

Fall Alarm and Inactivity Detection System Design and Implementation on Raspberry Pi

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Abstract— In this paper, a fall alarm and abnormal inactivity detection system is implemented on Raspberry Pi for security surveillance of empty-nesters in real time environment. We propose a novel method for fall alarm with a small amount of computing and we also present an inactivity detection method which we named “inactivity history” method to improve the accuracy of detection and it is a kind of adaptive method so it works well in even different environments. For fall alarm, we divide the image into many rectangular areas and according to the area of body in each rectangle we will judge whether the elderly fall or not. For inactivity detection, we count the average inactivity time of people in different rectangles to set up the inactivity history map to judge whether people are in abnormal inactivity accurately. There are also E-mail and SMS warning functionalities, providing a very good safeguard for the elderly. Meanwhile, terminal device have advantages of small size and low power consumption, which will lead to wide applications. The system satisfies real-time and reliable requirements. Extensive experiments carried out demonstrate the effectiveness of our system.

Keywords—Empty-nester, Raspberry Pi, Fall Alarm, Inactivity Detection, Computer Vision, Video Surveillance

I. INTRODUCTION

Nowadays elderly people especially those living alone [1] are with high risk to various accidents due to their vulnerable body. Tumble and abnormal inactivity are two main risks for elderly. Easy-to-use and being economical are two critical issues that must be taken into consideration for such products. With the quick development of image technology, computer vision methods provide a possible solution. A video surveillance based detection system is developed in this paper.

Plenty of methods for fall alarm have been proposed and they can be classified into three categories: wearable device based, ambience device based and computer vision based. Usually the wearable device based method need specialized equipment which is attached to human body. Chankyu Park [2] has proposed a reliable and low-cost watch-type fall detector and one of the disadvantages of these methods is that it is inconvenience when powered by batteries and it is often a burden. If the elderly forget to wear the watch, then it cannot work. Also there are many other wearable devices based method (e.g. [3]–[4]) sharing the similar problems. Ambience

device based method often needs many sensors installed and it has a low detection accuracy. Computer vision approach is a good choice but conventional approach need large computation (e.g. [5]) and they will not have good results when there are serious occlusions (e.g. [6]–[7]). Young-Sook Lee [8] also proposes a fall alarm method but it lacks an inactivity detection and can't be installed widely. Tao, Shuai [11] presents a privacy-preserved infrared ceiling sensor network, needing large amount of sensors on the ceiling, which is inconvenient for installing.

Based on these observations, we propose a novel fall alarm and inactivity detection method which is implemented on Raspberry Pi. Our method can effectively avoid the occlusion problem because our wide angle camera are installed on the ceiling. When looking down from the ceiling, there are rarely occlusion happening. Also, most of these methods need lots of computation and that can be a big cost and a high power consumption. Our detection method need low computing and can be very convenient by using Raspberry Pi [8] as main platform when considering the actual factors such as price, performance and size. The size of RPi is $85.6 \times 53.98 \times 17$ mm and its weight is 45g with a price of \$25-\$35 and also its performance is good enough to meet the real-time requirements.

Rest of the paper is organized as following. Section 2 briefly discusses the overview of our System. Our method about fall alarm and inactivity detection is presented in Section 3. Experimental results are given in Section 4 with discussion on performance of our system while Section 5 concludes the paper.

II. THE OVERVIEW OF OUR SYSTEM

The Raspberry Pi (RPi for short) is a small ARM-based single-board computer in the size of a credit card and it was developed by the Raspberry Pi Foundation and has become very prevalent in these years [9]. RPi runs a Linux system, by loading the corresponding Linux system and application programs, it can achieve a variety of functions. RPi also has many advantages, such as cheap, small volume, strong performance. Figure 1 (a) shows the top face of the RPi.

The Raspberry Pi (Model B) is based on a system on a chip (SOC) of the Broadcom BCM2835, including an

ARM1176JZF-S700 MHz processor, VideoCore IV GPU and 512 megabytes of RAM [10]. It also provides support to Secure Digital or Micro SD card, USB connection and network connection. Figure 1 (b) shows the major ICs and connectors of RPi.

