A New Approach for Counting Passersby Utilizing Space-Time Images

A. Elmarhomy, S. Karungaru and K. Terada

***Abstract*—**Understanding the number of people and the flow of the persons is useful for efficient promotion of the institution managements and company's sales improvements. This paper introduces an automated method for counting passerby using virtual-vertical measurement lines. The process of recognizing a passerby is carried out using an image sequence obtained from the USB camera. Space-time image is representing the human regions which are treated using the segmentation process. To handle the problem of mismatching, different color space are used to perform the template matching which chose automatically the best matching to determine passerby direction and speed. A relation between passerby speed and the human-pixel area is used to distinguish one or two passersby. In the experiment, the camera is fixed at the entrance door of the hall in a side viewing position. Finally, experimental results verify the effectiveness of the presented method by correctly detecting and successfully counting them in order to direction *with accuracy of 97%.*

***Keywords*—**counting passersby, virtual-vertical measurement line, passerby speed, space-time image

I. Introduction

VIDEO surveillance technology has received a great range of attentions because of its potential wide applications in restricted and open areas for safety and security requirements. Moreover, a home surveillance system is a perfect way to provide extra protection for families, home or business. A home safety system typically includes fire detection, as well as protection against break-ins. Therefore, the security and protection have become very important for many commercial areas and companies [1].

Counting people is an important task in automatic surveillance systems. To analyze store performance correctly, people counting must be accurate. It is a 'false economy' to select a people counting system on the basis of cost alone. As management consultant Peter Drucker once said: *"If you can't measure it, you can't manage it."* [2]. Moreover, many violent crimes have increased and become serious problems for many institutions and commercial areas [3]. Many of such measurements are still carried out on manually [4].

Therefore, it is necessary to develop the automatic method for counting the passing people. There are some earlier researches already proposed in counting the passing people. However, most of these papers have used over-head camera viewing.

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Hashimoto et al. resolve the problem of counting people using a specialized imaging system designed by using IR sensitive ceramics, mechanical chopping parts and IR-transparent lenses [5]. But, the system shows some problem in counting with large movements from arms and legs. So this system will be not appropriate in commercial center because of the high density traffic when people entering or exiting.

Terada et al. had suggested a system that can determine people direction movement and count people as they cross a virtual line [6]. The advantage of this method is it avoids the problem of occlusion when groups of people pass through the camera's field of view. But the problem is that this method needs to have a good calibration of two cameras (when 3D reconstruction is used). Terada and Matsubara had proposed a method of counting multi-direction passerby by using critical space- time image [7]. A critical measurement line is set on a sequence of the background subtraction images. However, the direction information of passersby cannot be obtained from this space-time image. Therefore, two circular measurement lines are set on a sequence of the background subtraction images which is a complicated processing. Terada and Atsuta had proposed a method for the automatic generation of passerby images from videos recorded by Internet cameras to facilitate their later use [2]. However, a passerby appears, his image exists in multiple frames, but only the single frame offering the best image for storage is selected and the rest are deleted.

This paper proposed an automatic method of counting passerby by recording images using virtual-vertical measurement lines. The process of recognizing a passerby is carried out using an image sequence obtained from USB camera located in side view position. It is necessary to note that there are different camera viewing; over-head view, front view and side view. However the previous approaches cannot applicable to wide installed side view cameras selected for this work. This new approach uses a side view camera that faced and solved new challenges: (1) two passersby walking in close proximity to each other, at the same time, and in the same direction, (2) two passersby moving simultaneously in opposite directions, (3) a passerby moving in a line, followed by another, or more, in quick succession.

In this study, space-time image is representing the time as a pixel distance which is used to support the algorithm to achieve the accurate counting. The human regions treated using the passerby segmentation process. The system is fixing automatically to select the best matching which determine passerby direction and speed. In the experiment, the camera is installed on the left side of the room near the entrance. The experimental results verify the effectiveness of the presented method. In other words, every person was detected by the proposed method and the passerby record image is correctly generated. Moreover, an additional and significant result was that the number of people passing the camera was successfully determined and counted.

II. The Proposed Algorithm

A. System Overview

The proposed algorithm steps as follows

The first step is acquiring the frame from the camera. The next step called preprocessing step which contents background subtraction, removing noise and establish the four measurement lines. After that movement detection is the key-point for the algorithm to start generate the space-time images. Then treat the human pixel area via segmentation process. The next step is performing the template matching to determine direction and speed. Finally, count according to the direction and number of passing people.

