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Development of a Wireless Obstacle Detection System

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Abstract

Obstacle detection systems are important for helping individuals with safer locomotion particularly for older adults and people with visual impairment. Such a system must be wearable and easier to use. This paper discusses the suitability of the available low cost range sensors (such as infrared and ultrasonic) in solving obstacle detection problems and introduces an approach to assist the elderly with safer locomotion. In the proposed technique, the sensors are attached to the front part of the shoes for detecting obstacles in the field of view of the sensors. An algorithm has been developed to alert the user if an obstacle is detected. Test results indicate that detection accuracies by the ultrasound and infrared sensors are about 95% and 92%, respectively. The proposed sensor system shows potential for application in obstacle detection during walking.

Key words

Elderly, infrared sensor, ultrasonic sensor, navigation.

1. Introduction

The general trend of the older people in developed countries is rising rapidly as shown in Figure 1[1]. The increased elderly population will affect the government expenditure in health care services and facilities. The tendency to lose balance and fall during walking is common within the elderly population. Falls are a major problem among the elderly [2], and it becomes critical when a person gets injured. The Center for Disease Control and Prevention (2010) [3] report states that 1 in 3 adults aged 65 years and older sustain a fall each year, and of those who fall, 20% to 30% suffer moderate to severe injuries that make it hard for them to get around or live independently.

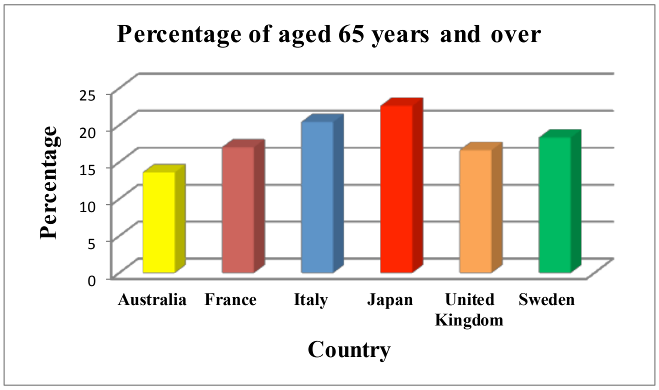


Fig.1. Percentage of people aged 65 years and over in developed country [1]

Statistics shown in Figure 2 suggest that the highest direct medical expenses in Australia come from falls related injuries (approximately $3 billion) relative to other types of injuries [4-5]. Modern scientific and technological advancements have opened up new possibilities for elderly care to support comfortable and dignified living of older persons. With use of assistive aids, the elders can look forward to safe and secure living, both inside the home and outdoors. Such devices reduce dependence on the care givers and facilitate independent living for the elders. Recently, researchers have shown an increased interest in developing mobility assistive devices for the elderly [6].

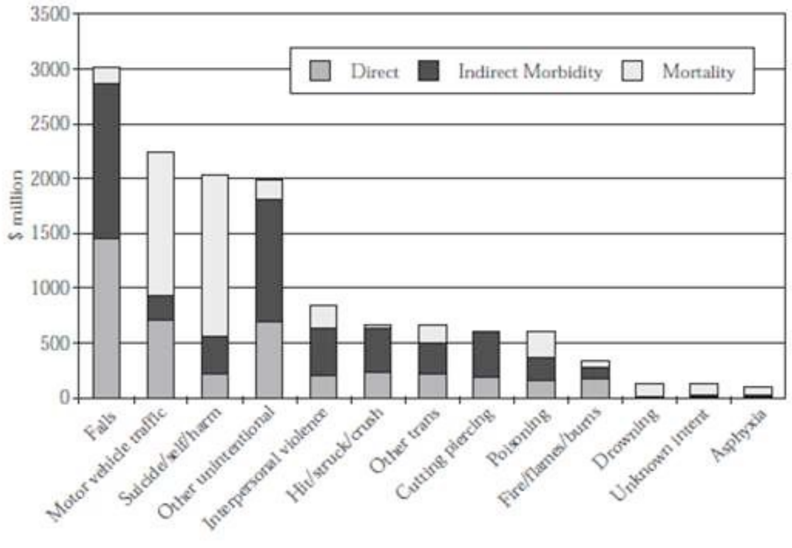


Fig. 2. Direct medical costs of all injuries in Australia [4]

Personal Aid for Mobility and Monitoring (PAMM) [7] has been developed and applied in nursing homes. The purpose of PAMM is to provide comprehensive data for researchers to identify risk factors, which cause falls during walking. Furthermore, it may assist doctors and care givers to respond quickly when the patients or the elderly sustains a fall or are in need of assistance. Researchers have developed several systems for mobility assistive devices (MAD) such as powered wheelchairs [8], smart canes and smart walkers [9]. These systems are aimed at providing mobility assistance to individuals in need, and movement monitoring to ultimately supporting functional independence at home or in nursing homes. More effective and user friendly mobility assistive devices (MAD) are required in order to improve the quality of life of the elderly and help them maintain their balance and minimize falling risks.

Biomechanical support, obstacle avoidance capability and navigational assistance are the three main functions that should be considered while designing an effective MAD device for the elderly and vision impaired people. In essence, these functions would reduce the need for supervision and the cost of care. Presently, several robot-based MAD are being developed. Figure 3 shows some examples of current mobility assistive devices, for example, Simbiosis Walker [10], Robotic Wheelchair [11], Shoe-mounted inertial navigation system [12] and knee orthosis as a supportive tool during walking [13].

(i) (ii)

(iii) (iv)

Fig. 3. Mobility Assistive Devices: (i) Simbiosis Walker [10] ; (ii) Robotic Wheelchair [11]; (iii) Shoe-mounted inertial navigation system [12]; (iv) Knee Orthosis [13]

These assistive devices are suitable for people who have a physical and visual disability. Recently, more focus has been given on designing wearable assistive devices rather than portable devices because of hands-free interaction capability [14]. The areas where these wearable assistive devices are attached to the body vary depending on applications such as fingers, hands, wrist, abdomen, chest, feet, tongue and ears. Some examples are shown in Figure 4. Fixation of these devices on the body is achieved by head-mounted devices, wristbands, vests, belts, shoes, etc.