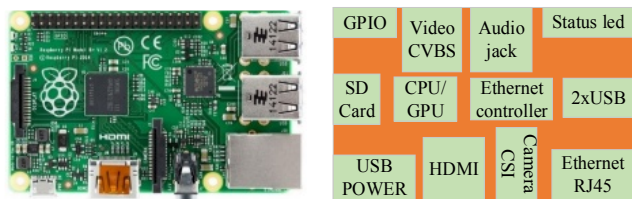


Figure 1. (a).Top face of the Raspberry Pi ;(b). Location on the PCB of connectors and major ICs of Raspberry Pi

Our detection system is implemented on the Raspberry Pi. A USB wide angle camera is connected to RPi to get video data. The algorithm of fall alarm as well as inactivity detection and also GSM control function are all implemented on RPi.

Figure 2 illustrates the hardware components of our system. We have a wide angle camera installed in the center of ceiling and if there is any abnormal situation RPi will inform the guardian through Internet and GSM by E-mail and SMS.

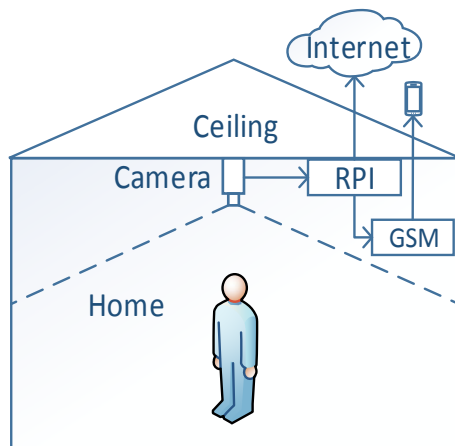


Figure 2. Illustration of hardware part of the detection system.

When there is an abnormal situation, alarm information is sent to the specified mailbox. RPi also sends the data collected by camera to the network through TCP/IP protocol and we can simply enter the IP address of the RPi in a device's browser to monitor online, the device may be a computer, mobile phone, etc. Fig 3 shows the RPi we use and the wide angle camera installed on the ceiling.

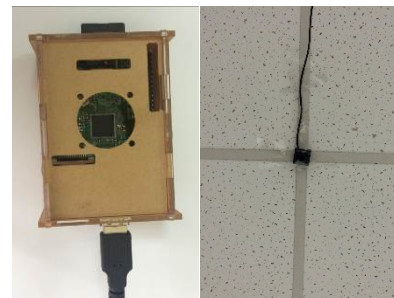


Figure 3. The RPi and the wide angle camera installed on the ceiling

We apply a wide angle camera of 150° to detect the whole space of our laboratory. The height of our laboratory is 2.4m and it is 4m long and 2m wide. The side view of the detected area is shown in Figure 4.

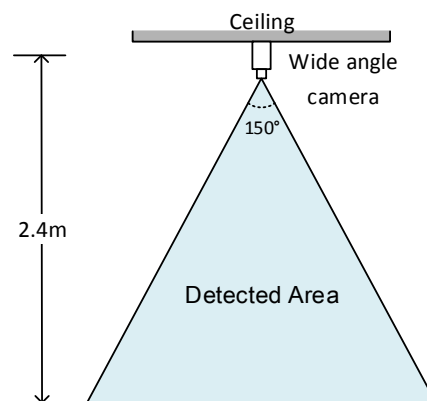


Figure 4. The detecting area of the wide angle camera

There are mainly 6 parts in the system and the corresponding block diagram is shown in Figure 5.

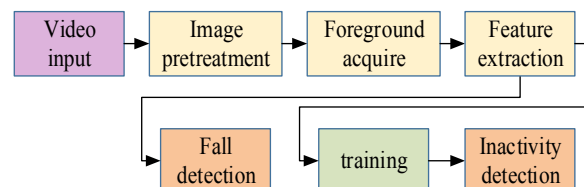


Figure 5. Block diagram of the software part of the detection system.

We first preprocess the image to remove noises and to get the foreground image. Then according to the foreground feature we can detect whether the elderly fall or not. We also use the feature to build up the inactivity history map to improve accuracy of abnormal inactivity detection.