The schematic flow chart for the proposed algorithm is shown as Fig.1. More details for the algorithm steps are discussed on the following sub-sections.

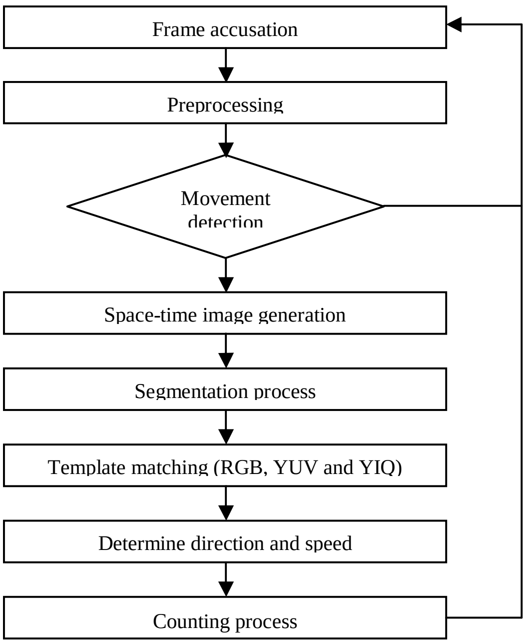


Fig. 1 The flow of the proposed algorithm scheme

B. Frame Acquisition

Frames are captured continuously by a camera installed at a surveillance site. The surveillance camera is connected to a personal computer to acquire the image data. Image data of passersby, from the time they enter the frame until they exit the frame, are extracted from the acquired image series.

Fig.2 shows an example of image sequences captured by the camera. The 320 × 240 pixel images are captured by the camera as bitmaps. The image is obtained by a USB camera at an average of 17 frames per second. The images in Fig.2 were acquired via a camera installed on the left side of the room near the entrance. In Fig.2 (a), a person enters the frame zone and movement is detected by the algorithm. In Fig.2 (b), one passerby is crossing in front of the camera. In Fig.2 (c), two passersby are walking in close proximity to each other, at the same time, and in the same direction. In Fig.2 (d), two passersby are moving simultaneously in opposite directions.

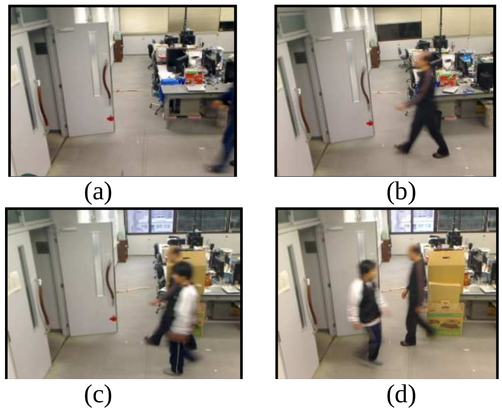


Fig.2 Images acquired using the camera: (a) and (b) show a single person passing; (c) and (d) show examples of two persons passing

C. Image Preprocessing

Possible detections of passersby are extracted from the frame using a preprocessing stage to generate space-time images. The algorithm employs the following steps to detect movement:

- The first step is to construct a static image to be used as a static background image [8]. This image can be acquired by capturing a frame without any motion. Moreover, the image is then used as a background reference in order to obtain subsequent images, via pixel subtraction. After subtracting the background reference, the remaining pixels represent possible detection of motion in the frame; this subtraction process is continuous for each frame.
- The second step of pre-processing is removing the noise from the frame by applying a specific morphological filter, a labelling filter, which is used to remove any irrelevant small areas. Therefore, the noise caused by lighting and the color of clothing is reduced.

To represent and establish the measurement lines, four vertical lines are set in the image, each line is two pixels in width.(Whenever the line is wide, the size of the passerby appears to be wide, inside the space-time image, and the magnitude of the human-pixel area is represented with a larger amount of pixels.). Two of the four lines, “middle lines,” are in the middle of the image. The two remaining lines, “outer lines,” are located to the left and to the right of the middle lines. The measurement lines used in this study are shown as in Fig.3.

