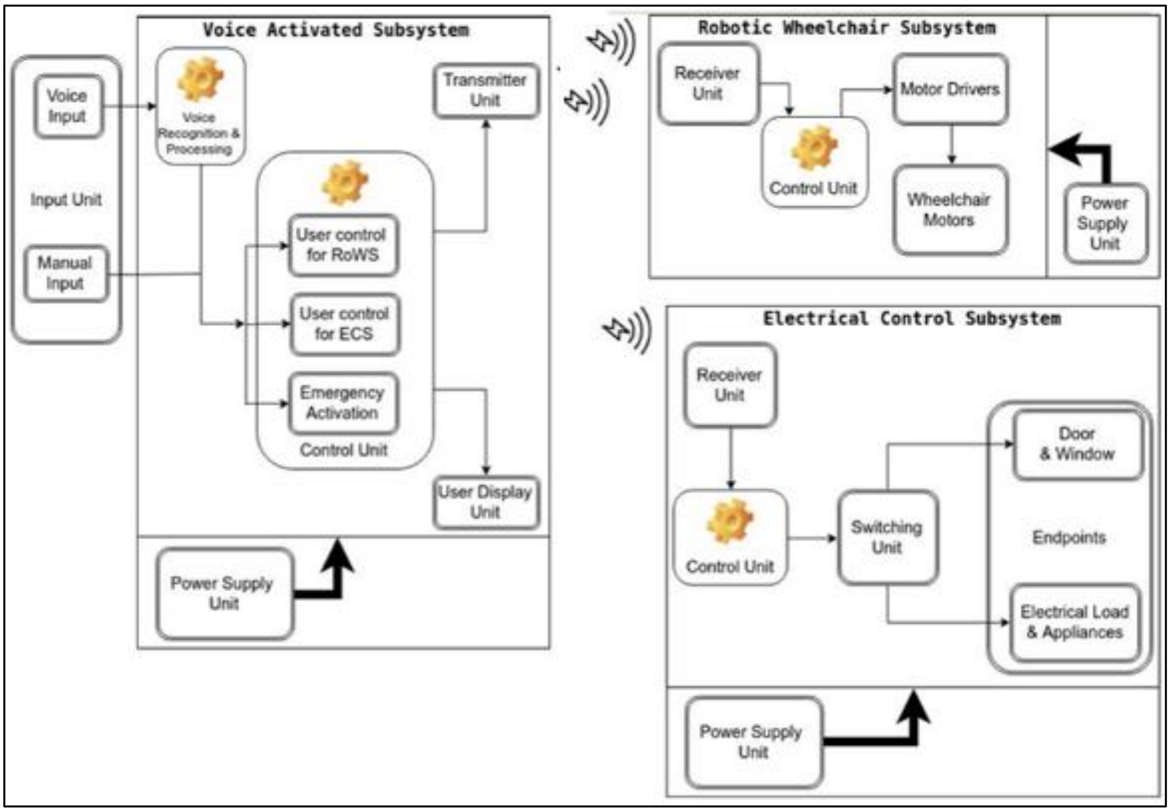


**Figure 1** Hardware architecture of the proposed IoT HAN for assisting mobility-impaired aged persons.

The information exchanged in this smart home multi-agent AI and IoT network is presented in a simplified smart home scenario model of Figure 2, and it consists of a living home with five sensors, i.e., Bulb, Fan, Door and Window sensor, and an Electrical Motor sensor.

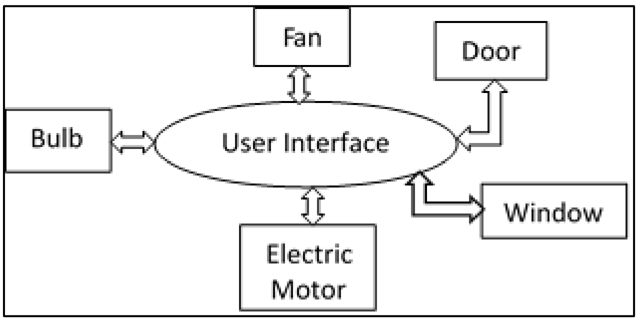


**Figure 2** A simple smart home scenario model.

In this multi-agent AI and IoT-Based smart home, every sensor used to create the HAN collects data and shares information via message passing with its neighbours, using routing nodes to forward messages until they reach their final destination.

Different actuators (switches and cellular technology) and sensors (light, window and door, electric motor and electric current sensors) contained in a simple sensor framework are used to model activities in this system. These sensors provide simple contact switches that trigger the opening and closing of changes in states in a smart home.