III. OUR PROPOSED METHOD

A. Fall Alarm Method

Moving object detection is a crucial and primary procedure in fall alarm system. One of the effective way is to construct a background model and then foreground segmentation is done to get the moving object. In our method we applied the Gaussian Mixture Model (GMM) which performs well on many different scenes to set up the background model. After

we have got the background we can extract moving foreground objects.

In order to adapt to the performance of RPi which doesn't have the ability to deal with a large amount of calculation in real time, we propose a novel and low computation cost method to detect falls. We divide the image into many rectangular areas and because our wide angle camera is installed on the ceiling so that the silhouette of the elderly when fall or not is very different and according to the area of body in each rectangle we can know whether the elderly fall or not.

Figure 6 shows a situation captured by the wide angle camera when many people work normally while a man falls. If we compute the body area in each rectangular area we can judge whether the old man falls.

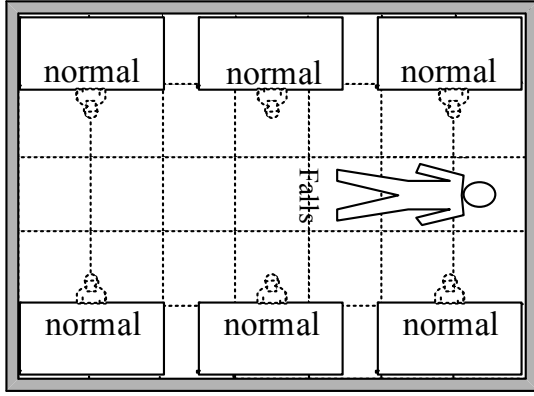


Figure 6. The home environment and its layout

Our method for fall alarm is proposed as follows:

- Use Gauss mixture model to obtain the background and background subtraction is done to get the foreground.
- Transform the foreground into binary image and then each rectangle are processed. If the white pixels in each rectangular area are less than 1/4, then the rectangular area is marked as black, else it's marked as white.
- Carry out the calculation of connected component and if the area are less than 640 white pixels, the area are excluded to ensure the accuracy.
- For each connected component, calculate the centroid by (1):

$$\bar{x} = \frac{\sum_1^n x_i}{n}, \bar{y} = \frac{\sum_1^n y_i}{n} \quad (1)$$

In the formula, n means the number of all the rectangle marked as white in one connected component and x_i and y_i means the coordinates of upper left corner of the rectangle marked as white and $\bar{x}$ and $\bar{y}$ means the coordinates of the centroid of one connected component.

- Calculate the average distance as (2):

$$distance = \frac{\sum_1^n [(x_i - \bar{x})^2 + (y_i - \bar{y})^2]}{n} \quad (2)$$

- If the distance we get is bigger than a certain threshold then it means the elderly fall. The threshold is determined by counting daily normal activities and average the distance of these activities.

B. Inactivity Detection Method

Because the elderly have weak activity and they often stay in one place for a long time watching TV or just sleeping in a sofa and these are normal activities and shouldn't alert as inactivity. Conventional methods will detect these behavior as inactivity. To improve this condition we proposed a novel method for inactivity detection.

After we split the background into many rectangular area, we will have a training process to set up an inactivity history map over a period of time. The method is proposed bellow:

- Use Gauss mixture model to obtain the background and background subtraction is done to get the foreground.
- Calculate the location of the elderly at time t by (3)

$$(x_t, y_t) = \frac{\sum (i,j) \times m_{(i,j)}(t)}{\sum m_{(i,j)}(t)} \quad (3)$$

In the formula, the location of each rectangular area is indicated by (i,j) and the mean value of each rectangle at time t is indicated by $m_{(i,j)}(t)$.

- Calculate the inactivity time of the elderly in the location (x_t, y_t) per frame and the result is indicated by $t_{(i,j,t)}$.
- Calculate the mean inactivity time of each rectangle.

$$T_{(i,j)} = \frac{\sum_1^n t_{(i,j,t)}}{n} \quad (4)$$

In the formula $t_{(i,j,t)}$ means the inactivity time of the elderly in a rectangle of location (i,j) at time t and n means the total number we record.

