Real-Time People Counting Using IR-UWB Radar

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Abstract. COVID-19 pandemic has introduced social distance regulations which are crucial to be followed by. In order to maintain proper social distancing, it is critical to regulate the number of people in a closed space. In this paper, we propose a people counting system based on Impulse Radio Ultra-Wideband radars for counting people walking through a doorway. The system uses two IR-UWB radars placed horizontally apart to create a lag effect when someone walks by the radars. This enables detection of movement's direction and subsequently, determination of the number of people in a room. The system proposed can be used for people counting in real-time and also on saved data which offers flexibility for real world applications. Several tests were conducted which shows the accuracy rate of system to be around 90%, validating the system. Contrary to conventional vision based people counting system, the proposed system is not limited by environmental factors such as light and also is privacy oriented.

Keywords: People counting · Occupancy counter · COVID-19

1 Introduction

Real-time people counting is an important feature that is useful in many circumstances. Situations such as monitoring congestion of railway or bus station, building or room occupancy is an increasingly important feature especially in current pandemic condition. Due to the COVID-19 pandemic, it is essential to regulate the number of people in a closed space, in order to adhere to the social distancing rules. Compliance of such rules is challenging for essential service providers such as pharmacies and supermarkets, where physical visits are essential. Therefore, an automatic monitoring system is required which can output the number of people in an enclosed area and allow the administrators to regulate the number of people as per the requirements.

Many research works have been conducted in people counting systems, with heavy emphasis in using vision sensors as the technology [1]. Typically, closed-circuit television(CCTV) footage is used to train neural network which can detect people using features such as head, shoulders, etc., and after training, the network is deployed to count the number of people on live footage [1]. However,

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vision based technology have several disadvantages, in that it is heavily dependent on the input video quality. Therefore, changes in illumination, haziness might affect the detection accuracy. In addition, the appearance of a person is also important for such technology e.g., a person covering their body while holding an umbrella might not be detected. However, a key disadvantage of vision based people counting system is the lack of privacy. Video monitoring is an aspect that make many people uncomfortable due to perceived privacy invasion. Since a people counting system is going to be reliant on Internet of Things (IoT) platform for processing, there are risk of video data compromise. Vision sensor based people counting systems are also usually reliant on heavy image processing, therefore high performance hardware are another component which might be required.

Other types of sensors have also been used for people counting research. In [2], passive infrared sensors were used, which although has the advantage of being illumination invariant, has poor resolution for large number of people. Thermal cameras, which offers privacy advantage compared to traditional cameras have also been used for people counting using a Convolutional Neural Network [3]. However thermal imaging based people counting system have difficulties in crowded situations where, due to high density, people block each other in the camera field-of-view. Furthermore, training a Convolutional Neural Network on thermal images, to achieve good accuracy rate, would involve collecting large amount of data, which is expensive in terms of both time and resource.

With high resolution, low power requirement and excellent penetration [4], Impulse Radio Ultra-Wideband (IR-UWB) is a trending technology for many applications such as vital sign detection [5], indoor positioning system [6], Time Of Arrival (TOA) [7], and also detection of people in disaster sites [8]. IR-UWB radar transmits a very short duration impulse signal, which occupies a wideband in frequency domain [9]. The reflected signal can then be analysed to extract useful information.

IR-UWB radar is a suitable technology for people counting and several research have been already conducted in this domain. In [10], Maximum Likelihood approach was used for people counting using IR-UWB radar. Similarly in [11], Convolutional Neural Network was used to count people using IR-UWB radar. However, both of these approaches were limited in the amount of people it can count, which is a critical drawback for a scalable people counting system in real world for application such as COVID-19 regulation monitoring. In [12], the count capacity limit was avoided by developing an in/out bound people counter.

In this study, a real-time people counting system using commercial IR-UWB radar has been developed, which can be used to count people in an enclosed space e.g., a room.

2 Methodology

The system developed uses the principle, that if a person entering and exiting a room can be detected, then the number of people inside a room can be counted using the expression:

Number of people in a room = Number of people entry - Number of people exit.

The basic overview of the system is illustrated in Fig. 1. By placing the proposed system beside a room entrance, any person going in or out can be detected, obtaining the total count of the number of people in the room. If there are multiple entrances to a room, then one system can be placed beside each entrance, and the result from each system can be integrated to output the total people count in the room as illustrated in Fig. 1.

