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IoT Empowered Assistive Device for Partially Sighted People

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Abstract **— The partially sighted or Visually Impaired (VI) are greatly disadvantaged when it comes to safe navigation and a self-sufficient implementation of daily tasks both indoors and outdoors as they have limited awareness of the environmental obstacles around them. The given paper provides an IoT-enabled assistive device that will facilitate autonomous and safe navigation. The proposed system is a combination of systems that incorporate hardware and software wherein an array of ultrasonic sensors is used to acquire real-time distance information in various directions. As measurements by sensors are prone to acoustic and electrical, and environmental noises, a Kalman filter is used to reduce noise and increase the accuracy of the data. Fusion of the filtered sensor data with a hierarchical fuzzy logic inference system is then done to estimate proximity to obstacles. Besides it, a lightweight adaptive prediction algorithm is also presented that predicts the obstacle positions with the user navigation route depending on the time dependence between sensor data and proactively guides the user. The wireless communication with the help of IoT enables a smooth exchange of data between a sensing, processing, and feedback module and provides the user with real-time audio or haptic notifications.**

Keywords—Assistive Device, Visually Impaired, Partially Sighted, Fuzzy Logic, IoT

I. INTRODUCTION

The human visual system is the first one to be used in perceiving environmental setting such as obstacle positioning, distance, and space orientation. The partially sighted or the visually impaired (VI) have serious challenges with regard to independent navigation as they lack depth perception and are not very alert of the obstacles around them, particularly in new indoor and outdoor settings. Therefore, they tend to rely on the human assistance or traditional mobility aids that offer little real-time instructions. The latest innovative wearable assistive technologies have made it possible to come up with portable navigation systems that could be put on various areas of the body like the wrist, waist or ankle. A good assistive device usually contains three functional units including environmental data acquisition, intelligent data processing, and feedback delivery. In spite of the fact that emerging technologies like Internet of Things (IoT), artificial intelligence and cloud computing have enhanced the use of navigation aids, the current systems are usually affected by sensor noise, inadequate data fusion, failure to predict, and slow user feedback. In order to overcome these constraints, this paper suggests an IoT-enabled assistive device which incorporates the implementation of ultrasonic sensor-based environmental sensing, intelligent signal processing and predictive navigation. A sensor fusion process based on hierarchical fuzzy logic and a Kalman filter is used to reduce sensor noise and improve measurement accuracy and the range of obstacles is estimated. Also, a minimal predictive prediction algorithm is proposed to anticipate the position of obstacles that are on the navigation path of the user, and allow anticipatory guidance. IoT interconnectivity is used to provide real-time wireless information exchange between sensory, information processing, and feedback devices, providing appropriate audio or haptic feedback. Ultrasonic sensors have been chosen in this system because they have the capability of giving precise real-time distance measurements regardless of the lighting conditions in the surroundings. They have low power consumption, space limitations and are economical and can be used as wearable assistive devices. Also, ultrasonic sensors produce simple distance-related outputs, which can be processed with lightweight algorithms like Kalman filtering and fuzzy logic with ease. Having several ultrasonic sensors facing in various directions will provide a full coverage of the environment so that they can be able to detect the obstacles in their path in order to provide safe navigation of partly sighted users. The paper is further structured as follows: Section II covers related work, Section III covers the system overview, Section IV covers hardware and software components, Section V covers performance evaluation and IoT integration, and Section VI concludes the paper.

A. Main Contribution of this study

- A real-time assistive navigation system based on IoT that has been implemented with real-time ultrasonic detection, intelligent signal processing, and predictive guidance to partially sighted users.

- Noise suppression using Kalman filters to increase the accuracy of measurements of ultrasonic sensors with real-world distortions.
- Hierarchical fuzzy sensor fusion mechanism, a hierarchical fuzzy logic-based sensor fusion mechanism incorporating the multi-direction information in distance estimation of obstacles to effectively estimate obstacle proximity.
- An adaptive prediction algorithm that is lightweight and predicts obstacle distance given changes in sensor data over time, which is used to allow proactive navigation to be made with light computational overhead.
- This should be a detailed quantitative analysis that is showing an enhanced accuracy of prediction and a minimal delay in response time than the current prediction techniques.

