Blind Navigation System with Signal Processing Filters

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ABSTRACT

In this paper we have discussed a system which uses ultrasonic sensors to detect the presence of obstacles and its coupling with vibration motors to give a sense of direction to the user. Between the sensor and the motor we have proposed a signal processing unit which takes care of outlier detection and signal smoothing to pass on the best input possible to the vibration motors to reflect the environment as accurately as possible. In the outlier detection mechanism, the Adaptive Hampel Filter is used to dynamically change the window size of sampled signals to deal with the real time outliers; moreover, in terms of smoothing filter, the Adaptive Exponential Moving Average is adopted into the procedure to cope with the rapid changes in the sensor observations and reduce the response time of the system.

Keywords

Hampel Filter, Exponential Moving Filter, Adaptive Filter, Ultrasonic Sensor, Arduino UNO, Signal Processing.

1. INTRODUCTION

Traditionally, blind people have been using the walking cane to detect the presence of any obstacle, to know the texture of the surface that they are walking on and to maintain their orientation. Some of the earlier researches have tried to either replacing the use of the cane or have introduced an add-on to augment the capabilities of a regular cane. We realize there is a need to improve and possibly increase the sensing range of cane to aid the person better to orient and to help them avoid any impending obstacles. We also realize this limitation of an aiding device and thus have attempted not to replace the cane but to augment the person's capabilities and thus have come up with an approach to increase the sensing range of a person and provide the sense of direction of the impending obstacle.

There have been many attempts to leverage this capability to build aiding devices for the visually challenged people. We have used ultrasonic sensors to find the existence of obstacles. However what is unique to our methodology is the use of signal processing to detect any outliers and to smoothen the signals to intelligently use the sensor's data and protect the accuracy of the surrounding environment. In our approach we have used a vibration motor, which will help to give the sense of direction. We use the output of the signal-processing unit as the input to the vibration motor to give the sense of direction. In the next few sections of the system architecture and the proposed methodology we will explore how exactly we are leveraging the capabilities of all these units to help blind people in knowing the direction of the obstacles.

2. LITERATURE REVIEW

This section explores what has been done in this field before to solve the problem at hand. As the evolution of microprocessors and microcontrollers, there have been numerous attempts to take advantage of these technologies to aid visually challenged people. Blind mobility aid devices based on ultrasonic Doppler Effect, which is a device which converts the inaudible ultrasonic echoes into audible sound using Doppler Effect.[1] Sonic electronic guide for the blind uses the same ultrasonic echoing technique but uses speech synthesizing technique to create an audible speech to give the sense of the environment.[2] MoTA, the MoBIC travel aid explores the user interface design for an ideal travel aid for blind people, which explores planning of the journey ahead of going out of the secure place and using GPS systems to navigate [3]. NAVBELT, a computerized travel aid for blind people, is a complete suit, which navigates blind people with a mobile robot navigating through a cluttered environment [4]. Some other papers have concentrated on discrete distance and water pit detection using the ultrasonic sensors [5].

Sensor measurements are subject to errors. In our case, the constant moving of cane might be an outlier or one leg coming in the way of the sensor might be an outlier, detecting this and taking that out from the sensor data becomes extremely important. Outlier detection has many methods, like Univariate statistical methods, Multivariate outlier detection. For the Univariate measures which is our concern, traditionally, the sample mean and the sample variance would give good estimation for data location and data shape, if the data is distorted with outliers, the parameters may deviate significantly. Hampel methodology introduced the concept of breakdown point, which is a measure of robustness, thus we decided to use this method over the other existing methods.

Simple moving average (SMA) algorithm is one of the most used methodologies and it is used to smooth signals consisting of equidistant points in the data set. Each data point is equally weighted in SMA, which is inaccurate thus to counter this weakness, weighted average smoothing was introduced, where the older data will get less weight and the most recent data gets higher weight. Although this method seems logical, the weight allocation happens linearly which is not usually the case. In the real scenarios such as stock market or economics, most recent data points in a time series contributes more to the next data in the time series. To counter this, exponential weighted moving average smoothing was introduced, which assigns the higher weight to the latest data but this distribution of weight is exponential and thus the name exponentially weighted moving average.