After we get the average time the man stay in each rectangle, if the time of the elderly stay in the area has exceeded more than 10% of the average time, then our system will give out information of inactivity. This method will adapt to different people and different environment and it can significantly improve the accuracy.

IV. EXPERIMENT RESULT AND ANALYSIS

We carried out experiments in our laboratory and the results of the experiment are analysed.

A. Detection Accuracy

Figure 7 shows a detecting process of our system. Figure 7(a) shows the restored background image and Figure 7(b) shows an image with human body and Figure 7(c) shows human body silhouette.

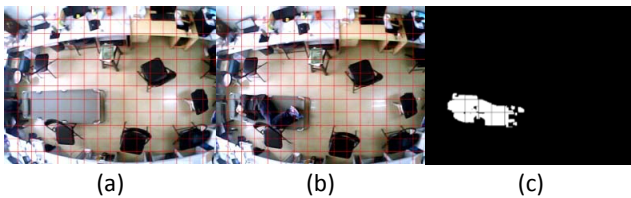


Figure 7. Human silhouette extraction.(a)restored background image;(b)an image with human body;(c)human body silhouette

Figure 8 shows the different attitudes when people moving and Figure 8 (a) shows there is a man sitting in the scope of the camera and Figure 8 (b) shows a man bending in the camera view and Figure 8 (c) (d) shows that there are a man standing in the camera view and Figure 8 (e) (f) shows there are a man walking in the camera view. As we can see, the shapes of above situations are similar. And also Figure 9 shows the detection results of different situations.

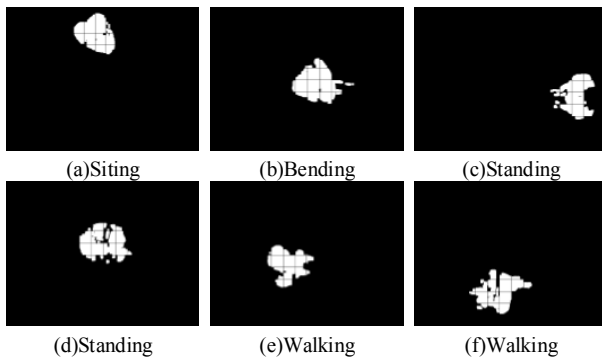


Figure 8. The different attitudes when people moving

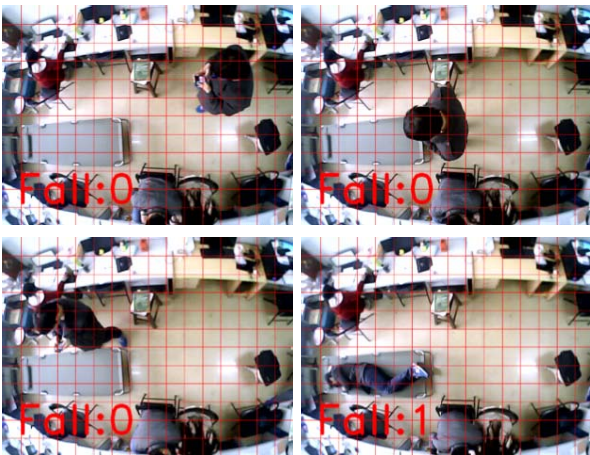


Figure 9. The detection results of different situations

We counted the inactivity conditions for 3 hours and our system generated the inactivity history map of our laboratory. Our system first get the location of the person by formula (3) and then it counts the mean inactivity time of the man in each

rectangle. For the convenience of description we displayed the mean inactivity time in a range of 0 to 255 and displayed the inactivity time by a gray image as shown in Figure 10.

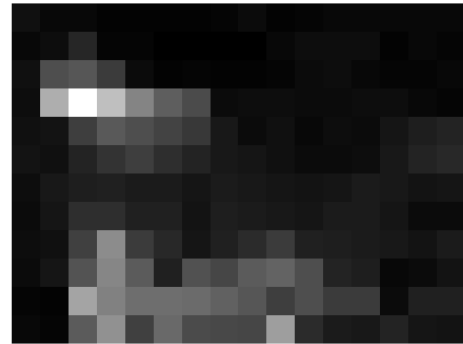


Figure 10. The inactivity history map generated by our system

The pixel values of the rectangle indicate the mean inactivity time of man. If the rectangle is white that means the man stay here for a long time and if the rectangle is back that means the man rarely stay here and if the pixel value is bigger(whiter) then the mean inactivity time is longer. And the bright area most are our workbench where we sit. This result means our algorithm works well.