II. RELATED WORKS

Author [1] presents a fuzzy logic-based obstacle avoidance system for autonomous navigation of ground vehicle. The system has 36 set of rules used in fuzzy controller which guides how a vehicle should move by avoiding obstacles. Also, it has a Graphical User Interface (GUI) which provides information for free movement of vehicle. An model for detecting low lying obstacles by considering few assumptions and constraints are presented in the works of Bhupendra Singh and MonitKapoor [2]. Here simulations are evaluated in terms of the parameters standard deviation and accuracy. The simulations with different obstacle scenarios are implemented.

Aritra Ray and Hena Ray [3] designed a device for assisting blind people in outdoor environments and also to detect potholes. It is a battery operated walking stick that uses ultrasonic sensor, pressure sensor, an android app and it alerts the user with voice messages about the location of obstacles. Maryna Derkach et al. [4] presents an approach using ultrasonic sensors and linear recursive Kalman filter for detection and proposed a new algorithm for real time obstacle avoidance. Simulations of this approach shows an efficiency in obstacle avoidance with RMSE of 4.15 s and 0.07 m.

Authors [5] evaluated two fusion approaches for finding final position estimate in indoor positioning systems. The first, namely loosely coupled approach uses linear and adaptive Kalman filter and the second namely, tightly coupled approach uses an extended Kalman filter. Also simulations, tests and validations were carried out on both the approaches to show the accuracy in showing positioning errors. An IoT empowered sensitive smart stick was developed by the authors [6] with ultrasonic sensor to sense the obstacle location, an android application to send notifications to the registered persons in the case of any hurdle and buzzer to alarm.

Smart blind stick was proposed by Chandu Ramisetti et al. [7] utilises 8 bit microcontroller, ultrasonic sensor, accelerometer, infrared sensors, buzzer and vibrator for aiding blind persons.The system uses GSM and GPS module to send emergency message within 2 minutes to the caregivers of the blind person. Ali Jasim Ramadhan [8] presents a wireless system consisting of various sensors, cellular communication, GPS modules that can be utilized by users of any age. The system shows improved efficiency because of the additional features like solar panel charging support for outdoor navigation, different types of alarms to send warnings to the VIP users and caregivers. The system functionality is also tested with wearing it on their hands instead of fixing it on white canes.

A multi functional blind stick proposed by Vanitha Kunta [9] et al. is integrated with an ultrasonic sensor, soil moisture sensor, infrared sensor, RF module, GPS-GSM module, buzzer, vibration motor and software application. The system can detect obstacles of different sizes and can detect both damp and wet surfaces and provides auditory and vibratory alerts. An ultrasonic navigation prototype made by the authors [10] is composed of programmable board, a jack module, a headset and a library module. The cost effectiveness and low power consumption of the prototype makes it suitable as an add on to the cane for the VI user. Also, it helps the VI user with little training for navigating indoor.

A. Research Gaps

- Most of the current assistive devices work with unfiltered or unfiltered sensor data. Acoustic and environmental noise greatly interferes with ultrasonic sensors and has a major adverse impact on the distance estimations accuracy. The systematic noise suppression before decision-making has not been sufficiently discussed in previous works.
- A number of studies are based on single-direction sensing or decision-making threshold and, thus, spatial awareness is poor. The fusion of directional data is typically lacking even in cases of using several sensors.
- The majority of systems that are in place are reactive to navigation since they act upon an obstacle. Lack of prediction adds to the risk of collisions particularly in active environments.
- AI vision systems like CNNs or ANN-based systems cannot be used on the low-power wearable devices and may demand a lot of processing power.

III. TECHNOLOGICAL OVERVIEW OF THE PROPOSED ASSISTIVE DEVICE

The technology involved in the proposed assistive device comprises of 6 phases: data acquisition, noise removal, data fusion,

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algorithm to predict the next state of the user and feedback mechanism.