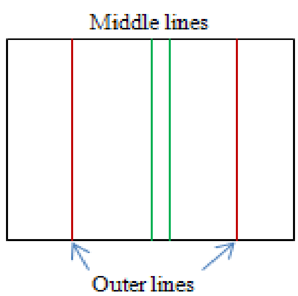


Fig. 3 The measurement lines used to generate the space-time image

The position of the lines is precisely selected, in order to clearly determine the movement directions. A separate background is prepared, from the static background image, for each of the four measurement lines. The data contained inside the four two-pixel-wide measurement lines will be used to generate space-time images.

D. Generating Space-Time Images

As discussed, in the previous subsection C, human regions are extracted from the captured images using background subtraction, and noise suppression via a labeling filter. Virtual measurement lines are superimposed on the original frame in order to obtain a measurement-line image. By repeating this process, and arranging measurement line images together with the x-axis (time) and the y-axis (space), a space-time image is produced. An example of how space-time images are generated is shown in Fig.4. After subtracting the static background from each frame, if a motion is detected the measurement lines of the current image are captured; the corresponding static background measurement lines, from the preprocessing stage, are likewise continuously subtracted. The resulting difference of the subtraction process is continuously recorded on the space-time image.

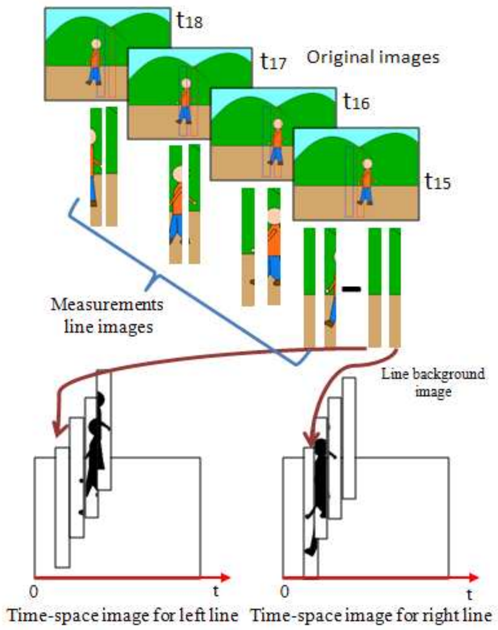


Fig. 4 Space-time images generation according to the time.

A space-time image contains data for all passersby. When a passerby moves left or right the resulting image is obtained. Since the measurement line are vertical, movement of passersby are seen moving through the measurement lines in a horizontal direction. This causes the shape of the passersby to also appear in a vertical position in the space-time image. When labeling is applied to the space-time image for shape extraction purposes, human objects can be identified.

After generating the space-time image the system treats the passerby as one single component, without specifying individual body parts which influences the counting results. Therefore, a segmentation process is applied to the passerby in order to assemble the disconnected components into a recognizable human shape by using a process of labeling.

E. Segmentation of the Passerby

One of the difficulties for the segmentation algorithm is the background noise that sometime produces different quantities of connected components for the same passerby [9]. Because, inside the space-time image, the shape of each passerby appears almost identical, it is necessary to sometimes assemble the appropriate shape of each passerby via segmentation. Additionally, this problem influences the template matching process: accurately matching the passersby. Template matching is discussed in more detail in section III. This problem also affects the magnitude and size of the human pixels area. This will be used in section III.

To solve the problem mentioned in the previous paragraph, the method calculates and counts the connected components that represent the same passerby with a different labeling object. This assigns all the connected components the same labeling number. In this case, the passerby is represented as one component. The position of the passerby is vertical. Thus the system search, for other connected components of the passerby, which is also vertical and is located between the left and right boundaries of the pre-segmented connected components. Fig.5 shows the passerby shape before and after segmentation process with the color space-time image.