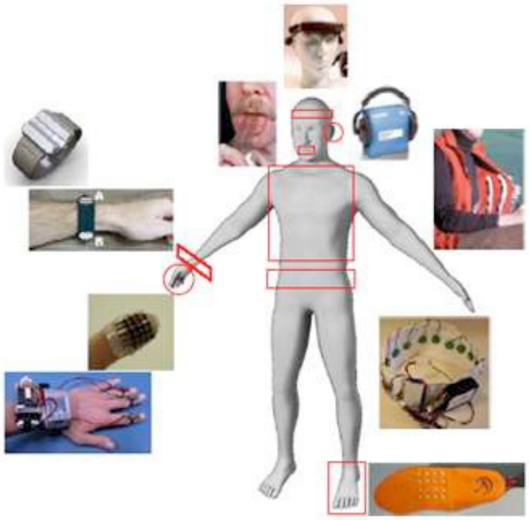


Fig. 4. Overviews the body areas involved in wearable assistive devices [15]

The development of wearable assistive devices is considered as a "current" research topic, especially for building devices that could help the elderly to be independent during their locomotion.

This paper discusses the suitability of multiple sensors (e.g. Infrared (IR) and ultrasonic (US)) in designing obstacle detection system (ODS) that might be suitable for the elderly and visually impaired persons. The paper is divided into 5 sections. Part II highlights the use of several distance sensors in the obstacle avoidance system. The system methodology is described in section III whereas part IV discusses some results obtained from the proposed ODS system. Finally, section V concludes and highlights further recommendation for future development.

2. Review of Obstacle Detection Sensors

Distance measurement sensors such as ultrasonic (US) and infrared (IR) sensors are among the popular sensors used in Obstacle Detection System (ODS) due to their low cost and high speed response. The other types of sensors that could be used in ODS include laser sensors, sonar sensors, radar sensors, vision sensors, and proximity sensors. Some of these sensors are expensive and hazardous such as lasers. The output signals from the sensors are obtained in the forms of either voltage (v) or current (amp), which is proportional to the distance between the sensors and the obstacles. The sensors chosen for this project are based on the following characteristics: miniature, low-cost and good sensing range to detect surrounding obstacles. The required key specifications for sensor performance include the range and angle of detection, resolution, sensitivity and high speed. Y. Donghe, et al. [16], K. Chung-Hsien, et al. [12] and T. Jyh-Hwa, [17] used ultrasonic sensors in their obstacle detection system to detect objects in indoor environment such as homes, nursing homes, assisted-living facilities and hospitals. Ultrasonic sensors have been employed at the shoulder of visually impaired people for detecting obstacles and assist them in indoor navigation [18-19]. The combination of the ultrasonic sensor coupled with vision sensor can identify the type of obstacle and then produce an appropriate warning signal to the users [20]. However, special consideration should be taken when using multiple ultrasonic sensors for any sensing system purposes, because it could produce mutual interference and crosstalks [21].

Many researchers used infrared sensors (IR) in Obstacles Avoidance System (OAS) because it is cheap and have a fast response time [17]. A. N. Aye, et al. used IR sensor (SHARP GP2D12) in Wheeled Mobile Robot (WMR) to detect an obstacle along its path and to measure distance [22]. H. Jinpyo, et al. employed infrared sensor coupled with laser range finder in their design of mobile robot navigation to ensure collision free movement [23]. However, environmental conditions could influence the measurement result of IR sensor such as sunlight, artificial lights, unless the external source is directly pointed towards the sensor [24]. Table 1 depict some of the mobility assistive devices, which utilize infrared and ultrasound sensors to detect obstacles for use in both indoor and outdoor environments.

TABLE 1 SEVERAL EXAMPLES of the MOBILITY ASSISTIVE DEVICES that UTILIZING INFRARED and ULTRASONIC SENSORS in the MARKET

Model	Sensor Name	No. of Sensor	Effective Sensing Distance	Environment
EPW[8]	Ultrasonic	4	6.45m	Indoor
GIMOS[23]	Infrared	16	0.8m	Indoor
Walbot[25]	Laser	9	0.41m	Indoor
Tom Pouce & Minitact [26]	Infrared	1	4m	Indoor and Outdoor
Johnnie[27]	Sonar	1	5m	Indoor
RVR[28]	Ultrasonic	16	NA	Indoor

A number of commercial products of assistive devices are available in the market. Most of them are limited in their function, and the cost is relatively high. Table 2 lists some assistive devices, especially for use by the visually impaired people; these devices provide information to the user in the form of sound and vibration. These types of mobility assistive devices employ ultrasonic sensors, which are attached to the light cane to detect obstacles. These devices can be classified as portable and wearable assistive devices. The working principles of these devices are similar.

TABLE 2: COMMERCIAL PRODUCTS of ASSISTIVE DEVICES [29]

Device	Sensor Type	Sensing Distance (m)	Price ($)	Warning Mode
K-Sonar Cane	Ultrasonic Range (sonar)	6.1	700	Audio
Mini-Radar	Ultrasonic Range (sonar)	3	600	Audio
Miniguide	Ultrasonic	8	330	Vibration
LaserCane	Laser range	3.7	3000	Audio & Vibration
UltraCane	Ultrasonic Range (sonar)	4	900	Vibration

3. Design Methodology

There are several constraints to be considered when designing a wireless obstacle detection system. The important parameters should be addressed in this work such as width of the pathway, minimum number of the necessary obstacle detection sensors and system architecture.

Width of the Pathway

Generally, the determination of a single walking path width is very important aspect and considered as a key factor to ensure a reliable performance of the designed obstacle detection system. A prior knowledge from literature on the gait parameters is necessary to justify the optimal path width and entire detection area for the system. Step width is an important gait parameter which can help to determine a suitable path width walking. Step width is determined using the medial–lateral distance between the locations of sequential left and right heel-strikes [30] as shown in Figure 5.

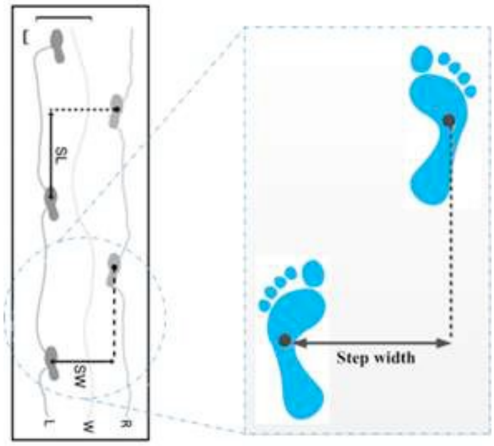


Fig. 5. Illustration of step width

Typical range of step width for the elderly is between 7.2 cm to 12.2 cm [31-33]. Considering a large foot width of 10cm, the maximum walkway path width can be estimated to be about 22cm [34]. According to a report by the Department of Transport of Western Australia [35], a minimum side clearance of 0. 5m is required between the path edge and adjacent hazards for shared paths. M. Tinetti [36] observed that an estimation of walking path width required for the elderly with a frontal plane gait disorder is 30cm. Based on these evidences, 0. 5m side clearance should be adequate to cover a single walkway path.