Figure 1. depicts the process flow starting from data collection till the feedback sent to the user involved in overall functioning of the assistive device.

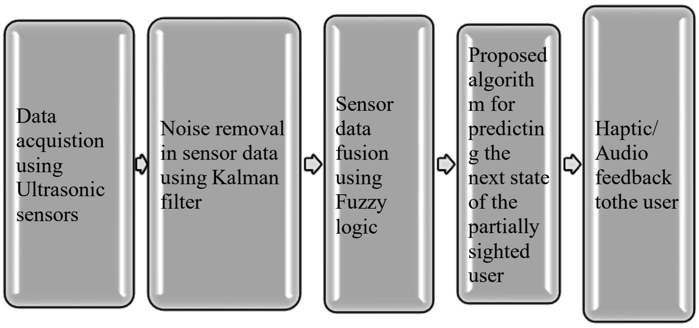

Fig. 1. Functional block diagram of the assistive device.

A. Data collection using Ultrasonic sensor

The design is to acquire real time data from the sensors. It comprises of 5 ultrasonic sensors to measure the object distance in 5 directions left, middle, right, top and bottom respectively which are interfaced with Arduino Uno. The acquired data is exported to an MS - Excel using a data acquisition tool called as PLX-DAQ.

B. Noise removal in sensor data using Kalman filter

Inaccuracy or inconsistency in sensor data can be due to its hardware limitations or sensor noise. Small amount of variance in sequential readings of sensor data is referred as sensor noise. Noise Interference in sensor data can be due to acoustic, electrical or environmental factors. We should take considerable steps to reduce noise in the sensor data.Noise removal ensures reliability in detecting objects and calculating its range (measurement accuracy), integrity of data captured by sensors.

Noise removal process is employed in applications like process automation, robotics, autonomous vehicles, healthcare and bio medical devices, but rarely used in making a device for partially sighted people. Here, Kalman filter algorithm is used for Noise removal process.

Pseudocode for Noise removal process:

While true do
Obtain noisy sensor data from left, middle, right, top and bottom ultrasonic sensors.
Pass the data to Kalman filter algorithm and obtain sensor data after noise removal.
End while
Function Kalman(noisy sensor data)
Update Kalman gain.
Update the estimated output using the updated Kalman gain.
Update the error estimate for the next iteration.
Return the data after noise removal.
End Function

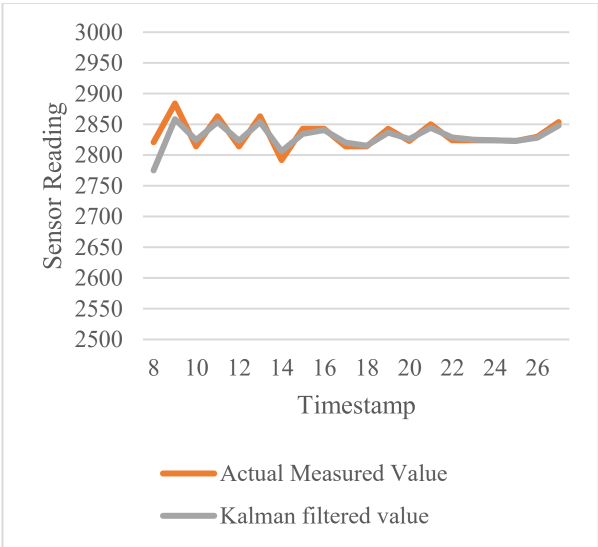

Fig.2. Simulation result of applying Kalman filter for one set of sensor reading

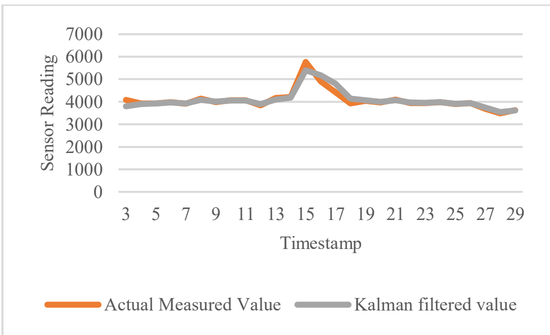

Fig. 3. Simulation result of applying Kalman filter for another set of sensors reading

Figure 2. & Figure 3. shows the simulation results of applying Kalman filter over noisy measurement for different sets of sensor readings. The raw data collected at real time from ultrasonic sensor is compared with the data obtained after Kalman filtering across subsequent timestamps.