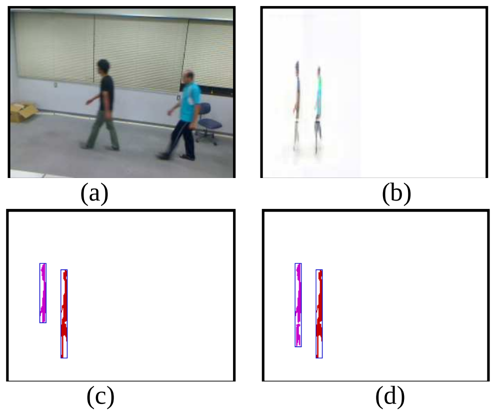


Fig. 5 The passerby shape before and after segmentation process: (a) the original image (b) the original color space-time image. (c) before segmentation process. (d) after segmentation process

III. Template Matching

A. Overview of the Problem

In general, the binary image is used to perform template matching, because it is fast. However, accurately matching more than one passerby appearing in the same space-time image is difficult because of the problem of mismatching [10]. For example, when using the binary image, the shapes of the passersby are nearly identical. This contributes to the problem of mismatching. In this case, when dealing with more than one passerby, using color space such as RGB, YUV, and YIQ is better for accurate matching. Details about these three space colors are discussed as flows:

B. RGB Color Space

The RGB color model is an additive color model in which red, green and blue light is added together in various ways to reproduce a broad array of colors [11]. The main purpose of the RGB color model is for the sensing, representation, and display of images in electronic systems, such as televisions and computers.

C. YUV Space Color

YUV is a color space typically used as part of a color image pipeline [12]. It encodes a color image or video taking human perception into account, allowing reduced bandwidth for chrominance components, thereby typically enabling transmission errors or compression artifacts to be more efficiently masked by the human perception than using a RGB-representation. Other color spaces have similar properties, and the main reason to implement or investigate properties of YUV would be for interfacing with analog or digital television or photographic equipment that conforms to certain YUV standards by the following equation (1):

$$\left.\begin{aligned} Y &= 0.299 \times R + 0.587 \times G + 0.114 \times B \\ U &= -0.147 \times R - 0.289 \times G + 0.436 \times B + 128 \\ V &= 0.615 \times R - 0.515 \times G - 0.100 \times B + 128 \end{aligned}\right\} \quad (1)$$

D. YIQ Color Space

The Y component represents the luma information, and is the only component used by black-and-white television receivers. I and Q represent the chrominance information [13]. In YUV, the U and V components can be thought of as X and Y coordinates within the color space. I and Q can be thought of as a second pair of axes on the same graph, rotated 33°; therefore IQ and UV represent different coordinate systems on the same plane. The YIQ system is intended to take advantage of human color-response characteristics. The RGB to YIQ conversion is defined as formula (2):

$$\left.\begin{aligned} Y &= 0.299 \times R + 0.587 \times G + 0.114 \times B \\ I &= 0.596 \times R - 0.275 \times G - 0.321 \times B + 128 \\ Q &= 0.212 \times R - 0.532 \times G + 0.311 \times B + 128 \end{aligned}\right\} \quad (2)$$

E. Optimal Matching

In the case of two shapes are detected, in the space-time image, the pixel distance between the two shapes is measured (MD). Moreover, the system performing the template matching using different space colors as shown in Fig.6. After performing the template matching with the space colors (RGB, YUV), the matching result covers the whole or a part of the passerby shape. However, using the lookup table inside the matching result areas, the given label of the shapes can be determined. After determining the given label of shapes, the pixel-distance between the two resulted shapes, in the space-time image, is likewise measured (TD). Comparing the MD value with the TD value the optimal match can be determined.

IV. Measurement Lines Functions

In this section, how measurement lines are used to determine the speed and direction of passersby will be discussed.

A. Passerby Direction Detection

To determine the passerby direction, two space-time images, one image for each of the two middle measurement lines, are used. It is important to consider the distance between the two middle measurement lines. Passerby movement crosses one middle measurement line before it crosses the second one. It is necessary to note that, the distance between the two middle measurement lines is sufficient to detect the direction. By measuring the difference between the passerby positions in the two space-time images, direction can be determined.

After applying the segmentation process, the passerby is represented as one component. By treating the passerby area as a template image, taken from the left middle measurement line space-time image, and then performing template matching, a match can be achieved. By applying the labeling concept (lookup table) to the resulting match the exact passerby position can be determined. By comparing the left position of the passerby in the both space-time images, the direction of the person can be determined as shown in Fig.7. Using the exact passerby position versus using the passerby matching position, to detect the direction produces more accurate results.