However, since mobility-impaired aged home occupants can perform home activities at desired times; these activities are performed at different convenient times and ways, using different sequences. The system models are illustrated by extrapolating such occurrences and actions with their performance sequences into a mathematical notation and form. The input event X is $X_1 \ldots X_N$ to the system through the sensors in the time window $t = 1, \cdots, t + T$ at left-hand side, to the identifier. Events identified are fed to the controller algorithm that determines state information S = $[S_1, \ldots, S_Q]$ with output Y in the time window $t = 1, \cdots, t + T$.

In the time window, the sensor input events are placed in a time recognizer, which can be expressed as a binary observation vector (i.e., the sensor data):

$$\dot{x} = \{x_t^1, x_t^2, \ldots, x_T^N\} \qquad (1)$$

where $x_t^i$ is the event $i$ arriving at time instance $t$, $i \in \{1, \cdots, N\}$ and $N$ is the number of sensors. These data are fed to the controller process located in the centre of Figure 4. Its output $y_t$ is always in one particular state at a time. Thus, the predicted action $y_t$ in time instance t has Q possible state values $S_i = [S_0, \ldots, S_{Q-1}]$, which in this thesis are written in a short form that leaves out the S. Thus, $y_t$ is denoted:

$$y_t \in \{1, \ldots, Q\} \qquad (2)$$

In smart home applications, Q is often in binary form, i.e., the state values can be either One or Zero (true or false, High or Low). Hence, to describe if an action such as eating is ongoing or the light is on, only two states are needed, i.e., true or false.

Since the sensor data arrive at different times, the time buffer is a matrix, i.e., it needs space for N sensor data (the columns) sampled in T instances (the rows) in Figure 4. A notation that expresses this contains one sensor vector (Equation 1) in T instances:

$$\dot{x}_{1:T} = \{x_1, x_2, \ldots x_T\} \qquad (3)$$

Its corresponding output vector:

$$y_{1:T} = \{y_1, y_2, \ldots, y_T\} \qquad (4)$$

The algorithm for implementing the above model is depicted in Figure 3.