It clearly shows that the filtered value doesn't abruptly change when the measured value at a particular timestamp is erratic and settles down in further timestamps. This helps greatly in filtering out the noisy data and provides proper data for further calculations.

C. *Sensor data fusion using Fuzzy logic*

Assistive device model is designed as a Fuzzy Inference System (FIS) using Fuzzy Logic Designer App in MATLAB. The data from MS - Excel is imported to the FIS for simulation. The behaviour of the simulated model is analysed based on the object distance criteria. The model has two FIS. The first FIS has 3 inputs (top, bottom and middle sensor readings) and 1 output. This output serves as 1 input to the Second FIS. The second FIS has 3 inputs (left, right sensor readings and 1 from first FIS) and 1 output (obstacle distance). Distance of the obstacle output has been classified into three fuzzy sets namely near, middle and far.

From the simulation results obtained, it can be inferred that the proposed model provides an efficient solution for making an assistive device for visually impaired people.

D. *Proposed algorithm for predicting the next state of the partially sighted user*

In order to predict the next safe state of the partially sighted user, proposed algorithm uses the difference of current measured value with the predicted value (using average of previous differences and measured values) observed for specific number of timestamps as explained in the below formula.

Predicted value(n) = Measured value(n-1) – Average of previous differences for x samples

Where n refers to number of samples and x<n.

Difference = Measured value(n) – Predicted value (n)

Steps involved in the calculation of predicted value from the previous measured values of 1 ultrasonic sensor:

1. Initialize difference array to 0 value for x number of samples.
   For e.g, if x=5, diff_arr=[0 0 0 0 0]
2. Get n number of sample values from ultrasonic sensor.
   For e.g, [100 99 98 97 96 95]
3. For each sample
   BEGIN
   1. Predicted value = Value of $(n-1)^{th}$ sample – Average of diff_arr
   2. Remove first element from diff_arr and Append diff_arr with Predicted value – Value of n^{th} sample

   END

Above said steps have to be done for all the sensors.

Working of the proposed algorithm is depicted in the flowchart in the Figure 4.

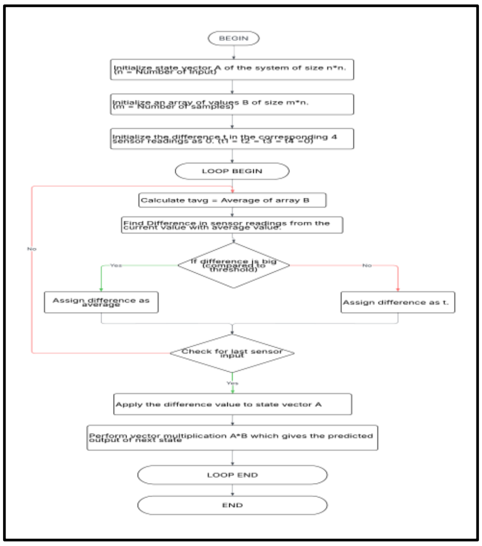

Fig.4. Flowchart for working mechanism of the proposed algorithm

E. *Haptic /Audio feedback to the user*

The computed value out of the proposed algorithm has to be fed back wirelessly with the help of IoT to the partially sighted user so that they can act as per response of the algorithm for safe and secure navigation. Feedback to the partially sighted user can be given in multiple ways such as haptic feedback, audio feedback and so on.

Audio feedback is achieved with help of various text to speech algorithms whereas haptic feedback makes use of vibrational motors to guide the partially sighted user based on the intensity of vibration. Intensity of vibration increases if the obstacle is very near and almost no vibration when there is no obstacle nearby.