Sensor Constraints

Path width is also an important criterion in determining the number of sensors that would be required for obstacle detection. In this project, a combination of ultrasonic and infrared sensors are found to be the best option to detect most types of obstacles within the pathway width. Due to the fact that any sensor has detection problems, which are strongly dependent on weather conditions, the use of different sensors for the same task is justified so that the drawback of one sensor is compensated for by the others. According to technical specification of the sensors [37-38] as shown in Table 3, the response time of ultrasonic sensor is approximately 50ms whereas it is 38ms ±10ms for infrared sensor. Since both sensors indicate fast processing time compared to typical walking speed, 1.5m/s and 1.0m/s to 1.2m/s for young adults and elderly respectively [39], they were chosen in the proposed system.

TABLE 3 TECHNICAL SPECIFICATIONS of the SENSORS

Sensor	MaxSonar LV EZ1	Sharp GP2Y0A02YK0F
Range	0.15 – 6.45m	0.2-1.5m
Resolution	2.54cm	1cm
Response Time	50ms	38ms
Beam Width	± 30º	10º
Mass	4.3g	4.8g

Hence, two important considerations should be taken in order to ensure that the majority of the obstacles are detected. First, the entire range of obstacle detection should be specified in terms of the minimum and maximum single path width, taking into account that the obstacles in the travel path can be detected by at least one sensor. Second, for the purpose of alarm signal generation, the obstacle distance should be estimated conservatively based on the worst case scenario. An optimum detection occurs when one of the feet touches the ground and any existing obstacle within the walking base region is detected. Figure 6 illustrates the coverage region using three sensors (two infrared and one ultrasonic) attached to the front part of the shoe. This diagram is based on data sheets and actual experimental results carried out when the sensors were attached to the shoe.

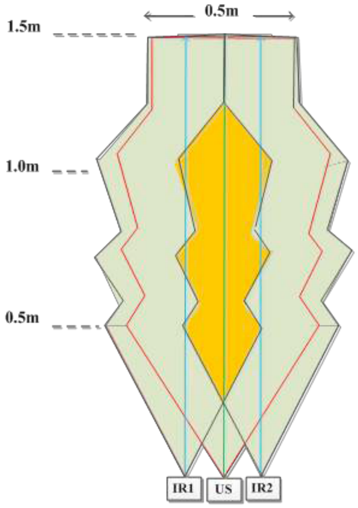


Fig. 6. Sensing area using 3 sensors (IR1, IR2, US)

Based on our design, using three sensors (2 IR and 1 ultrasonic) on one shoe will cover detection area of 0.5m width at 1.5m distance from an obstacle. Therefore, by using the same number of sensors on two shoes (3 sensors on right shoe and 3 sensors on left shoe), these will detect obstacles within 0.75m band of the travel path. Thus, in theory, our sensor placement and design should be sufficient for pathway coverage, which is typically 0.5m. Figure 7 illustrates the effective sensing area of the proposed system and its relationship to the step width.

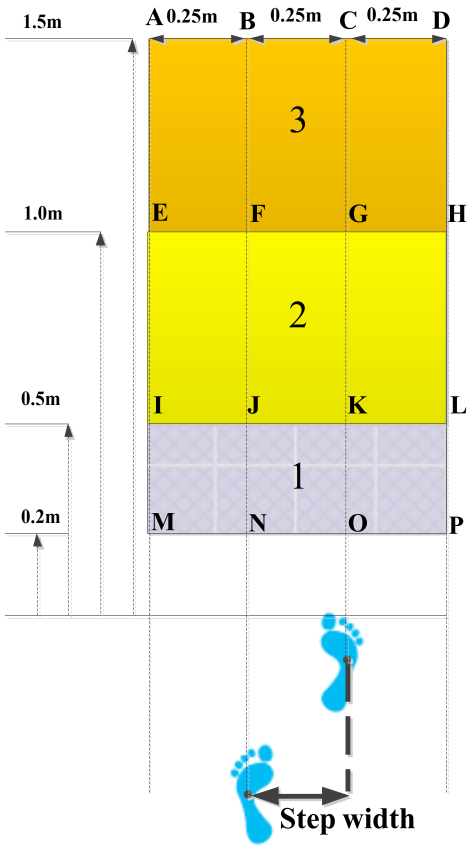


Fig. 7. Effective sensing area of the system

The ADPM rectangle as shown in Figure 7 is the effective sensing area of the proposed system. Any obstacle in this region should be detected by the sensors, and subsequently, an appropriate alarm will be activated. By considering the physiological effect on the users, which have a variety of walking styles, the alarming module is divided into three stages (e.g., 0.2m-0.5m, 0.5m-1.0m and 1.0m-1.5m). The alarm is triggered continuously since the obstacle is detected at 1.5m from the user until a cut off distance of 0. 2m is reached. The alarm is automatically switched off when no obstacle is detected (i.e., obstacle is not in the active sensing region). Three types of alarms (e.g., buzzer, vibration and audio synthesizer or audio messages) are provided throughout the effective sensing region. The user can choose the preferred alarm option for each of the determined sensing regions depending on individual's suitability and need. Each alarm type can be set to one of three levels of tones or intensities (i.e., low, medium and high). The duration of each tone depends on the walking style. For example, if the step length of the user is short, the tone duration may be longer. A fast reaction (obstacle avoidance) by the user would force the alarm to stop immediately. Typical step length (see Figure 8) for healthy elderly (men and women) ranges from 44 cm to 94.17 cm [40-45]. The closer the obstacle to the user, the higher the tone or intensity.

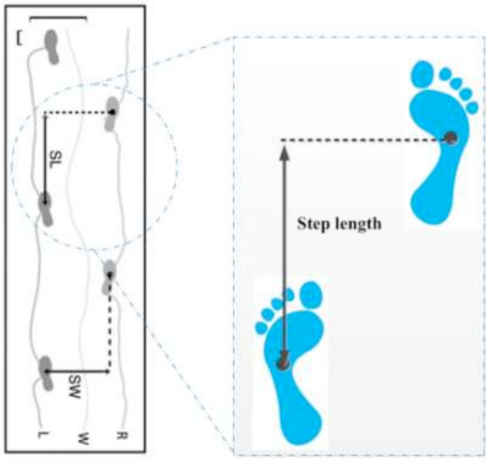


Fig. 8. Illustration of step length

System Architecture

Block diagram of the proposed wireless obstacle detection system is illustrated in Figure 9. It comprises of three sensors (IR1, IR2, US), microcontroller (µc), transceiver (wireless transmitter and receiver module) and alarming units. The sensors utilized are ultrasonic (Maxbotics LV EZ1) and infrared (medium range sensor GP2Y0A02YK0F). PIC microcontrollers from Microchip Technology are used in this system. The chosen microcontrollers are compatible for wireless application.