3. PROPOSED METHODOLOGY

This section is dedicated to illustrate the proposed mechanisms in the signal processing part to deal with the noisy real time sensor data and the decision-making procedure to provide the user the sense of direction.

The overall system architecture is shown in the Figure 1.

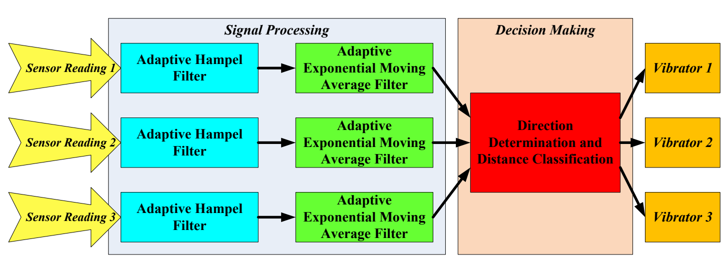

Figure 1 System Architecture

The system is composed of three main parts: I/O, signal processing and decision-making. The inputs are the three ultrasonic sensors and the actuator outputs are three vibrators corresponding to each ultrasonic sensor. The signal processing part is the part, which refines the noisy sensor observations from each sensor reading. The decision making part utilizes the outputs from signal processing to determine the accurate direction of the existing obstacles and tell the user their locations by vibrating the vibrators. There are two stages in the signal processing procedure. The first stage is outlier detection mechanism and the second stage is the smoothing filter. The sensor readings are subject to errors and, eventually, it will affect the decision making process. Therefore, to obtain more accurate measurements and reduce the response time of our system, the paper proposes the adaptive signal-processing scheme, which combines the adaptive outlier detection and the smoothing filter to fulfill the requirements. The outlier detection is used to remove the outliers in the sequences of sensor readings. On the other hand, the sensor readings are not a stable value. To have better decision, the smoothing filter should output the smooth sensor reading and input to the decision making part, especially the sensor readings are around the boundaries of distance interval we have in our system.

3.1 Adaptive Outlier Detection

The main objective for outlier detection is to accurately detect the outliers in the real time sequence in the sensor reading. One of the most conventional outlier detection mechanisms is the "3 σ edit rule" which judges a data point as "outlier" or "inliner" based on the standard deviation and the mean. Nonetheless, due to the outlier-sensitiveness of the mean and standard deviation, "3 σ edit rule" could be easily misled by the outliers existing in the observed data sequence.

Hampel Filter, on the other hand, uses outlier-resistant median and median absolute deviate from median (MAD) instead of mean and standard deviation respectively. For a sequence of data $D = \{d_i\}$, the $median(D)$ is the median of the set of data. The MAD is defined as

$$MAD(D) = 1.4826 \times median\{|d_i - median(D)|\}$$

where the scale 1.4826 is chosen so that the expected value of MAD(D) is equal to the standard deviation for normally distributed data. To detect the outlier, in our system, the Hampel filter identifies a data point as outlier by the following step:

$$|d_i - median(D)| > (T \times MAD(D))$$

where T is the threshold defined by the user. The inequality implies that if the data point deviates from the median for a certain distance, the data point is an outlier. In the system, the mechanism of outlier detection will replace the outlier with the median of the data set within the current dataset.

Furthermore, to cope with real time sensor observation, the proposed adaptive Hampel filter uses a window to queue the data and detect the outliers within this window length. Due to the dynamic feature of the real scenario, the window size should be flexible and adjustable to deal with the rapid change in the sensor reading. Therefore, the proposed adaptive Hampel filter introduces the adjustable window to incorporate the feature. There are ten different size of window in the system. To choose the appropriate window length, the system will automatically decide the window length based on that the difference of median between the current window size and the previous (smaller) and the difference of median between current and the next (larger) window length are close enough.

