Persons Counting and Monitoring System Based on Passive Infrared Sensors and Ultrasonic Sensors (PIRUS)

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Abstract. Counting systems are widely used for applications related to counting people within a certain area or traffic monitoring in a crowded commercial area, for automatic settings of air-conditioning systems depending on the number of the persons located in that space, etc. Persons counting and identification systems are useful in educational domain or in cultural and entertaining areas where resource allocation must treat differently every class of customers. Therefore the main goal of the paper is to present a sensor-based system that can be used either to monitor the presence of the students in a classroom or to differentially count adults and children that enter parks, museums, etc. The implemented system (PIRUS) comprises passive infrared sensors and ultrasonic sensors. Multiple scenarios have been depicted in order to analyze and improve the performances of the designed system.

Keywords: Persons counting · PIR · Ultrasonic · Height discrimination

1 Introduction

People counting and classifying systems are necessary tools in many daily situations, such as registering the students' attendance to courses, estimating the presence of people that belong to different age categories (adults-children) in order to provide different services or to improve the quality of the existing ones according to the customer profile. Counting systems may comprise modules of sensors of the same type [1, 2] or several types of sensors in the so-called fusion-based sensor based networks [3–5]. These systems may also use vision-based motion sensors [6] or motion sensors based on other technologies, such as passive infrared sensors and pressure mats [3]. As opposed to vision sensors, passive infrared sensors are mass- produced at low costs [7] and are non-intrusive. For relevant results, though, PIR sensors must be used together with other types of technologies, sensors and/or devices. However, there is a need for continuous research as the real world scenarios modify and new issues must be solved.

This paper proposes to configure a low-cost counting and discriminating system based on a minimum number of passive infrared and ultrasonic sensors. The paper is

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organized as follows: Sect. 2 briefly describes the functioning principle of the motion sensors used. In Sect. 3, we mention the parameters that may be extracted using the two types of sensors and we present the people counting and discrimination system diagram, explaining its functioning. We also include the experiments and the results of four different scenarios through which we tested the system. Section 4 presents our conclusions and future research prospects.

2 Motion Sensors Used for Human Tracking, Counting and Discrimination

2.1 Passive Infrared Sensors (PIR)

Passive Infrared Sensors are sensitive to infrared radiation modification, that is, to the heat exchange between the sensing elements and moving body [8]. They are designed to consider only radiation in a certain domain, specific to human body thermal radiation (7–14 μm). In this paper, we considered Passive Infrared Sensor from Pololu [9]. The functioning principle presented for this sensor is valid also for other PIRs. The sensor has a dual sensing element based on both metal and pyroelectric films whose polarization changes as the temperature changes due to pyroelectric phenomenon. In response to the material heating, a temporary voltage will be generated on each sensing element [10]. When a (human) being passes in front of the sensor orthogonal on the sensing elements, they are sequentially activated and the motion is detected.

2.2 Ultrasonic Sensors (US)

Ultrasonic sensors are distance measuring sensors based on reverse piezoelectric effect [8]. They produce ultrasonic bursts that may be sent to a target through their emitters. When arriving on the target, the wave reflects and goes back to its receiver. The received wave is converted in a voltage. The parameter of interest is the travelling time. Knowing the speed of sound, duration may be translated into distance. There are different output interfaces for an ultrasonic sensor (TTL, RS232, Analogue and PWM [11, 12]). In this paper we chose LV EZ4 Sensor from MaxBotix [12] and PWM output interface. This means that the travelling time is given by the duration of logic “1”. The distance is computed using the scale factor given by manufacturers.

3 PIRUS System Parameters, Diagram and Testing

Motion speed, distance with respect to sensor and persons dimensions may significantly influence PIR sensors output [1]. In this paper, we analyse the PIR output in order to extract information about direction of target.

The output of US gives information about the presence and even on the dimensions of the target in its field of view. This happens due to its narrow beam width which allows the detection of persons up to approximately 121.92 cm (4 ft).

Figure 1 presents the disposal of the two sensors at an entrance of 70 × 200 cm. US is placed at the middle of the upper door case, considering that US board has 1.99 × 2.21 cm. PIR sensor is placed on the left lateral part of door case, at a height of 70 cm.