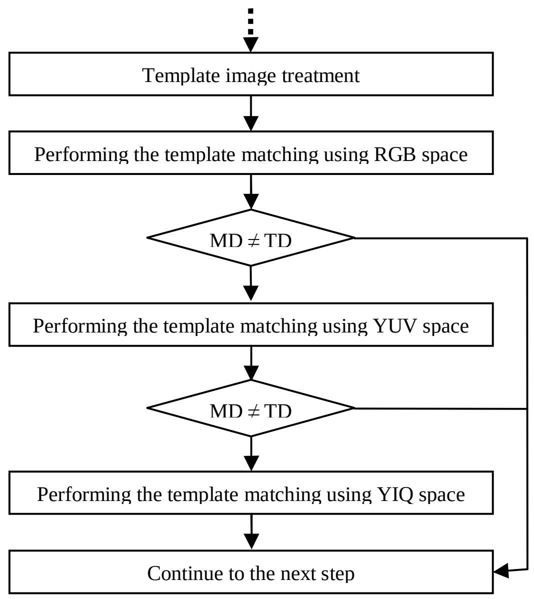


Fig. 6 Optimal matching

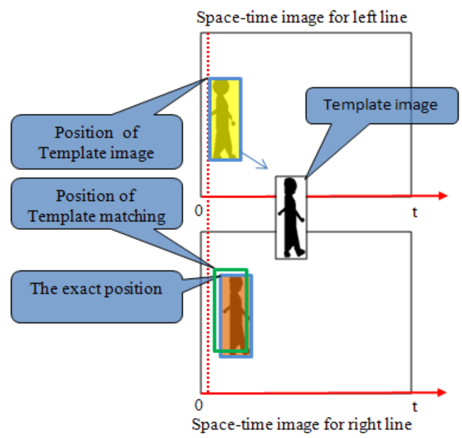


Fig. 7 Space-time image for direction detection

B. Measurement of Passerby Speed

To determine speed, the two middle measurement lines space-time images are used. Distance and time are used to calculate the speed; the distance between the two middle measurement lines is measured manually in centimeters, as shown in Fig.8.a. The elapsed time calculation will be discussed in detail.

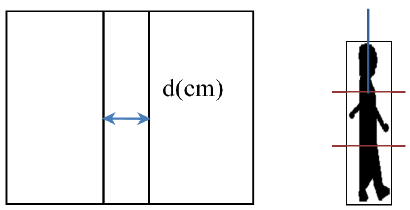
1. Head Position

Since the measurement lines are vertical, passersby move through the measurement lines in a horizontal direction. This causes the shape of the passersby to also appear in a vertical position in the space-time image, as discussed in section (D). By dividing the shape of the passersby into three equal parts, and considering the uppermost part as the passerby head position, the head position can be detected, as shown in Fig.8.b. Therefore, the head position of the passerby is detected twice, once for each of the two middle measurement lines.

2. Time Determination

As noted in subsection II (D), the difference between the passerby positions in the two space-time images is used to determine the passerby direction. Since the x-axis represents time, this difference can be used to calculate the elapsed time. The calculated time is not the precise elapsed time, which is what is needed; without the correct elapsed time the speed calculation is inaccurate. In this case, the exact elapsed time can be calculated, by using the (vertical) center of the body position.

The center of the body position can be calculated, by using the head position. The difference between the centers of the passerby body position, in the two space-time images, is calculated in pixels. Since each measurement line is two pixels in width, the number of frames can be ascertained. As a result, by multiplying the frame rate by the number of frames, the precise elapsed time can be calculated.



(a) (b)

Fig. 8 Speed calculation (a) the distance in d (cm) (b) allocated the passerby head

3. Speed Calculation

After calculating the precise elapsed time, as discussed in the previous section, by dividing the distance on the precise elapsed time, the speed is calculated.

C. Human- Pixel Area

The human-pixel area is the number of pixels, which represent the magnitude of the passerby shape, in the space-time image. There are several important factors that influence the size of the passerby shape and the magnitude of the human-pixel area: the measurement line width, frame rate, speed of the passerby, and passerby segmentation. The width of the measurement lines and the passerby segmentation, have been discussed in subsections (C) and (E). Using different examples, the following discussion focuses on the influence of the frame rate, and speed.