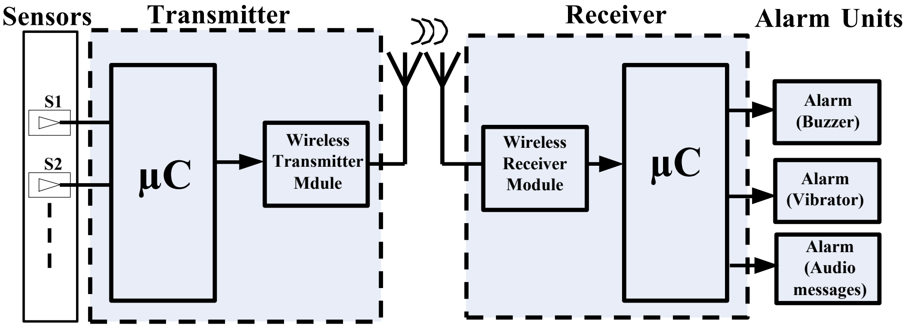


Fig. 9. Architecture of a Wireless Obstacle Detection System

The function of the system is described as follows:

I. Ultrasonic and infrared sensors are attached at the front part of the shoe (see Figure 10) and able to detect obstacles in its path from 20 cm to 1.5 meter of length. The sensors need careful installation due to critical requirement on both functionality and the mechanical specifications of the devices. The main function of the combined sensors is to ensure all types of obstacles are detected in the specified range.

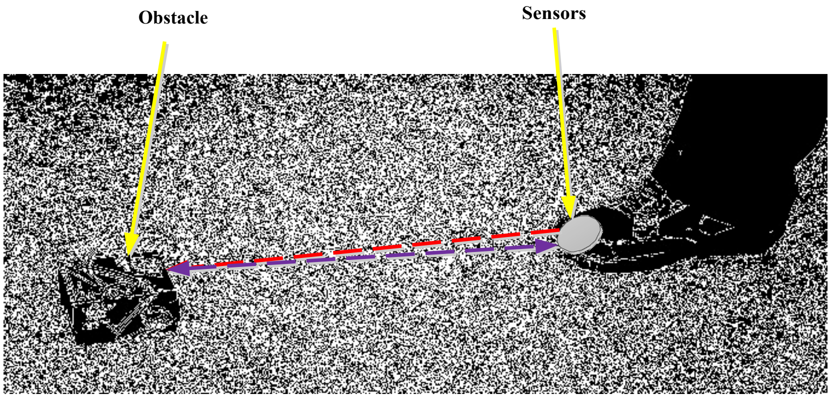


Fig. 10. Illustration of the sensor placement on the shoe

II. The microcontroller gathers information from all sensors, process these signals and convert their values into empirical distance. The microcontrollers produces output data (in digital) form and sends it to the wireless transmitter through the serial port to be coded and transmitted.

III. The receiver section of the system receives the signals from the transmitter, decodes it and feeds them to the microcontroller. The microcontroller unit converts the digitized signal to analogue equivalent. Signals are conditioned to be able to drive an appropriate alarm (e.g. buzzer, vibration and audio messages). The flow chart of the system's main function is shown in Figure 11.

IV. Multiple alarm units are used in this system, which are buzzer, vibrator and audio messages. The alarm is triggered according to the set of threshold values at certain distances and the position of the user foot. The user can select the preferred alarm type based on their physical ability.

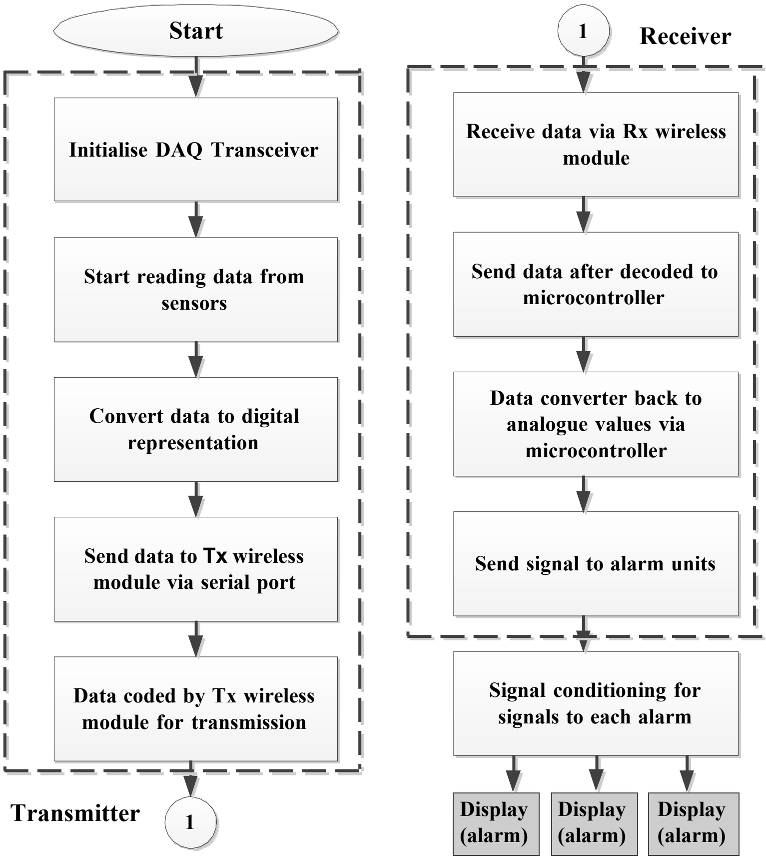


Fig. 11. Flow chart of the algorithm for the ODS

4. Results and Discussion

The proposed system has been tested for determining its functionality and accuracy of sensing in the detection area. The test performed for several determined distances and different types and sizes of the obstacle commonly seen in the environment such as wood, plastic product, mirror, plywood and concrete. The testing consisted of collecting data from the range sensors at fixed distances. Each experiment has been run a number of times for each distance to confirm the repeatability of the system. The distance measurement technique used in this experiment is based on time of flight principle, which is emitting the pulse, and then measuring the reflected pulse. Normally, the popular method of distance measurement used for infrared sensor is triangulation method [46-47]. The output voltage generated by the IR sensor verses the distance of the obstacle, shown in Figure 12.