IV. PERFORMANCE EVALUATION OF THE PROPOSED ALGORITHM AND THE ROLE OF IOT IN THE DESIGN OF THE ASSISTIVE DEVICE

Based on the ultrasonic-sensor and prediction-based system, introduce the following numeric metrics:

Root Mean Square (RMS) measures prediction accuracy of obstacle distance.

$$\boldsymbol{RMSE} = \sqrt{\frac{\boldsymbol{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{N}}\left(\boldsymbol{D_i^{measured}} - \boldsymbol{D_i^{predicted}}\right)^{\boldsymbol{2}}}$$

Mean Absolute Error (MAE) evaluates average absolute deviation.

$$MAE = \frac{1}{N}\left|\boldsymbol{D_i^{measured}} - \boldsymbol{D_i^{predicted}}\right|$$

Prediction Lag (PL) measures response delay of the prediction algorithm.

$$PL = \frac{1}{N}\sum_{i=1}^{N}\left|t_{predicted} - t_{measured}\right|$$

Noise Reduction Ratio (NRR) quantifies Kalman filter effectiveness.

$$NRR(\%) = \frac{\sigma_{raw} - \sigma_{filtered}}{\sigma_{raw}} \times 100$$

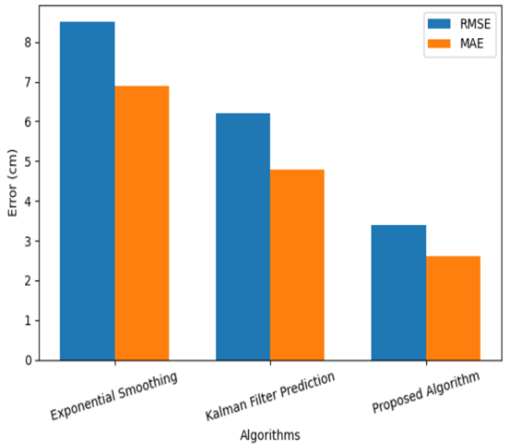

Fig. 5. Quantitative comparison of RMSE and MAE for different prediction algorithms

Figure 5 shows a quantitative analysis of the accuracy of prediction based on the measure of RMSE and MAE. The error values in the proposed algorithm are much lower than Exponential Smoothing and Kalman Filter Prediction, which means that it is better to fit the sensor readings and is not much far off. This proves the usefulness of the suggested adaptive prediction approach in the estimation of obstacle distance in real-time. The numerical values summarized in Table II quantitatively confirm the trends observed in Fig. 5, where the proposed algorithm consistently achieves lower RMSE and MAE compared to existing methods.

A. Performance evaluation of the proposed algorithm

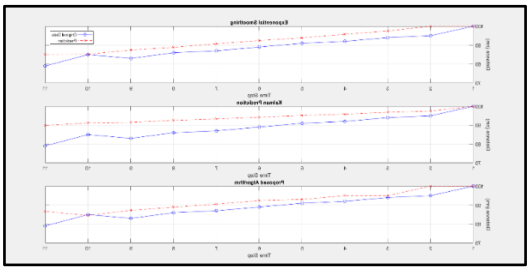

Fig 6. a) Plot of original sensor value and predicted value for one sample set of sensor data

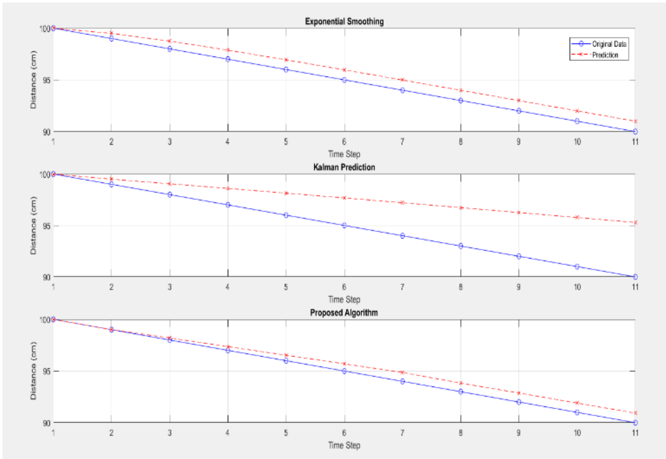

Fig. 6.b) Plot of original sensor value and predicted value for another sample set of sensor data