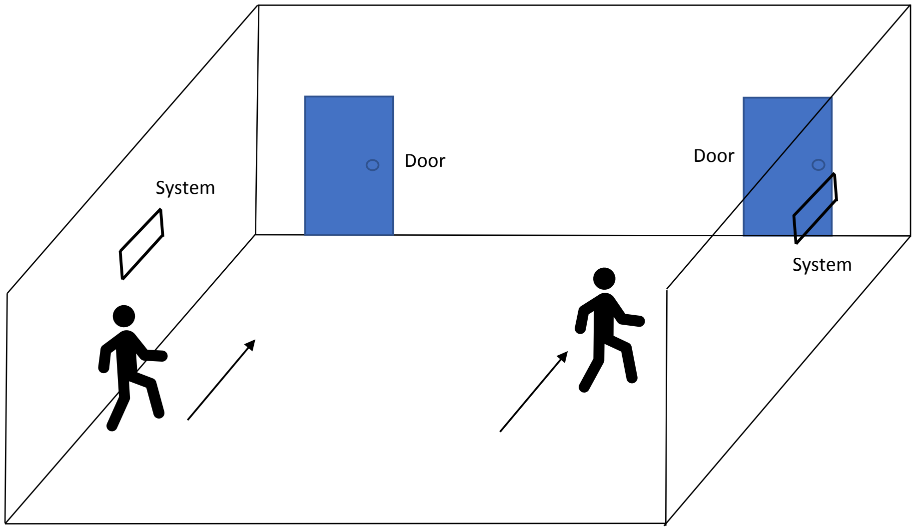

Fig. 1. System placement position in a room for people counting.

For this study, two commercial IR-UWB Radars, Xethru X4M200 by Novelda, were utilised. Both the radars have a centre frequency of 7.29 GHz. The radars were placed horizontally apart at distance d, to create a lag response when a person is walking in front of the radars, as shown in Fig. 2. This allows the direction of movement to be recognized and therefore, determine whether a person has moved in or out of a room. The separation distance d is a vital parameter, as too large distance d will output a clearer lag effect, enabling easier direction identification. But a person can walk in between the radars, distorting the return radar waveform. On the other hand, a small distance d will reduce the time taken by a person to walk across the two radars and thereby, reducing the accuracy in direction determination. Therefore, a value was chosen after trial and error. The algorithm was developed and run on Matlab platform using a laptop.

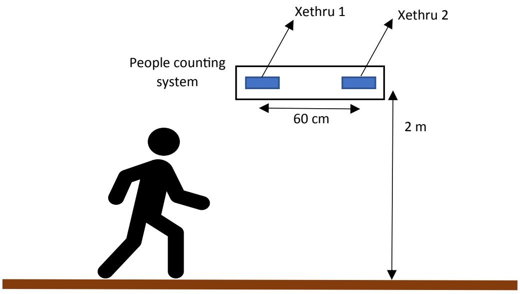

Fig. 2. System placement side view.

2.1 People Counting Algorithm

The I and Q signals output from the radars are mixed to create the IQ signal using the expression:

$$IQ = I_{signal} + i \times Q_{signal} \tag{1}$$

The resultant signal is then passed to the developed algorithm. The algorithm is described and illustrated in Fig. 3.

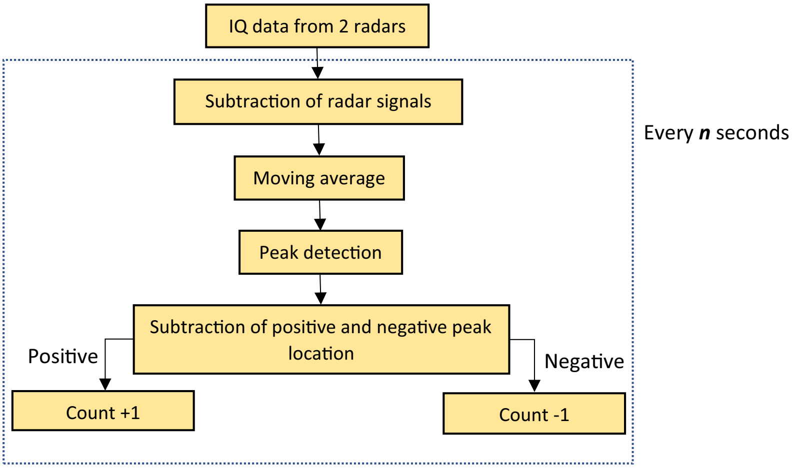

Fig. 3. Signal processing block diagram.

The algorithm is developed based on the principle of being able to run real-time. This is because, it will provide an opportunity for administrators to act in an instant, if the occupancy limit of a room is exceeded at any time. Each step of the algorithm is described as follows:

1. **Signal subtraction:** The IQ signal from the 2 Xethru radars are subtracted to ensure that the resultant output signal only contains the difference signal.
2. **Moving average:** To discard stray peaks and smoothen the signal.
3. **Peak detection:** Peak detection allows identifying positive and negative peak in the signal.
4. **Peak location subtraction:** The negative peak location is subtracted from the positive peak location. If the resultant number is positive, it indicates entrance to the room and vice versa for negative resultant number.

The algorithm takes the data and runs every specified n second e.g., every 3 s, 7 s, etc. After trial and error, n was set to 10 s. This value was chosen based on running the algorithm at real-time speed whilst keeping the computational cost low.

2.2 Experiment

The experiment was set up with the radars separation distance d set to 60 cm after trial and error. The vertical distance was set to 2 m. Two types of experiment were conducted: Controlled and Uncontrolled.

– **Controlled**: Specific number of people were instructed to walk up and down a corridor.
– **Uncontrolled**: Device was set up in a corridor and the experiment was conducted with free flowing crowd.