- Frame rate: As illustrated in the following cases, how the frame rate influences the human-pixel area can be observed. In the case of acquiring the frame using a slow frame rate, the size of the passerby appears to be thin, inside the space-time image, and the magnitude of the human-pixel area is represented with a smaller amount of pixels. On the other hand, in the case of acquiring the frame using a high frame rate, the size of the passerby appears to be wide, inside the space-time image, and the magnitude of the human-pixel area is represented with a larger amount of pixels.
- Speed: How passerby speed influences the human-pixel area, when the frame rate is constant, can be clearly observed. In the case of a passerby passing at high speed (fast), the size of the passerby appears to be thin, inside the space-time image; the magnitude of the human-pixel area is represented with a smaller amount of pixels, in comparison to the case of a passerby walking at a normal speed. On the other hand, in the case of a passerby passing at slow speed (slowly), the size of the passerby appears to be wide, inside the space-time image; the magnitude of the human-pixel area is represented with a larger amount of pixels, in comparison to the case of a passerby walking at a normal speed.

V. Counting Process

In this section, the count process will be discussed in detail, based on different variations: one passerby, two passersby moving in the same direction, two passersby moving in opposite directions, one passerby followed by another. As noted in the previous section, direction, speed and human pixels area are determined first, and then each passerby is counted based on movement direction. Each variation will be explained in the next sections.

A. Same Direction

In the case of two passersby walking in close proximity to each other, at the same time, and in the same direction, their combined shape appears to be wide, in the space-time image, and the magnitude of human-pixel area is represented with a larger amount of pixels. This case is similar to the case of one passerby passing at slow speed, as discussed in subsection III (C) Therefore, it is difficult, by using only the passerby shape, to ascertain whether it is one passerby, or two passersby. Because of this problem, a ratio for distinguishing single or multiple shapes is needed.

1. Pixel-Speed Ratio

In section (G.3), the human-pixel area is counted. Additionally, in section (G.2), the speed of the passerby is determined. By multiplying the human-pixel area by the speed of the passerby, the pixel-speed ratio (R) is calculated, as shown in equation (3).

$$R = (human\_pixel\ area) \times (passerby\ speed) \tag{3}$$

2. Counting

Whether the shape is only one passerby or two passersby can be ascertained, by using the pixel-speed ratio. If the average value of the R ratio, in the two middle measurement line space-time images is more than the threshold (The value of the threshold chosen after many try and error in the experiment, in this work, the threshold is implicitly set 5000.), the system detects two passersby walking in the same direction; otherwise, the system detects one passerby. In other words,

$$if\ R\begin{cases} < \text{threshold} & one\ passerby \\ > \text{threshold} & two\ passerby \end{cases}$$

B. Counting Passerby Walking on the Opposite Direction

To count two passersby walking in opposite directions, instead of using the two middle measurement lines, the two space-time images of the two outer measurement lines are used. The passerby crosses one of the two outer lines before crossing the second line. The time needed to arrive at the second outer line is represented with distance, in the space-time image. In the case of two connected components detected, in one or both of the space-time images, the distance between the two passersby, is measured in pixels. If the pixel-distance is greater than the established threshold, the system recognizes and counts two passersby walking in opposite directions.

C. One Passerby Followed by Others

To count passersby in a line, followed by another, or more, in quick succession, the count function is modified. When two connected component shapes are detected, the pixel distance between the shapes, in the space-time image, is measured. The measurement process is repeated and applied to each of the four space-time images. The average value of the four distances is then calculated according to the following equation (4):

$$Average\ distance = \frac{D_1+D_2+D_3+D_4}{4} \quad (4)$$

After calculating the average value, the relationship between the average value and the distance is defined based on the equation (5).The low (L) and high (H) values are threshold values. After experimentation, the most effective L and H values, for purposes of counting, are chosen. Using the equation(5), if the four values, of the dividing results, is Achieve the relationship the system can detect two passerby shapes passing one followed by another.

$$L < \frac{Average\ distance}{(distance)D_n} < H \quad (5)$$

Finally, the template matching is performed to match the corresponding passerby, to detecting the left position and passerby head's. Moreover, pixel-speed ratio is calculating by multiplying human-pixel area in human speed. This processing is done for each passerby separately. After that the passerby is counted according to their direction.