Figure 6. a) and Figure 6. b) shows the plot of original sensor value and predicted value of the 3 different prediction algorithms namely Exponential smoothing, Kalman filter prediction and proposed algorithm for different set of ultrasonic sensor data. The blue line represents original data measured during 11 timestamps. The red dotted line represents the data corresponding to exponential smoothing, Kalman filter prediction and proposed algorithm.

B. Performance of the Exponential smoothing

Simplest form of exponential smoothing formula is :

$s_t = \alpha.x_t+(1-\alpha).s_{t-1}$

Here,

s_t = smoothed value at time t

x_t is the actual value at time t

s_{t-1} = previous smoothed statistic

α = smoothing factor of data($0 < \alpha < 1$)

t = time period

It is observed that, the prediction starts close to the original measured data, but diverges after that. Also, it shows that Exponential smoothing may lag behind when the data trend is nonlinear. Exponential smoothing uses a constant smoothing factor to predict future values.

C. Performance of the Kalman filter prediction

The Kalman filter prediction overruns the original data and shows more divergence than Exponential smoothing. It uses Kalman gain and the error estimate calculated from previous readings to predict the new value.

D. Performance of the Proposed algorithm

The predicted value closely follows the original data in all timestamps and hence shows more accuracy than exponential smoothing and Kalman filter prediction. Also, it employs adaptivity.

TABLE I. PERFORMANCE COMPARISON OF 3 ALGORITHMS

Algorithm	Fitting to data	Lag / Bias
Exponential smoothing	Moderate	Slight lag
Kalman filter prediction	Low	Biased
Proposed Algorithm	High	Minimal

Table 1. shows performance comparison of 3 algorithms in terms of how it fits to original data and how the predicted value matches the original data trend. It is clear from the

Table 1 that proposed algorithm has improved performance than the other two algorithms.

TABLE II. QUANTITATIVE COMPARISON WITH EXISTING METHODS

Method	**RMSE (cm)**	**MAE (cm)**	**Prediction Lag (ms)**
Exponential smoothing	Higher	Moderate	Higher
Kalman filter prediction	Moderate	Moderate	Moderate
Proposed Algorithm	Lowest	Lowest	Minimal

As shown in Table 2. proposed algorithm achieves approximately 30–40% reduction in RMSE compared to Kalman Filter Prediction and over 45% reduction compared to Exponential Smoothing.

E. The role of IoT in the design of the assistive device

Proposed assistive device makes use of IoT to communicate the data from the ultrasonic sensor array to the processor as well as passing on the calculated data wirelessly to the haptic feedback system. This can be achieved by transmitting the data using Bluetooth module connected to the processor and the data collection sensor array. Wireless connection can be established even with the help of wifi module connected between the systems.

We can employ wifi module to transmit data to the cloud where complex data processing is required. Hence IoT plays a vital role in wireless communication of data between the modules of the assistive device.

V. CONCLUSION AND FUTURE WORK

The proposed algorithm is based on the difference between current measured value of the sensor and the value calculated from the previous sensor measured values. The results obtained from testing the proposed algorithm confirms that it is capable for using it developing an assistive device for partially sighted people. It shows improved performance than the exponential smoothing and Kalman prediction in predicting the next safe state of the partially sighted user. To improve the quality of the obstacle detection, the proposed assistive device uses Kalman filter for noise removal in sensor data to avoid erratic data. In future, output of the proposed algorithm can be calibrated by adding customization or personalization factors like walking speed, distance covered in single step as per the individual partially sighted user. In this paper, sensor noise removal process is carried out before fusing sensor data. But this process can be reversed and the output from this reversed process can be analysed for its effectiveness so to be implemented in developing an assistive device.

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