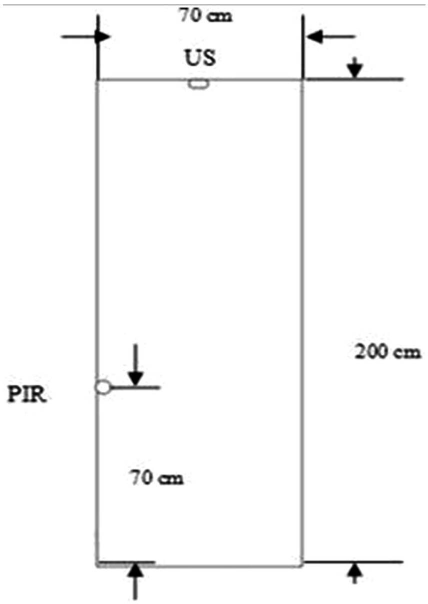

Fig. 1. Disposal of sensors at an entrance

The flowchart of the proposed system is depicted in Fig. 2. The system is based on Arduino Uno Prototyping Platform and IDE. For monitoring the sensors' output signals, we used both Serial Monitoring provided by Arduino IDE and Arduino Support Package for MATLAB. In the initialisation step, PIR and US are calibrated. The latter sends an initial burst for achieving the distance between the sensor output (found at 1.55 cm below the door case or at 198.45 cm above the ground) and bottom part of the door case found at 0 cm because it was embedded in the floor. After initialisation, the two low-power sensors are interrogated continuously. In a first experiment, three sets of 20 initialisation readings were done in order to verify the accuracy of the readings. For every set, we computed the average and the relative error of the average with respect to the real value, 198.45 cm (Table 1).

The results in Table 1 reveal inaccuracy of US and non-constant relative error, which is very important for discrimination issue. This happens due to the fact that US output depends on medium changes (temperature and humidity) and the scale factor for distance computation considers the standard sound speed of 345.57 m/s instead of following the environmental changes. In a future work, this aspect will be improved.

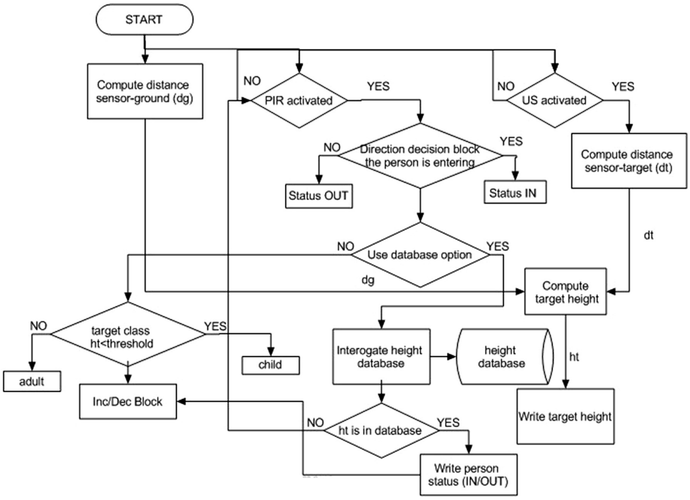

Fig. 2. PIRUS system diagram

Table 1. Measurement sets for initialisation step

Measurement set	Average [cm]	Relative error [%]
I	198.40	0.025
II	200.00	0.781
III	200.15	0.856

The previous experiments showed that US is not able to detect targets with small surfaces (e.g. children with height less than 85 cm, because of their small shoulders width and not because of their height!). One may consider this as a disadvantage, but we fructified this using the information given by PIR. Thus, if US is not triggered ($ht = 0 < threshold$), but only PIR, we considered a child entered.

PIR output signal is analyzed and a function is implemented in order to fulfil the *direction decision block*. At this stage of research, we do not take into account the occlusion phenomenon, i.e., when many persons pass simultaneously. According to the diagram, the system offers two extra options: either counting and identifying persons already registered in a database or counting differentially adults and children.

In order to test the system, we realized four scenarios and each of them was reproduced in order to obtain at least 3 sets of experimental results for each scenario.