3.2 Adaptive Exponential Smoothing Filter

After removing the outliers from the data sequence, the second stage of the data processing is the smoothing filter. Simple moving average replaces the middle point with the mean of the data points in the current window. However, the simple moving average weights every data point equally which means there is no importance in each data, which is not usually the case. In the real scenarios such as stock market or economics, most recent data points in a time series data have more influence and contribute more to the next data in the time series. Therefore, weighted moving average (WMA) is introduced to deal with this problem. The weighted moving average weights the data points differently based on their importance. As an example, exponential moving average (EMA) applies the exponentially decreasing weights for the data from the most recent to the oldest in the accessible data set. The idea of EMA is similar in our situation that changing of the obstacles in the real environment should weight more on recent data than the old ones. Therefore, we adopt the EMA into our smoothing filter mechanism. Nevertheless, one major problem for moving average is that the response time for reflecting the real situation is long. Due to the nature of the moving average, including EMA, it will take some time to reflect the true distance from obstacles to the sensor. Even though the EMA already improves the response time, it still takes around 1 second to report the acceptable distance from sensor readings.

Thus, we introduce the adaptive EMA to overcome the issue. In our system, the EMA has an adjustable window length which is based on the difference between the variance of current window and the variance of current window plus the new reading from the sensor. Let a sequence of data $D_t = \{d_i\}, i \ni \{1,...,t\}$ and the data set includes the newly arrive data is $D_{t+1} = \{d_i\}, i \ni \{1,...,t,t+1\}$; if the variance of D_{t+1} is larger than D_t for a certain amount, the system will decrease the window length; otherwise, it increases the window length. This design implies that the system takes the rapid changes into consideration. As an example, if the user turns right and there exists an obstacle, the system will response to the sudden change in the signal readings and notify the user.

3.3 Direction and distance determination

In this stage data from signal processing output is used as input to actuators. As shown in Figure 1 vibration motors are used as actuators to give sense of direction and distance to a user. Each vibrator is activated based on corresponding data from sensor i.e. Vibrator 1 is activated based on data from sensor 1, and so on. If there is overlap between beam angles of two sensors both will detect an obstacle if it falls between angular range covered by two sensors. Utilizing this property two vibrators can be actuated if data is collected by two sensors at same time. With this we were able to provide direction sense of five different directions using three vibration sensors. Using ultrasonic sensors distance of an obstacle can be measured, and in our experiment we used same vibrators to give sense of disance as well. It is achieved using vibration at different frequencies. For example, if obstacle is beyond certan distance small frequncy of vibration (mild vibration) is used and if obstacle is in close proximity, higher frequency of vibration is used (strong vibration) is used. Next section describes experiemental setup in detail.

4. EXPERIMENTAL SETUP

The block diagram for experimental setup is shown in Figure 2.

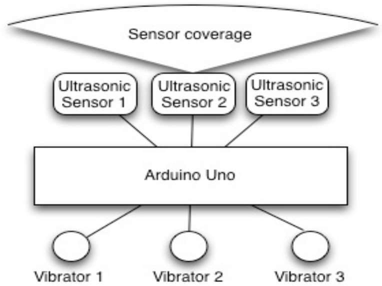

Figure 2 Experimental setup

Setup is composed of three main components: Arduino UNO, ultrasonic sensors and vibrators. The following sections aim at describing the components and the interaction in between.

4.1 Arduino UNO

Arduino UNO [8] is an open source programming and computing platform for developing the mobile applications. Arduino UNO contains microcontroller board based on ATmega328 and 14 digital input and output pins, 6 analog inputs and a USB connection. Also, the programming interface for Arduino UNO is open source software IDE which could develop client applications and upload them to Arduino UNO board. The connections of sensor 1 uses pin 7 and 8 of Arduino UNO for trigger and echo, respectively. Similarly, sensor 2 uses pin 9 and 19 and sensor 3 uses pin 11 and 12. On the other hand, the vibrator 1, 2 and 3 occupy pin 2, 3 and 4 respectively.

4.2 Ultrasonic sensor and vibration motor

Ultrasonic sensors are used, as it can be used to measure the distance between objects. These sensors work on principle of 'ping'. They send ping at certain moment and receive ping, which is bounced back from obstacle. Ping is the ultrasonic sound wave, which is not audible to humans. Suppose sensor sends the sound wave at time t_1 and receive back echo at time t_2. Then knowledge of speed of sound and the time difference $\Delta t = (t_2 - t_1)$ can be used to get an idea of distance of obstacle. For the experiment purpose we have considered the speed of sound 340 m/s or 29 microseconds per centimeter [7]. Vibration motor is used for experiment. As mentioned earlier, since frequencies of vibrations can be controlled, giving sense of direction and distance is easy with smaller devices.