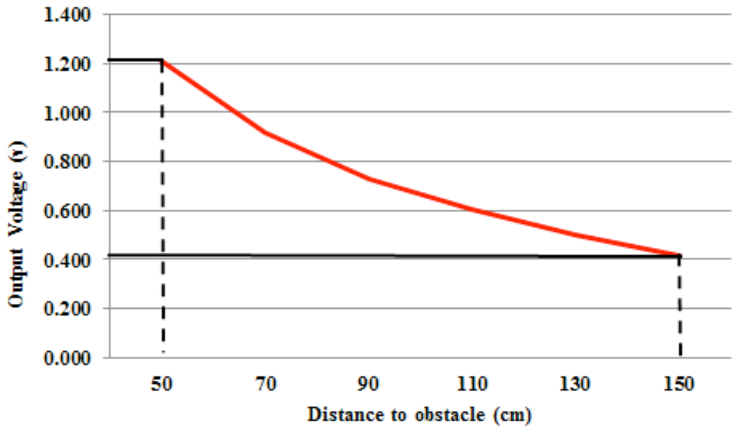


Fig. 12. Output pattern of infrared sensor

There are several methods to calibrate the infrared sensor output such as fractional function, lookup table, gradient-based interpolation, nonlinear regression, best fitting equation and etc. In our work, best fit equation was used to calculate the distance as shown in Figure 13.

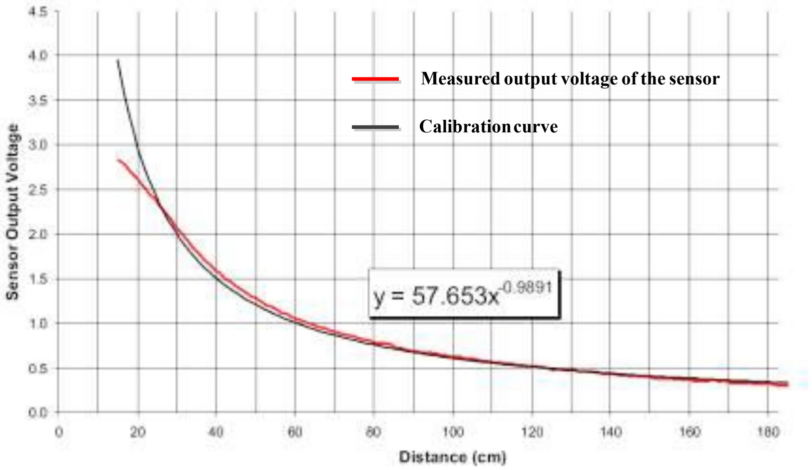


Fig. 13. Infrared calibration average voltage best fit equation [47]

Distance measurement using the ultrasonic sensor is relatively easy compared to the infrared sensor. Generally, in several industrial applications, pulse-echo technique is utilized to measure obstacle distances in the air medium. In this method, a short pulse train is generated by the transducer, which propagates to the target and reflected back, and received by the same sensor as shown in Figure 14. The transmitted signal is a noise-free signal, while the received pulse-echo signal is an attenuated and delayed version of generated signal plus the white-noise [49].The distance was be measured by calculating the reflection time interval between the target and sensor.

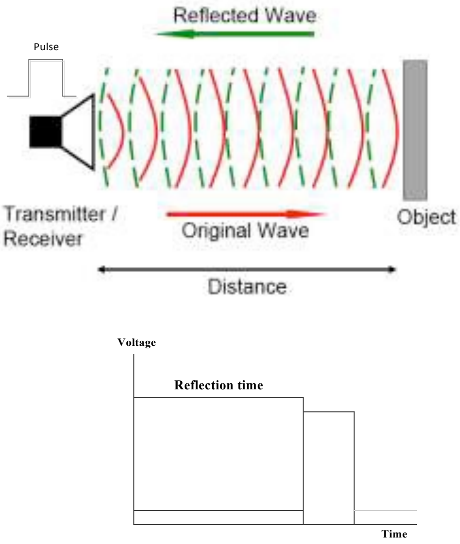


Fig. 14. Distance measurement process using ultrasonic sensor [48].

Figure 15 shows the result of detection of 5 types of materials placed at a distance of 50cm from the shoe sensors.

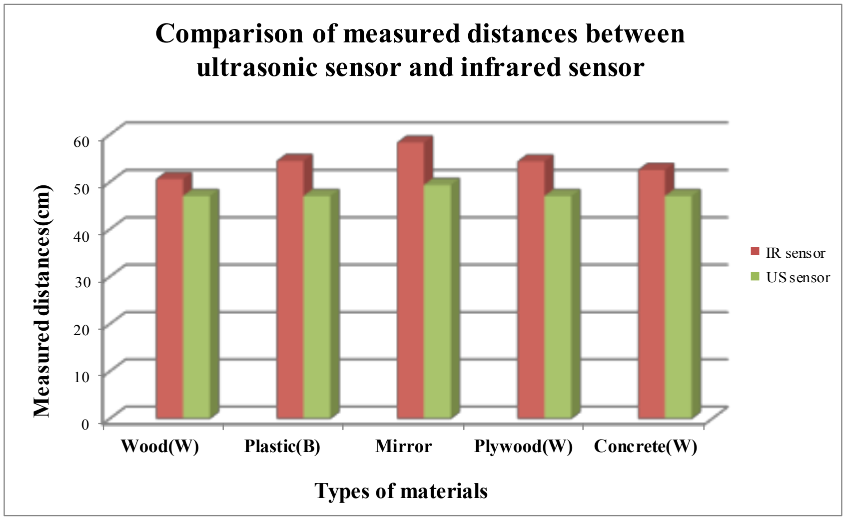
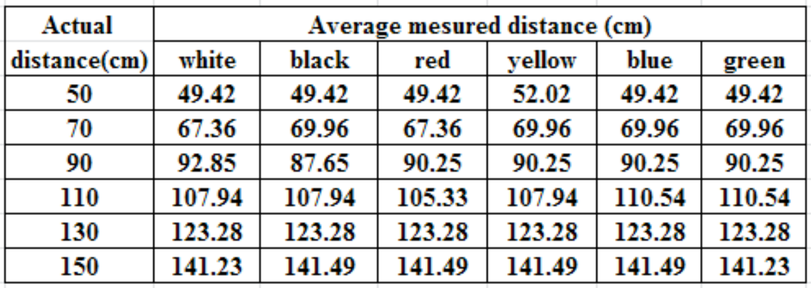


Fig. 15. Measured distances of the ultrasonic and infrared sensors for different types of obstacles at a distance of 50cm.