The main aim of the experiments were to monitor the accuracy of the algorithm, in determining the direction of movement (in to out, out to in) in real-time. Direct observation of people movements were used as reference.

3 Results

Figure 4 shows the ideal wave pattern for the algorithm, Fig. 5 illustrates each step of the signal processing blocks and Table 1 shows the experiment results.

Results in Table 1 validates the performance of the system as the results for both controlled and uncontrolled tests have an accuracy rate around 90%. Majority of the error during controlled test were due to the laptop slowing down as a result of driving two Xethru radars at the same time. In addition to that, uncontrolled test also had cases where a person would stop in the path to look at the system, thereby corrupting the data. Also, for uncontrolled test there was 1 instance where two people walked in side by side, resulting in an error.

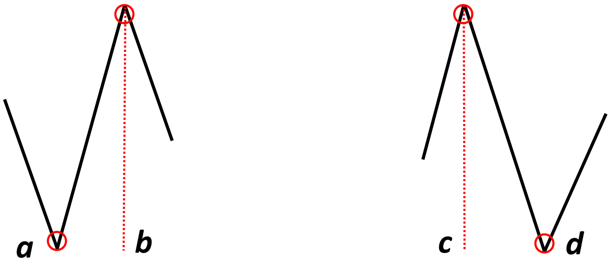

Fig. 4. *Left:* Ideal pattern for positive count where Positive peak **b** index minus Negative peak **a** index will give a positive number. *Right:* Ideal pattern for negative count where Positive peak **c** index minus Negative peak **d** index will give a negative number.

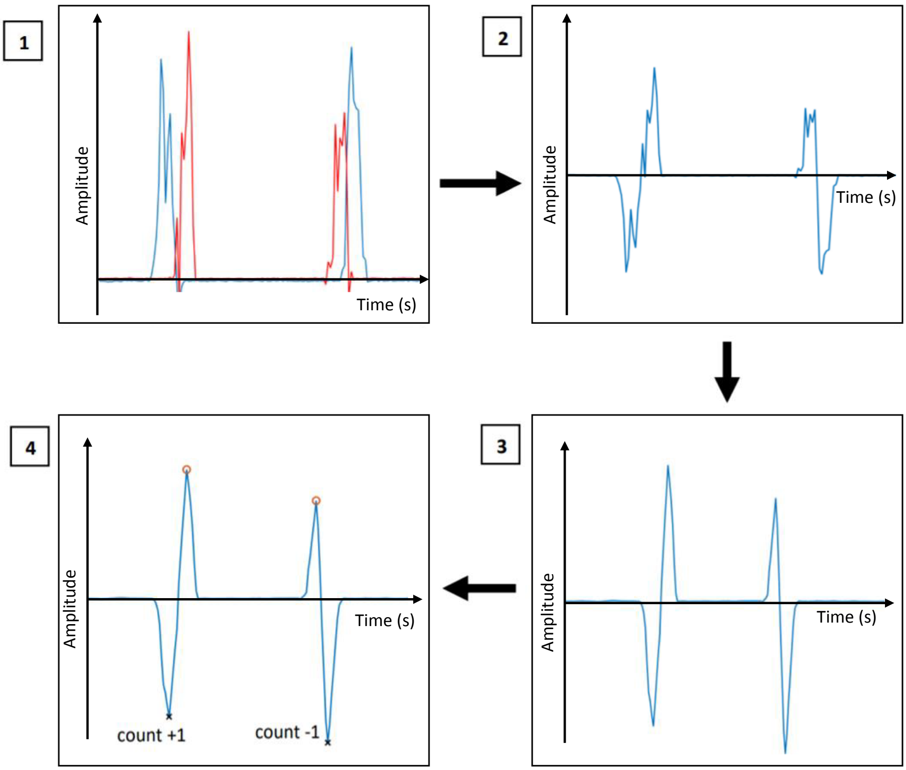

Fig. 5. Algorithm signal processing diagram. 1. IQ signal of both radars 2. Subtraction of the signals 3. Applying moving average 4. Peak detection and subtraction which enables determination of direction and hence, the count.

Table 1. Experimental results for the system in controlled and uncontrolled tests.

Test type	Controlled	Uncontrolled
Reference In	30	25
Reference Out	30	19
Predicted In	28	22
Predicted Out	27	17
Reference total	60	44
Predicted total	55	39
In accuracy rate (%)	93	88
Out accuracy rate (%)	90	89
Total accuracy rate (%)	92	89

4 Conclusion

In this paper, a real-time people counting system using IR-UWB radar has been proposed. Compared to conventional people counting technologies, which are predominantly camera based, the proposed technology does not have drawbacks of being light variant and privacy invasive. In addition, due to low algorithmic complexity, the system can be adapted to run on Raspberry Pi, and the IQ radar signal can be further utilised for additional functionalities such as posture classification. Two types of tests were conducted to validate the accuracy of the system developed. Overall, the high accuracy rate of the system demonstrate a feasible technology for robust people counting applications. In the future, further work will be done to improve the accuracy and also develop additional functionality for multiple people walking side by side.

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