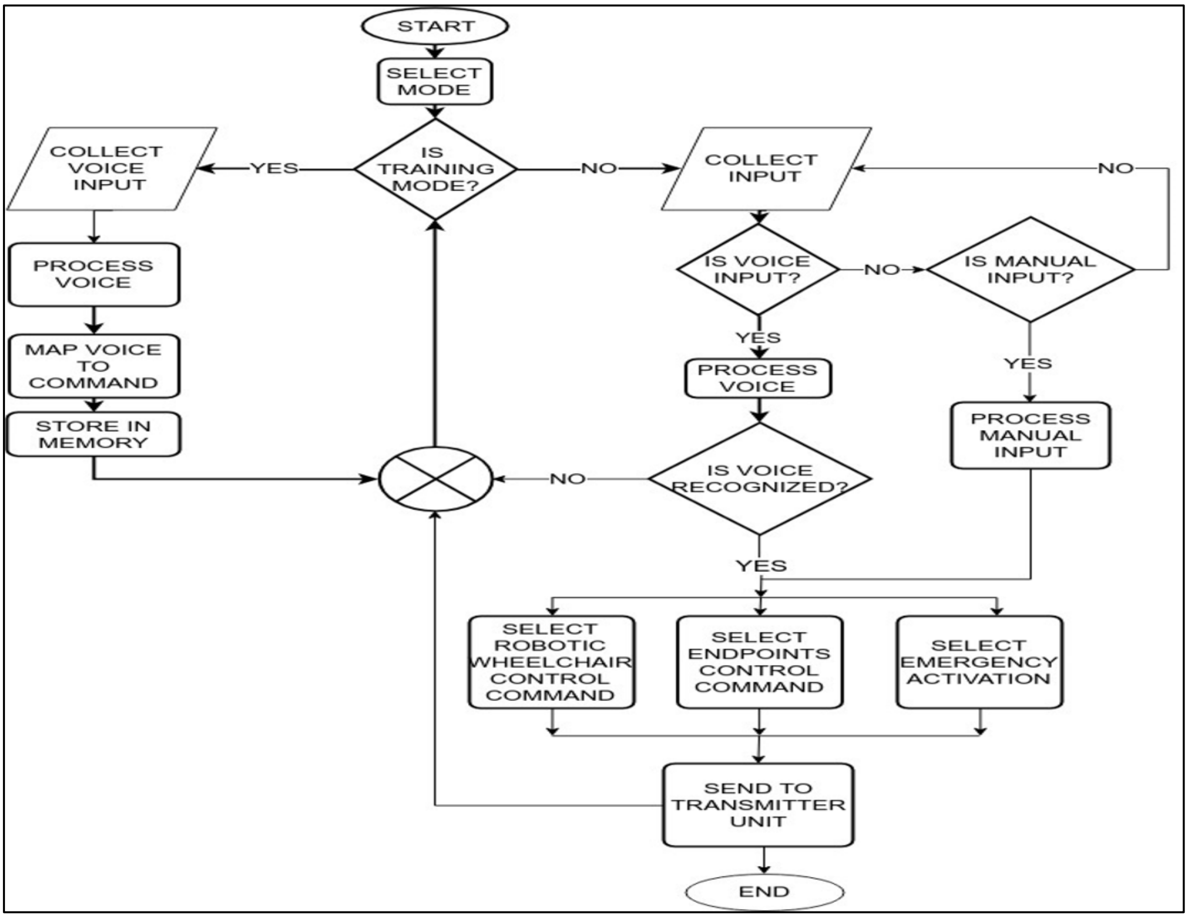


**Figure 3** Flowchart of the algorithm for implementing the developed multi-agent AI and IoT HAN for assisting mobility-impaired aged persons in a Smart Home System

This multi-agent AI and IoT-based system deployment includes the system design validation and functionality of a series of simulation tests conducted using computer software tools. These simulation tests involved modelling the system behaviour, analyzing performance metrics, and refining system parameters to enhance responsiveness and reliability. The multi-agent AI and IoT system schematic model is depicted in Figure 4. Machine training techniques were utilized to improve the system's ability to accurately recognize and respond to voice commands, ensuring seamless interaction for users to enhance the security of the system.

### 3.2. Smart Home System Prototype

The simulated Schematic Diagram of the implemented Voice-Controlled Smart Home Systems Supporting Mobility-Impaired Aged Users is shown in figure 4

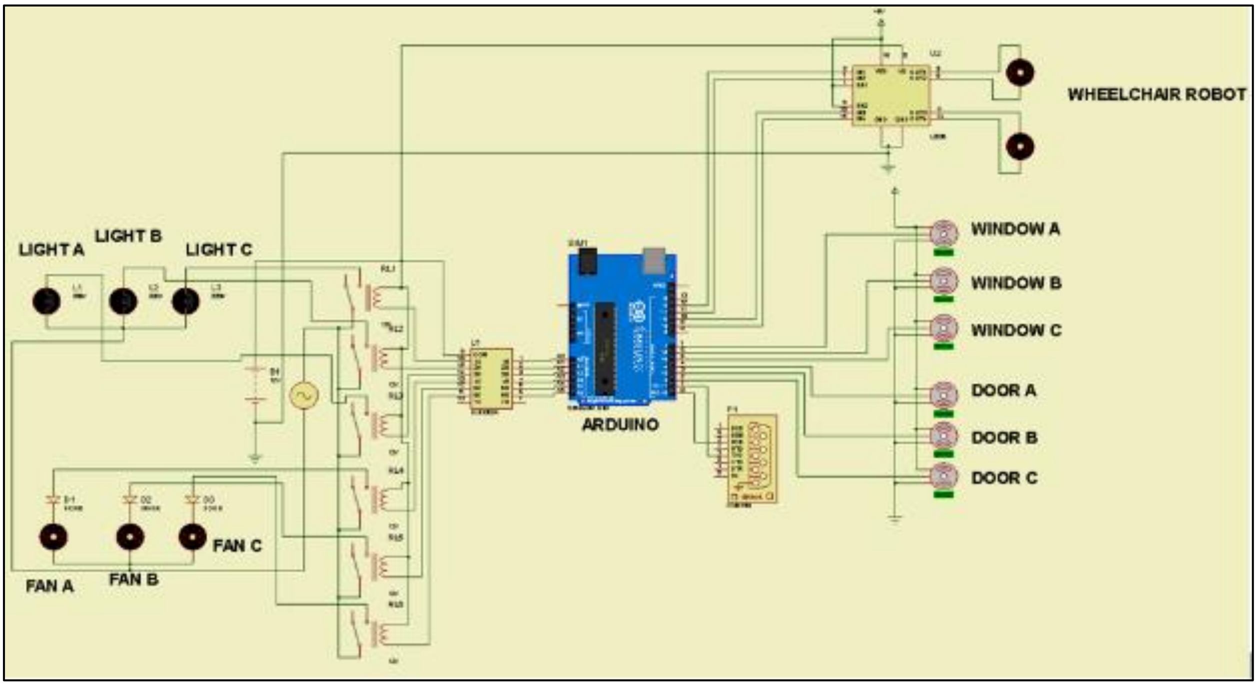


**Figure 4** Schematic model of the developed multi-agent AI and IoT HAN System for supporting mobility-impaired aged and persons in a Proteus environment

The smart home system prototype comprises the smart home subsystem prototypes shown in Figure 5.