4.3 Operating mechanism

In this section we describe the operating mechanism of our prototype. As per datasheet [7] effective beam angle for ultrasonic sensor is 30 degrees, we had set angle of 30 degrees between each sensor. Thus using three sensors, we were able to cover the beam angle of 90 degree. Since our focus was to extend the range to detect obstacle, this range is sufficient during practical scenario when person is walking.

After the sensor receives the data, it is processed using signal-processing block and later provided as input to direction and distance determination block. Based on the sensor, which detected the obstacle particular vibrator is actuated. Vibrators are virtually tagged to each sensor. Thus if more than one sensor detects the obstacle corresponding vibrators will be activated. Although section 3.3 discussed five different direction, there is one more scenario, which is not visible, i.e. suppose there is wall or large obstacle which is detected by all three sensors, in that case all vibrators will be actuated. For higher frequencies voltage HIGH is provided to perticular vibrator for longer time than other scenarios. Since the range of ultrasonic sensor used was limited (2 cm to 3.2 m), for the experiment pupose we divided the distance into three different ranges by using three levels of frequencies: high, medium and low frequencies for distance below 120 cm, 120 to 220 cm and 220 to 320 cm, respetively. Minimum distance for higher frequency was considered as 120 cm, because we considered a user would be alert and use the cane in necessary way. Length of cane we assumed is 1 m. If there is no obstacle, sensor readings give default maximum, thus readings greater than 320 cm were filtered during signal processing part.

5. RESULT AND DISCUSSION

5.1 Signal Processing Performance

As shown in the Figure 3, the performance comparison of outlier detection is illustrated. The window length used in the conventional Hampel filter is 23 data points while the window length for adaptive Hampel filter is adjusted automatically.

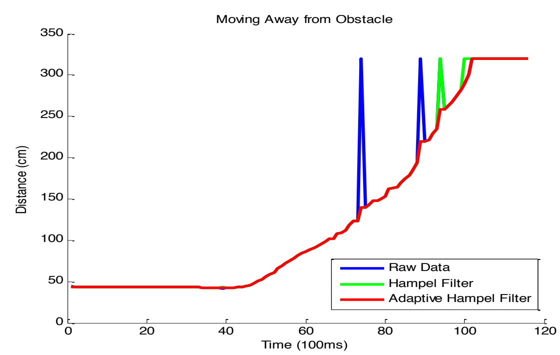

Figure 3 Performance Comparison of Outlier Detection Schemes

From the experiment shown in Figure 3, one may notice that both schemes perform well as the outlier is obvious which means the outlier is away from the group of the data in the current window. As the outliers become not so obvious, the adaptive Hampel filter outperforms the conventional Hampel filter due to the adaptive window length.

By incorporating the adaptive Hampel Filter, the performance comparison between the SMA, EMA and adaptive EMA is illustrated in the Figure 4, which shows the scenario that the user

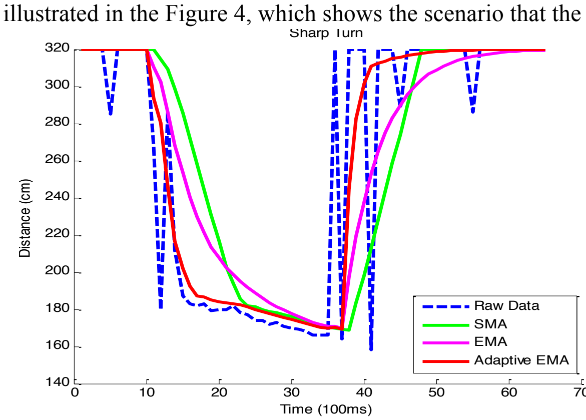

Figure 4 Performance Comparison of Smoothing Filters

turns to an obstacle. The window length used by both SMA and EMA are all 10 data points while the adaptive EMA can adjust its window length based on the design scheme.

In Figure 4, due to the sharp turn of the user, the obstacle suddenly appears in the detection range of the ultrasonic sensors and causes the dramatically drop of the sensor distance readings as shown in the results. From the Figure 4, one can observe that the response time of adaptive EMA outperforms SMA and conventional EMA schemes. Moreover, the combination of the two proposed scheme can eliminate the effects of outliers and also obtain better response time for the system.