Based on the results presented in the tables 5 and 6, it can be concluded that the sensors are able to detect all types of obstacle materials at a distance from 20cm to 1.5m. However, we also observe that there is a small measurement error as compared to the actual distances for each type of sensors and obstacle materials.

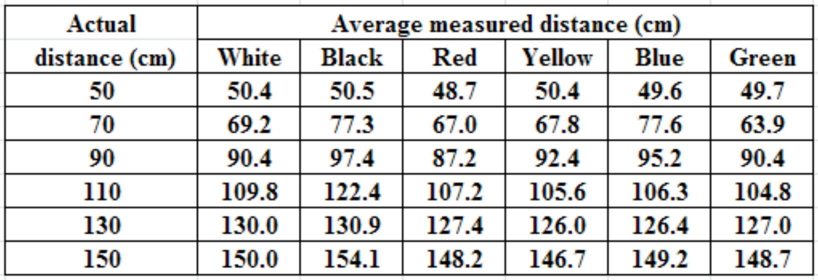
The average measurement error for both infrared and ultrasound sensors obtained on distance 20cm to 150cm range is approximately 4cm and 2.5cm, respectively. The average accuracy obtained for infrared sensor is 92%, and 95% for the ultrasound sensor. Further measurement has been carried out for the different types of surface color of obstacle, e.g., white, black, red, yellow, blue and green. According to measurement results, we found that the sensors do not have a problem in detecting obstacles with different surface colors. However, ultrasonic sensor provided more reliable results compared to the infrared sensor. Infrared sensors were affected slightly by the surface colors of the tested obstacles. The experimental results for all surface colors of obstacle at different distances are provided in Table 4.

TABLE 4 COMPARISONS BETWEEN ACTUAL DISTANCE and MEASURED DISTANCE for the ULTRASONIC SENSOR and INFRARED SENSOR



Actual	Average mesured distance (cm)					
distance(cm)	white	black	red	yellow	blue	green
50	49.42	49.42	49.42	52.02	49.42	49.42
70	67.36	69.96	67.36	69.96	69.96	69.96
90	92.85	87.65	90.25	90.25	90.25	90.25
110	107.94	107.94	105.33	107.94	110.54	110.54
130	123.28	123.28	123.28	123.28	123.28	123.28
150	141.23	141.49	141.49	141.49	141.49	141.23

(a) Ultrasonic sensor

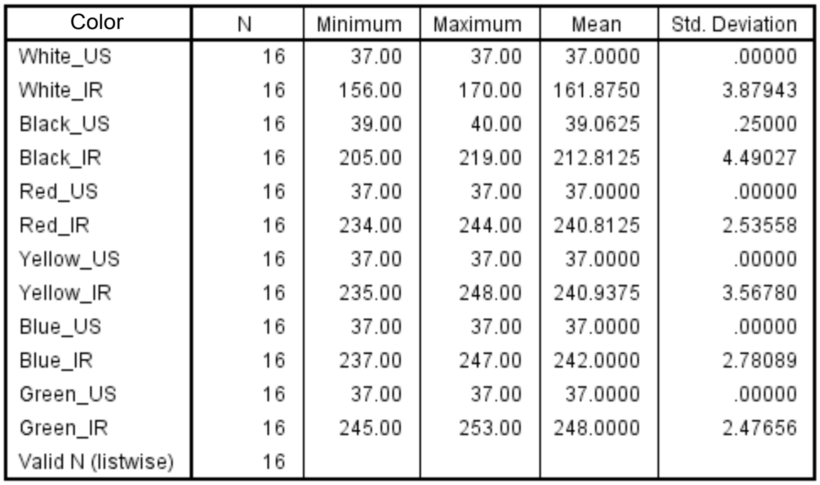


Actual	Average measured distance (cm)					
distance (cm)	White	Black	Red	Yellow	Blue	Green
50	50.4	50.5	48.7	50.4	49.6	49.7
70	69.2	77.3	67.0	67.8	77.6	63.9
90	90.4	97.4	87.2	92.4	95.2	90.4
110	109.8	122.4	107.2	105.6	106.3	104.8
130	130.0	130.9	127.4	126.0	126.4	127.0
150	150.0	154.1	148.2	146.7	149.2	148.7

(b) Infrared sensor

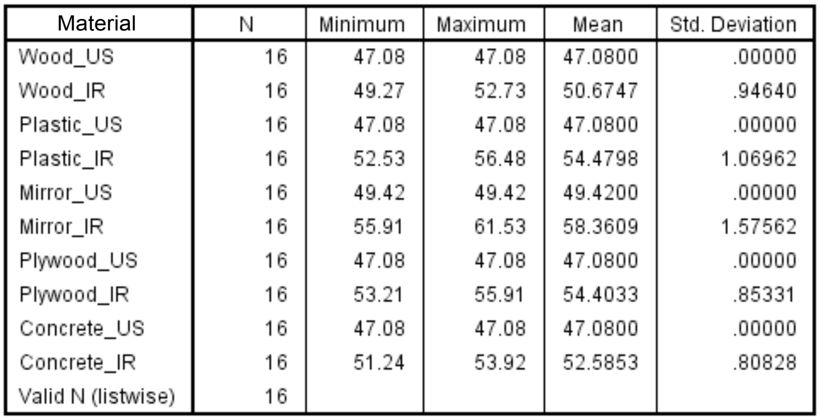
The developed system has been tested to evaluate its reliability and accuracy. The obstacles have been placed starting at 50cm to 150cm from the user with 20cm interval. Descriptive statistical analysis shows that the standard deviation values for the sensors is very low; less than 1cm for ultrasonic and less than 5cm for infrared sensor. The results also show that the measurement values from the sensors are reliable for different colors of a surface obstacle (e.g., white, black, red, yellow, blue and green), as well as different types of materials such as wood, plastic, mirror, plywood and concrete as shown in Table 5 and Table 6.