**Figure 5** A prototype of the developed multi-agent AI and IoT HAN for assisting mobility-impaired aged persons in a Smart Home System. (Okorafor et al., 2019)

An H-bridge is implemented with four switches such that when the switches Sw1 and Sw4 are closed, and Sw2 and Sw3 are open, a voltage flows throughout the motor. The voltage is reversed by opening S1 and S4 switches and closing Sw2 and Sw3 switches, thereby allowing reverse operation of the motor. Two H-Bridge are needed, and each of them has four transistors for motor operational switches. The four conditions on which the motor movements are based are all shown in Figure 6.

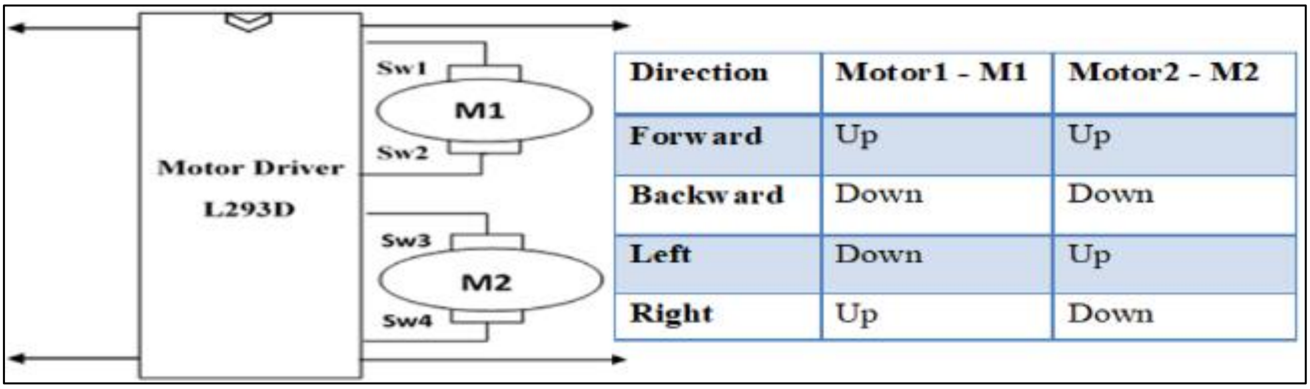


**Figure 6** The H-Bridge Motor Operation Switch and Wheelchair Direction with Respect to that of Motors

The wheelchair directions that are based on the direction of the motors are shown in Table 1.

**Table 1** The Logic States of the Switches

| Switch (Sw) Combination | Logic State of the Switches | | | | Output | Output Description |
|---|---|---|---|---|---|---|
| | Sw1 | Sw2 | Sw3 | Sw4 | | |
| Sw1, Sw2 | 1 | 1 | 0 | 0 | | Move Right |
| Sw1,Sw3 | 1 | 0 | 1 | 0 | | Move Forward |
| Sw1,Sw4 | 1 | 0 | 0 | 1 | | Halt |
| Sw2,Sw3 | 0 | 1 | 1 | 0 | | Halt |
| Sw2,Sw4 | 0 | 1 | 0 | 1 | | Move Backward |
| Sw3,Sw4 | 0 | 0 | 1 | 1 | | Move Left |

## 4. The System Performance Result and Analysis

### 4.1. Response Time

The system performance was evaluated using- the time that elapsed once the control signal has been activated and the corresponding operation executed. This result showed the records of the time difference between the period the control signal was sent and the period in which the corresponding operation was executed. The time response results for four sets of all five wheelchair control commands (20 commands) sent to the smart wheelchair are represented in Figure 7.