5.2 Use Cases Testing

The three main real world use case scenarios of the system are moving toward an obstacle, moving away from the obstacle and the sharp turns of the user.

The scenario for moving toward an obstacle is illustrated in Figure 5. From the results, one may observe that the proposed scheme could efficiently reduce the influence of outliers, especially after around 12 seconds as the user approach the obstacle.

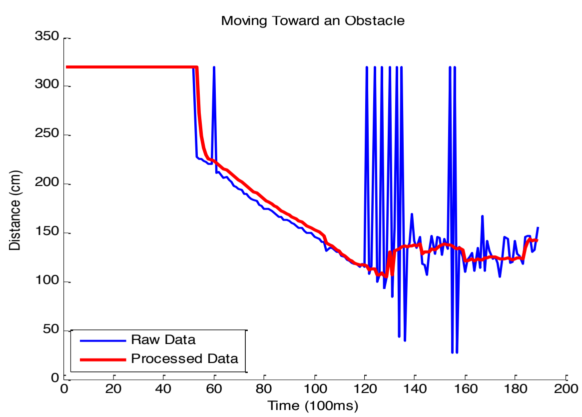

Figure 5 Moving Toward an Obstacle

The scenario for moving toward an obstacle is shown in Figure 6. From the experiment results, the scheme can eliminate the outliers as the user moving away from the obstacle. Also, the quick response for the output data after 16 seconds can fulfill the requirement as we discussed in the early section.

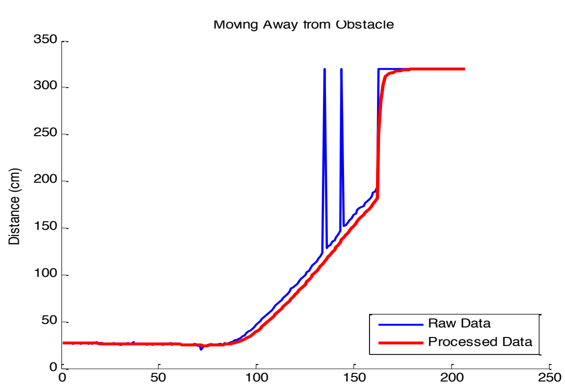

Figure 6 Moving Away from Obstacle

The last scenario we would like to discuss is the sharp turn scenario, which is shown in Figure 7. The experiment result for the sharp turn also demonstrates that the proposed scheme can not only eliminate the influence of the outliers such as the data

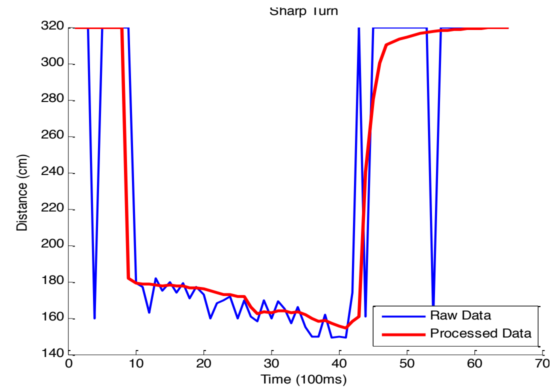

Figure 7 Sharp Turn

at 0.5 second and 5.5 second, but also can smooth the noisy data points during 1 to 4.5 second while the obstacle is in front of the ultrasonic sensors.

Regarding the integration test scenario, we set up a maze and we used our device with the people walking in the maze with the eyes covered. In the 10 times experiments with different combinations of right and left turns, the person can walk from the start to the end 10 times successfully. However, due to the inherent hardware limitations such as delay, the person still bumped into the obstacles several times. The total number of the person bumped into the walls is 7 out of 50 turns, which means the success rate of the person in avoiding the obstacles is 86%.

6. CONCLUSION

In this project we have demonstrated the use of ultrasonic sensors coupled with vibrating motors to build a robust direction guiding system. This system was made robust by the help of two signal processing filters, one of which was an outlier detection filter to remove the distorted outlier and the other filter was to smooth the signals. As discussed in the experiment section, our proposed system can not only eliminate the outliers efficiently but also smooth the data for data consistency. Our future work with this would be to solidify the system and making it a user wearable device and extensively testing in various scenarios.

7. REFERENCES

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