VI. Experimental Results

A. Experimental Observation

In the experiment, the camera is fixed on the entrance door of the hall. A PC is connected to the camera with a frame rate 17 frame per second. The system was tested by different video sequences with different cases and directions. For example the system is test when one passerby and two passersby walk in the same direction and in the opposite direction.The system successfully counted a single passerby walking in any direction, incoming or outgoing, as shown in Fig.9.In the case of two passersby walking together, at the same time, in the same direction, the system counted the two passersby based on the pixel-speed ratio, as shown in Fig.10. In the case of two passersby walking in opposite directions, the system was tested to count two passersby walking in the opposite directions; it precisely counted the two passersby, based on the measured distance between the two passersby in the outer measurement line space-time image, as shown on Fig.11.

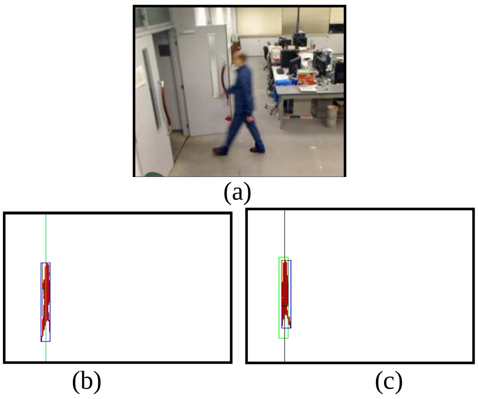


Fig. 9 Single passerby walking in exit direction. (a) is the original images. (b) and (c) are the left and right middle measurement line space-time images

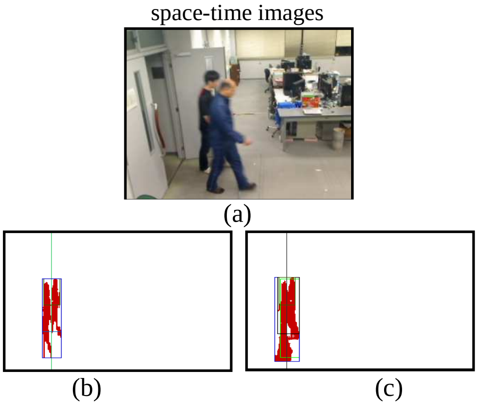


Fig. 10 Two passersby waking together in the same direction (a) is the original images. (b) and (c) is the left and right middle measurement line space-time images

Finally, to count passersby in a line, followed by another, or more, in quick succession, the system is measured the distance between the passing people shapes, in the four space-time image. And use the average value between the four distances to detect the two passerby shapes. After that performing the template matching to determine the passerby direction and calculate speed. Then, count according to direction as shown in Fig.12.In conclusion, our experimental are correctly counting the two passersby walking in the same or opposite direction.

B. Experiment Results

In this section, our experimental results representing the achievement of the accurate matching and counting automatically the passersby, in various cases and directions, with different video sequences as in the following subsections.

1) Accurate Matching

Accurately matching more than one passerby appearing in the same space-time image is difficult because of the problem of mismatching.

TABLE I
EXPERIMENT RESULT OF COUNTING ALGORITHM IN VARIOUS STATUSES

Status		Number of passersby	Not detected	Detected direction (%)	Speed	Speed-pixel ratio	Counting accuracy (%)
One passerby		one	0	100	Measured	Used	100
Two in close proximity to each other		two	0	100	Measured	Used	90
Opposite direction		two	0	100	Not measured	Not used	100
passerby in a line, followed by another, or more	One followed by one	Two	0	100	Measured for each	Used	100
	One followed by Two in close proximity to each other	Three	0	100	Measured for each	Used	95
	Two in close proximity to each other followed by two in close proximity to each other	Four	0	100	Measured for each	Used	90

In this case, when dealing with more than one passerby, the system is using space colors such as RGB, YUV, and YIQ in order to achieve the accurate matching. When performing the template matching using RGB space color only the result error is about 19 %. After using RGB and YUV space colors the result error is about 8 %. Finally using three space colors (RGB, YUV and YIQ) the result error is unnoticed (is about 3%). Figure 15 shows a complete example explaining the determination of the optimal matching.