We carried out extensive experiments in our laboratory and collected 550 groups of image data containing 100 groups of normal situations (the man normally walking and siting) and 250 groups of fall situations and 200 groups of inactivity situations in total. The results are listed in TABLE 1.

TABLE 1. THE RESULT OF THE SYSTEM

Method	Fall Alarm	Inactivity detection
NS	100	
FS	250	
IS	200	
AG	242	196
NF	5	7
PF	13	11
CA	237	189
CR	94.8%	94.5%

The abbreviation used in the table are described below:

- NS: The number of normal situation
- FS: The number of fall situation
- IS: The number of inactivity situation
- AG: the number of inactivity generated by the system
- NF(Negative False):the number of real normal situation with alarm
- PF (Positive False): the number of real abnormal situation without alarm
- CA (Correct Alarm): the number of real abnormal situation with alarm
- CR(Correct ratio):the correct percentage of abnormal situation alarm

CR is calculated by 5:

$$CR = CA/(PF + CA) \quad (5)$$

When we further examine the result, we find out that although people walk normally, the moving of the man changes the light of our laboratory environment and this causes the false alarm. In addition, when the man falls but his body is out of the camera view, in this situation the fall would not be detected. When the man are inactive for a long time but there are other moving objects and in that situation our system cannot distinguish the inactive man or other moving object. But usually the elderly live along and these situations can be avoided.

B. Analysis of CPU Usage

We also made a statistics on the change of CPU usage when conducting an experiment in our laboratory. When nobody moves into the camera's view, the CPU occupancy rate is relatively stable and when people enter the camera's view, the program detects people, CPU occupancy rate has a sudden rise as shown in (A) of Figure 11. And then when the program gets the foreground, CPU occupancy rate has a small increase as shown in (B) of Figure 11. When people are in the camera's view keeping moving, CPU occupancy rate is relatively stable. When there is fall or inactivity condition, CPU occupancy rate has a small rise as shown in (C) of Figure 11. Then the program starts to save images and video files and then send an e-mail or SMS to alarm, so that the CPU occupancy rate continues to rise as shown in (D) of Figure 11. After the detecting ends, the CPU occupancy rate begin to decline back to the normal level, which is shown in (E) of Figure 11. During this time, CPU occupancy rate has been below 62%.

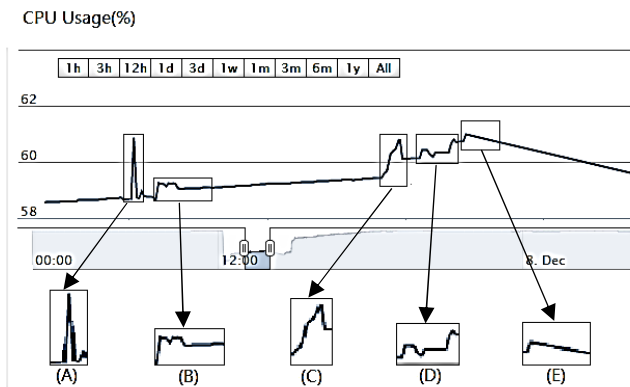


Figure 11. The CPU usage when following situations occur.(A) People is detected;(B) get the foreground image;(C) Fall alarm or inactivity detection ;(D) Send the E-mail and store video and images; (E) Processing ends.

V. CONCLUSION

Fall alarm and inactivity detection system design and implementation on Raspberry Pi is proposed in this paper. Minicomputer RPi is adopted as the processing terminal of the system, which has cheap price, good performance and small volume and so that it can be installed and used widely. In this paper we also proposed a novel fall alarm method and a novel inactivity detection method which are proved work well in our experiments. This system will record the situation when empty-nesters are in abnormal situation in the form of photographs and videos. And also it will send an e-mail or SMS to alarm, providing a very good safeguard for the security of the elderly.

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