TABLE 5 DESCRIPTIVE STATISTICS of SENSORS DETECTION for the DIFFERENT COLOR of SURFACE OBSTACLE



Color	N	Minimum	Maximum	Mean	Std. Deviation
White_US	16	37.00	37.00	37.0000	.00000
White_IR	16	156.00	170.00	161.8750	3.87943
Black_US	16	39.00	40.00	39.0625	.25000
Black_IR	16	205.00	219.00	212.8125	4.49027
Red_US	16	37.00	37.00	37.0000	.00000
Red_IR	16	234.00	244.00	240.8125	2.53558
Yellow_US	16	37.00	37.00	37.0000	.00000
Yellow_IR	16	235.00	248.00	240.9375	3.56780
Blue_US	16	37.00	37.00	37.0000	.00000
Blue_IR	16	237.00	247.00	242.0000	2.78089
Green_US	16	37.00	37.00	37.0000	.00000
Green_IR	16	245.00	253.00	248.0000	2.47656
Valid N (listwise)	16				

TABLE 6 DESCRIPTIVE STATISTICS of SENSORS DETECTION for the DIFFERENT TYPES of OBSTACLE MATERIALS



Material	N	Minimum	Maximum	Mean	Std. Deviation
Wood_US	16	47.08	47.08	47.0800	.00000
Wood_IR	16	49.27	52.73	50.6747	.94640
Plastic_US	16	47.08	47.08	47.0800	.00000
Plastic_IR	16	52.53	56.48	54.4798	1.06962
Mirror_US	16	49.42	49.42	49.4200	.00000
Mirror_IR	16	55.91	61.53	58.3609	1.57562
Plywood_US	16	47.08	47.08	47.0800	.00000
Plywood_IR	16	53.21	55.91	54.4033	.85331
Concrete_US	16	47.08	47.08	47.0800	.00000
Concrete_IR	16	51.24	53.92	52.5853	.80828
Valid N (listwise)	16				

5. Conclusion and Further Recommendation

A wireless obstacle detection system has been developed. It is a wearable device, easy to use, which has the potential to assist the elderly and visually impaired people in their daily locomotion activities. The developed system shows an average accuracy of the sensor detection of obstacle (distance measurement) to be 95% and 92% for ultrasound and infrared sensors, respectively. This system is designed to trigger an alarm automatically when obstacles are detected in the path of the user. Further development is currently being considered for extra calibration and other potential functionalities

References

1. www.abs.gov.au/ausstats/abs@.nsf/mf/3201.0 2012 (April).
2. A. Sixsmith, N. Johnson (2004) "A smart sensor to detect the falls of the elderly," *IEEE Pervasive Computing*, vol. 3 (no. 2), pp. 42-47.
3. www.cdc.gov 2010 (November).
4. B. Rezaul, B. Russell (2006) “Overview of movement analysis and gait features”, *Idea Group Inc.*, pp. 1-69.
5. www.nhmrc.gov.au 2011 (May).
6. B. Mustapha, A. Zayegh, R.K. Begg (2012) “Multiple sensor-based obstacle detection system”, Proc. of the 4th International Conference on Intelligent and Advanced Systems, June 2012, Kuala Lumpur, Malaysia, vol. 2, pp.562-566.
7. S. Dubowsky (2000) “PAMM - a robotic aid to the elderly for mobility assistance and monitoring for the elderly”, Proc. of the ICRA '00 IEEE International Conference on Robotics and Automation, April 2000, San Francisco, California, vol. 1, pp. 570-576.
8. H. Murakami, H. Seki (2009) “Fuzzy algorithm based obstacle avoidance control of electric powered wheelchair using ultrasonic sensor”, Proc. of 35th IEEE Annual Conference of Industrial Electronics, November 2009, Porto, Italy, pp. 4251 – 4256.
9. M. Spenko, Y. Haoyong, S. Dubowsky (2006) “Robotic personal aids for mobility and monitoring for the elderly”, *IEEE Trans. on Neural Systems and Rehabilitation Engineering*, vol. 14, no. 3, pp. 344-351.
10. A. Frizera, R. Ceres, J. L. Pons, A. Abellanas, R. Raya (2008) “The smart walkers as geriatric assistive device. The SIMBIOSIS purpose”, Proc. of the 6th Conference of the International Society for Gerontechnology - ISG08, May 2008, Pisa, Italy, vol. 7, no. 2, pp. 789-791.
11. K. Chung-Hsien, H. H. W. Chen (2006) “Human-oriented design of autonomous navigation assisted robotic wheelchair for indoor environments”, Proc. of the IEEE International Conference on Mechatronics, pp. 230-235.
12. Castaneda, S. Lamy-Perbal (2010) “An improved shoe-mounted inertial navigation system”, Proc. of the International Conference on Indoor Positioning and Indoor Navigation (IPIN), September 2010, Zurich, Switzerland, pp. 1-6.
13. A. Frizera, R. Ceres, E. Rocon, J. L. Pons (2011) “Empowering and assisting natural human mobility: The Simbiosis Walker”, *International Journal Advance Robotic System (Special Issue Assistive Robotics)*, vol. 8, no. 3, pp. 34-50.

14. B. Mustapha, A. Zayegh, K.B. Rezaul, A.H.A. Razak (2012) “Design and implementation of wireless obstacle detection system for safe locomotion”, Proc. of 3rd International Conference on Intelligent Systems Modelling and Simulation, February 2012, Kota Kinabalu, Malaysia, pp. 718-722.
15. R. Velázquez (2010) “Wearable assistive devices for the blind”, *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment*. vol. 75, pp. 331-349.
16. Y. Donghe, X. Jinsong, X. A. Liu (2010) “The research on intelligent mobile robot's avoiding obstacle by ultrasound”, Proc. of the International Conference on Artificial Intelligence and Computational Intelligence (AICI), pp. 77-79.
17. T. Jyh-Hwa, C. Feng-Chun (2009) “The development of the mobile robot for taking care of elderly people”, Proc. of the 4th International Conference on Innovative Computing, Information and Control (ICICIC), pp. 540-543.
18. M. Bousbia-Salah, B. Maamar, A. Larbi (2011) “A navigation aid for blind people”, *Journal of Intelligent Robot System*, vol. 64, pp. 387-400.
19. C. Sylvain, T. Daniel, V. Frederic (2007) “A wearable system for mobility improvement of visually impaired people”, *Journal of Visual Computer*, vol 23, pp. 109-118.
20. A. Kumar, P. Rusha, M. Manjunatha, J. Mukhopadhyay, A. K. Majundar (2011) “An electronic travel aid for navigation of visually impaired persons”, Proc. of the 3rd International Conference on Communication Systems and Networks (COMSNETS), January 2011, Bangalore, India, pp. 602-606.
21. S. Shoval, I. Ulrich, J. Borenstein (2000) “Computerized obstacle avoidance systems for the blind and visually impaired,” *CRC Press*, pp. 414-448.
22. A. A. New, W. P. Aung, Y. M. Myint (2008) “Software Implementation of Obstacle Detection and Avoidance System for Wheeled Mobile Robot”, *World Academy of Science, Engineering and Technology*, pp 572-577.
23. H. Jinpyo, C. Youjun, P. Kyihwan (2007) “Mobile robot navigation using modified flexible vector field approach with laser range finder and IR sensor”, Proc. of the International Conference on Control, Automation and Systems, October 2007, Seoul, Korea, pp. 721-726.
24. T. Mohammad (2009), “Using ultrasonic and infrared sensors for distance measurement”, *World Academy of Science, Engineering and Technology,* pp. 293-298.