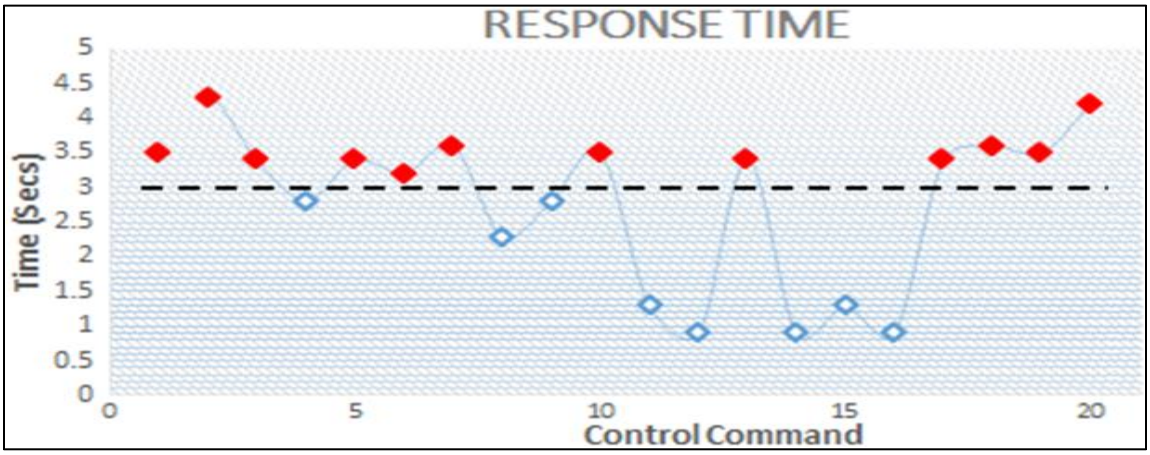


**Figure 7** System Response Time Plot for four sets of five different commands

$$T_{AR} = \frac{T_{TR}}{N_T} \quad (5)$$

where $T_{AR}$ is the average system response time, $T_{TR}$ is the total response of all readings = 58.2, and $N_T$ is the number of trials = 20. Therefore, $T_{AR} = 58.2/20$ = 2.91 (seconds).

### 4.2. The System Performance Error Rate

Using the percentage error obtained by calculating the percentage error. This is done by evaluating if the transmitted command is executed within the elapsed system response period. Hence, the system errors for four sets of five commands were recorded and used to determine the average system percentage error shown in Figure 8, where an error and no error are entered as 1 and 0, respectively.

$$\%\,Error = \left(\frac{N_E}{N_T}\right) \times 100 = \frac{6}{20} \times 100 = 30 \quad (6)$$

where $N_E$ is the number of errors. It follows that the percentage of error in the system is 30%.

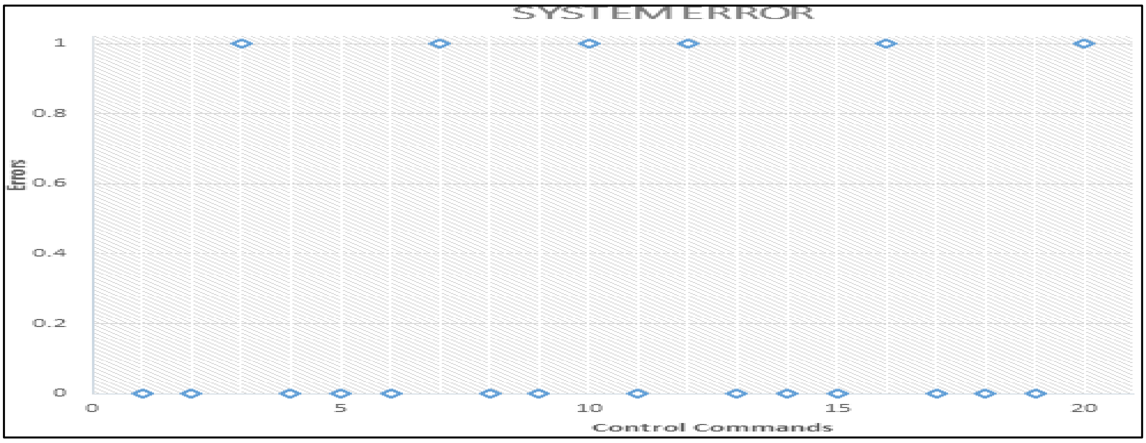


**Figure 8** System Error Plot for a variation of consecutive commands

In this final test, the average response time of the system is high and the system can be prone to errors if the user wishes to make quick consecutive changes in navigation.

## 5. Conclusion

In this study, the multi-agent AI and IoT-based smart home system is developed to assist mobility-impaired aged persons in a multi-agent AI and IoT home area network. A prototype is created using IoT sensors. The model uses machine voice command training to secure the multi-agent AI and IoT HAN from the intrusive control of an untrained person. The model was tested in a three-bedroom apartment for a trained mobility-impaired aged person by integrating hardware and software components, simulation tests, and evaluating system performance. The prototype demonstrates the potential to revolutionize home environments for mobility-impaired aged persons, providing them greater independence, convenience, and safety in their daily lives. The results decreased as the noise level increased, leading to a 30% error in the detection rate.

## Compliance with Ethical Standards

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### *Disclosure of Conflict of Interest*

No conflict of interest to be disclosed.

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