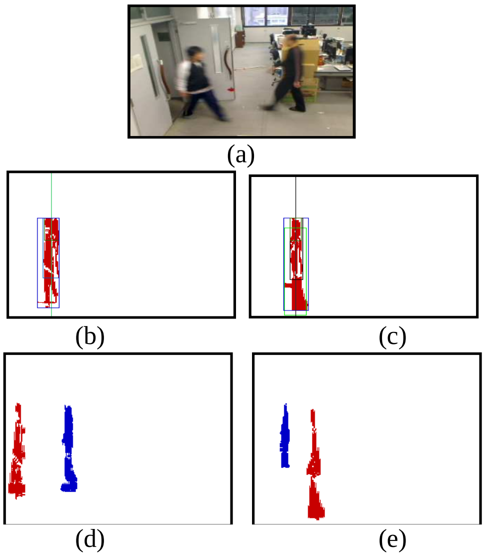


Fig.11 Two passerby waking together in opposite directions. (a) is the original images. (b) and (c) are the middle measurement line space-time images. (d) and (e) are the outer measurement line space-time images

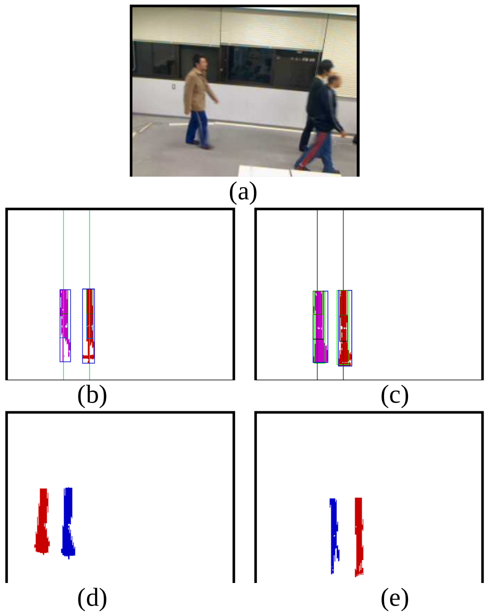


Fig.12 Two passerby waking together in opposite directions. (a) and (c) are the time space image without any processing while (b) and (d)are the space-time images

2) Passersby Counting Accuracy

In this subsection, the method was automatically counted the passersby, in various cases and directions, with different video sequences. Table 1 shows the counting accuracy for multiple experiments with status: one or two passersby moving in the same direction, two passersby moving in opposite directions, and one passerby followed by another, where the number of passersby is one, two, three or four; and the speed sometime measured and sometime not measured.

From the results in Table 1 for 50 cases in each status, it verifies that the new method is effective and efficient for counting passersby.

From the results of sample of long time experiment the manual count was (Exit: 185 and Enter: 209) and the method determined (Exit: 180 and Enter: 205). It is significant that the number of people passing the camera was successfully determined and counted with high accuracy about 97%.

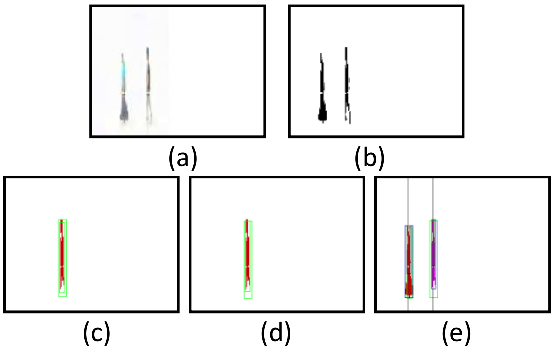


Fig.12 Template matching with a complete example to explain the method can determine the optimal match. (a) is the color space-time image (b) is the binary image (c) and (d) are represent an example of Mismatching with RGB and YUV space color, (e) the correct matching with YIQ space color

VII. CONCLUSION

This paper has proposed a new automatic approach for counting passersby using four virtual-vertical measurement lines. The process of recognizing a passerby is carried out using an image sequence obtained from the USB camera. In this study, four space time images are generated one from each measurement lines. Space time image is representing the human regions which treated using the passerby segmentation process. In this study, different color space has been used to perform the template matching which chose automatically the best matching to obtain passerby direction and speed. The head position is detected in order to calculate the precise elapsed time which is used to determine the passerby speed. The relation between the passerby speed and the human-pixel area has used to distinguish between one or two passersby. Furthermore, the pixel distance between the passersby, inside the space-time image, has used to count passersby in a line, followed by another, or more, in quick succession and determine the direction of passersby. Moreover, an additional and significant result was that the number of people passing the camera was successfully determined and counted.

Future work could be made by improving the proposed method to allow counting group of peoples. Also could be focused on improving the background subtraction to be more sensitive to the environment changes.

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