25. J. Sin-Yi, H. Shang-Chun, S. Kai-Tai (2011) “A call-to-service design for mobile robots using Zigbee sensor networks”, Proc. of the 8th Asian Control Conference (ASCC), May 2011, Kaohsiung, Taiwan, pp. 317-322.
26. J. Villanueva, R. Farcy (2012), “Optical device indicating a safe free path to blind people,” *IEEE Transactions on Instrumentation and Measurement,* vol. 61. No. 1, pp. 170-177.
27. Y. Kuan-Ting, L. Chi-Pang, C. Ming-Fang, M. Wei-Hao, T. Shi-Huan, F. Li-Chen (2010) “An interactive robotic walker for assisting elderly mobility in senior care unit,” *IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO),* pp. 24-29.
28. N. Huu-Cong, K. Shim-Byoung, K. Chang-Hak, P. Dong-Jun, H. Sung-Hyun (2009) “Integration of robust voice recognition and navigation system on mobile robot,” Proc. of the ICROS-SICE International Joint Conference ICCAS-SICE, August 2009, Fukouka, Japan, pp. 2013-2018.
29. A. Discant, R. Alexandrina, C. Rusu, B. Abdelaziz (2007) “Sensors for obstacle detection - A survey”, Proc. of the 30th International Spring Seminar on Electronics Technology, pp. 100-105.
30. T.M. Owings, M.D. Grabiner (2003) “Step width variability, but not step length variability or step time variability, discriminates gait of healthy young and older adults during treadmill locomotion”, *Journal of Biomechanics*, pp. 935-938.
31. J. L., Helbostad, R. Moe-Nilssen (2003) “The effect of gait speed on lateral balance control during walking in healthy elderly”, *Gait Posture,* vol. 18, no. 2, pp. 27-36.
32. D. M.Wert, J. Brach, S. Perera, J. M. Van Swearingen (2010) “Gait biomechanics, spatial and temporal characteristics, and the energy cost of walking in older adults with impaired mobility”,*Phys Ther,* vol. 90, no. 7, pp. 977- 985.
33. J. H., Hollman, E. M. McDade, R.C. Petersen (2011) “Normative spatiotemporal gait parameters in older adults”, *Gait Posture*, vol. 34, no. 1, pp. 111-118.
34. J. S. Brach, R. Berthold, R. Craik, J. M. Van Swearingen, A.B. Newman (2001) “Gait variability in community-dwelling older adults”, *Journal of the American Geriatrics Society,* vol. 49. No. 12, pp. 1646-1650.
35. Department of Transport of Western Australia (2012) “Planning and designing for pedestrian:guidelines”, version 5, pp. 1-221.
36. M. Tinetti (1986) “Performance-oriented assessment of mobility problems in elderly patients”, *Journal of the American Geriatrics Society,* vol. 34, pp.119–126.

37. Sharp Microelectronics (2006) “GP2Y0A02YK – Long distance measuring sensor”, *Technical Datasheets*, January 2006.
38. MaxBotix Inc. (2007) “LV-MaxSonar-EZ1– High performance sonar range finder”, *Technical Datasheets,* July 2007.
39. S. Studenski, S. Perera, K. Patel, C. Rosano, K. Faulkner, M. Inzitari, J. Brach, J. Chandler, P. Cawthon, E. B. Connor, M. Nevitt, M. Visser, S. Kritchevsky, S. Badinelli, T. Harris, A.B. Newman, J. Cauley, L. Ferrucci, J. Guralnik (2011) “Gait speed and survival in older adults”, *The Journal of American Medical Association,* vol. 305, no. 1, pp. 50-58.
40. A. H. Patricia, J. B. Daniel (1986) “Comparison of gait of young women and elderly women”, *Journal of the American Therapy Association,* vol. 66, pp. 1382-1387.
41. A. H. Patricia, J. B. Daniel (1989) “Comparison of gait of young men and elderly men”,*Journal of the American Therapy Association,* vol. 69, pp. 144-148.
42. A. Zijlstra, N. Bruins, W. Zijlstra, E. D. de Bruin (2008) “The step length–frequency relationship in physically active community-dwelling older women”, *European Journal of Applied Physiology*, vol. 104, no. 3, pp. 427-434.
43. B. S. Moreira, R. N. Kirkwood, A. J. Lopes, R. C. Dias, R. F. Sampaio (2012) “Gait velocity and step length may discriminate active from sedentary elderly women,” *Rev Bras Ativ Fis e Saúde*, vol. 17, no. 1, pp. 33-38.
44. Y. Taniguchi, H. Yoshida, Y. Fujiwara, Y. Motohashi, S. Shinkai (2012) “A prospective study of gait performance and subsequent cognitive decline in a general population of older Japanese,” *Journal of Gerontology, Series A, Biological Sciences and Medical Sciences*, vol. 67, no. 7, pp. 798-803.
45. T. H. L. Daniel, R. K. Begg and M.Palaniswami (2009) “Computational intelligence in gait research: A perspective on current applications and future challenges,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 13, no. 5, pp. 687-702.
46. R. Siegwart, I. R. Nourbakhsh, D. Scaramuzza (2011) *Introduction to Autonomous Mobile Robots,* The MIT Press Cambridge, Massachusetts London, England.
47. Solarbotics (2010) “Analog Infra-Red Ranging Sensor”, *Sharp GP2Y0A02YKF Sensor Datasheets*, December 2010.
48. M. Ishihara, M. Shiina, S. Suzuki (2009) “Evaluation of method of measuring distance between object and walls using ultrasonic sensors”, *Journal of Asian Electric Vehicles,* vol. 7, no. 1, pp. 1207-1211.

49. A. Naik, M.S. Panse (2012) "Modelling of ultrasonic sensor for range measurement for visually impaired", *International Journal of Emerging Technology and Advanced Engineering*, vol. 2, pp. 672-675.