In the first scenario, 5 persons (2 children and 3 adults) entered one after the other. We gathered information about their heights (if available) and direction. The results are tabulated in Table 2. The heights absolute error was computed as the difference between theoretical and experimental values. We observed that lower absolute values were obtained for smaller subjects. We showed, thus, that at this moment, the system must consider deviations $x = 9.62$ cm in order to work properly. This means that it is not suitable to discriminate between persons whose heights differ with less than

Table 2. 1st scenario. Height determination and status identification (inside/outside)

Set		# 1 (93 cm)		# 2 (159 cm)		# 3 (173 cm)		# 4 (162.5 cm)		# 5 (127 cm)	
Cm	%	Meas. (cm)	|Δ| (cm)	Meas. (cm)	|Δ| (cm)	Meas. (cm)	|Δ| (cm)	Meas. (cm)	|Δ| (cm)	Meas. (cm)	|Δ| (cm)
I		94.45	1.45	151.88	7.12	167.54	5.46	156.76	5.74	121.96	5.04
II		92.45	0.55	149.38	9.62	165.19	7.81	159.40	3.1	124.36	2.64
III		89.45	3.55	154.37	4.63	172.6	0.4	159.38	3.12	126.85	0.15

Set		# 1 (93 cm)		# 2 (159 cm)		# 3 (173 cm)		# 4 (162.5 cm)		# 5 (127 cm)	
		Th.	Exp	Th.	Exp	Th.	Exp	Th.	Exp	Th.	Exp
I		IN	IN	IN	IN	IN	OUT	IN	IN	IN	OUT
II		OUT	OUT	OUT	OUT	OUT	OUT	OUT	IN	OUT	OUT
III		IN	IN	IN	OUT	IN	OUT	IN	IN	IN	IN
IV		OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT

9.62 cm, as in the cases #2 and #4. Using such a threshold, #2 was always confounded with 4. Also, we applied median filtering of absolute errors and we assigned a value m = 3.55 cm for the deviation. In only 33.3% of cases #2 was correctly identified. #4 was always confounded with #2 for this value. This is why we chose finally a value of x − m = 6.58 cm for which #2 and #4 are recognized correctly. In what concerns the direction of movement, the system recognized correctly 15/20 events.

In the second scenario, using the data in Table 2 (real heights and absolute errors) we stored the heights in a database with appropriate height deflection and the task of the system was to recognize the persons that entered by their heights.

Table 3 comprises the results of *the third scenario*, in which the system had to classify the target as adult or child. The considered abbreviations in Table 3 are: I- person identified = YES/NO, #Passing order, T-Theoretical, E-Experimental determination, C-child, A-adult.

Table 3. 2nd/3rd scenario. Person identification using database and discrimination adult/child

Set	# 1 (93 cm)				# 2 (159 cm)				# 3 (173 cm)				# 4 (162.5 cm)				# 5 (127 cm)			
	#	I	T	E	#	I	T	E	#	I	T	E	#	I	T	E	#	I	T	E
I	2	Y	C	C	3	Y	A	A	1	Y	A	A	5	Y	A	A	4	Y	C	C
II	5	Y	C	C	4	Y	A	A	3	Y	A	A	2	Y	A	A	1	Y	C	C
III	3	Y	C	C	5	Y	A	A	4	Y	A	A	1	Y	A	A	2	Y	C	C
IV	4	Y	C	C	1	Y	A	A	2	Y	A	A	3	Y	A	A	5	Y	C	C

The last scenario implies four or less persons, entering or exiting with a delay of 1 s one after the other. The system had to approach the event and to return the number of persons (Table 4).

Table 4. 4th scenario. People counting testing (Delay IN, Delay OUT = 1 s between passers-by

Set	IN	OUT	Th. No.		Exp. No.		Percentage [%]
			IN	OUT	IN	OUT	
I	#1	#3	1	1	1	1	100
II	#2,#3	#4	2	1	2	1	100
III	#1,#2	#3,#4	2	2	2	2	100
IV	#2,#3,#1	#4	1	3	1	1	50%

4 Conclusions and Future Research

The paper emphasizes the work and results concerning the design of a people counting and discriminating system. By using PIR sensors and US, we developed a low-cost system aimed to provide information about the number of persons that enter or exit a place by extracting the motion direction parameter with a success rate of 75%. Moreover, the system may recognize passers-by through their height with a result of 100%, if information regarding their height is stored in a database and if we use the difference between maximum and median value of absolute errors in order to obtain the deviation. Also, the system may discriminate between adults and children with the same promising results of 100% if a threshold of 145 cm is chosen. We succeeded in counting persons that enter and exit in different numbers with a percentage of 100% when two or fewer people entered or exited with a small delay of 1 s and a success rate of 50% when more than two persons exited or entered with the same delay.

Future plans include enhancement of our system and its capabilities by considering the variation of the speed of sound with respect to medium conditions for the ultrasonic measurements. Also, we propose improving the extraction of the motion direction parameter using a more specialized method of comparing the output signal samples.

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