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Optimizing Fall Detection System as an Early Warning System for the Elderly to Enhance Quality of Life

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Abstract.
Purpose: The main objective of this research is to develop a fall detection system and improve rapid emergency response or early warning systems for falls in the elderly.
Methods: In this research, the waterfall method was used for image analysis to detect falls with high accuracy. We also used Raspberry Pi 3, and OpenCV3 to set up a server to receive fall detection alerts and forward them to email.
Results: This system integrated a camera mounted on a Raspberry Pi 3 to continuously monitor the area captured by the camera. In the fall detection system, the results of testing with data showed that the system accuracy was 72.22%, sensitivity 72.72%, and error 27.77%.
Novelty: The approach this research adopted can be used in a variety of settings, including home healthcare, elderly care facilities, or places that require safety monitoring. With this system, we hope to improve rapid response in emergency situations, thereby protecting and improving the quality of life for people in need.

Keywords: Fall detection, Early warning system, Elderly, Quality of life
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INTRODUCTION

Falls are one of the leading causes of death, but they are often underestimated. Because for many people, falls are not a cause of concern. Unlike terrorist attacks, shark bites, Ebola outbreaks, viruses, and other dangers, falls are sometimes considered a minor less dangerous problem [1]. However, according to Reader's Digest, around 646,000 people worldwide are estimated to have died from this. Adults and older people may have to be careful after hearing this fact, primarily because of the fragility of their bones [2]. However, they do not seem to be the most vulnerable group. In a study published in PLOS One in 2017, nearly 18% of men aged 18 to 44 reported sustaining injuries from falls within three months. Due to, the large elderly population in Indonesia, attention should be paid to older people to avoid the risk of falls, which can lead to impairment of functional physical movements [3]. Living at home without full-time support poses health risks for older adults, including falls. This is twice the rate for men aged 65 and above. Every fall, even from a bed, can be life-changing. It can render an otherwise healthy person disabled in less than a second. No wonder scientists are encouraging people of all ages to learn to fall safely to minimize injuries. It is also important to recognize that falls are unexpected and can be avoided by being prepared [4], [5]. As individuals age, their physical and mental abilities gradually decline. This deterioration can impact their daily activities, ultimately diminishing their independence [6]. Elderly individuals frequently fall, which may result from multiple factors. Internal factors such as abnormal, muscle weakness, and joint stiffness, along with external factors, such as slippery floors, obstructive objects, and poor lighting, contribute to the risk of falls [7], [8].

The influence of oxygen concentration in the blood can affect the quality of life of older people when carrying out activities such as walking, sitting, and standing. This monitoring can be done using a pulse oximeter [9], which is very helpful clinically. Camera-based fall detection can use a camera to detect objects in elderly patients who fall, and this can help monitor patients at risk of falling [10]. Therefore, clinical and

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non-clinical monitoring of the risk of falls in older people can help people around them or their families monitor the daily condition of older people.

Several methods have been used to create fall detection systems [11], such as installing a device on the subject's object's body as a sensor [12], [13] or using a camera [14], [15]. In the Indonesian context, fall detection using sensors is less effective. In addition, since the average population in Indonesia is Muslim, the sensors are often removed when they want to pray. Fall detection using a camera is a solution to detect objects because it can analyze the condition of objects without direct contact [16]. This method uses image processing to process images or images captured by a camera and detect motion based on changes in camera pixels [17].

According to [18] developing a portable multisensory-based surveillance system by providing warnings related to unusual activities. The system notifies users or caregivers via email when it detects unusual activities, such as falling motion in the elderly or children. This research used multiple sensors, including an accelerometer gyroscope, and a camera sensor was added to make the information more accurate. The evaluation was divided into two categories: human fall detection and image capture. The evaluation results for fall motion detection were 88%, recall 88%, specificity 88%, and precision 93%. In addition, the results of the evaluation of the image capture were 86% accuracy with 51% accuracy of camera movement toward the object.

Another study conducted by [19] detects falls using the motion history of an image with a bounding box. In this case, the system fails if the object is concealed by other objects. Studies have shown, that infrared light cannot be used to distinguish between people who are falling and people who are sitting position. In their research, they used a camera mounted on the wall to increase coverage. The motion history of the image method detects a wide range of motion in video footage.

Fall detection can be defined as part of the internet of things (IoT) that offers the possibility to connect all devices and appliances in a network, allowing us to control all parts of the house and others indirectly or wirelessly. Therefore, fall detection can be defined as an innovative IoT-based indoor fall detection system that utilizes low-power wireless sensor networks, smart devices, big data, and cloud computing [20].

METHODS

The method used to implement this final project is referred to as the waterfall method. The waterfall method was first discovered by Winston W. Royce in 1970 to explain the process of designing a system. The stages in the waterfall method are seen as a downward process flow (like a waterfall) through certain sequential phases [21]. Each existing phase must be completed one at a time before to the next phase. Each phase in the waterfall method is recursive and can be repeated endlessly until the system is fully completed [22].

This research began with installing the program on the Raspberry Pi 3, Python environment, and OpenCV3, installing a camera, and setting up a server to receive fall detection alerts and forward them to email. Then, data collection was carried out by adjusting the camera position. During data collection, data was collected according to predetermined parameters. The parameters related to fall detection in this test detect a person's fall, and a notification was sent to the recipient.

Fall detection system design

In this research, the fall detection system was used to detect falls indoors when the user wanted to monitor the movement of human objects when a fall occurred indoors. Whenever a movement occurred and was identified as a human falling movement, the system saved the falling movement data or images to photos stored in the Raspberry Pi's programming folder [23]. The processes carried out in this human fall detection system are the process of taking the initial capture results made by the Raspberry Pi camera board v1.3 (5MP, 1080p), the process of detecting any falling movement with the initial capture made by the camera marked with a boundary box. The process of detecting/identifying whether the movement is a fall or not, the image capture process, and the process of sending notifications on email if there is a fall on the object detected by the pi camera [24].

The workflow of the fall detection system is shown in Figure 1

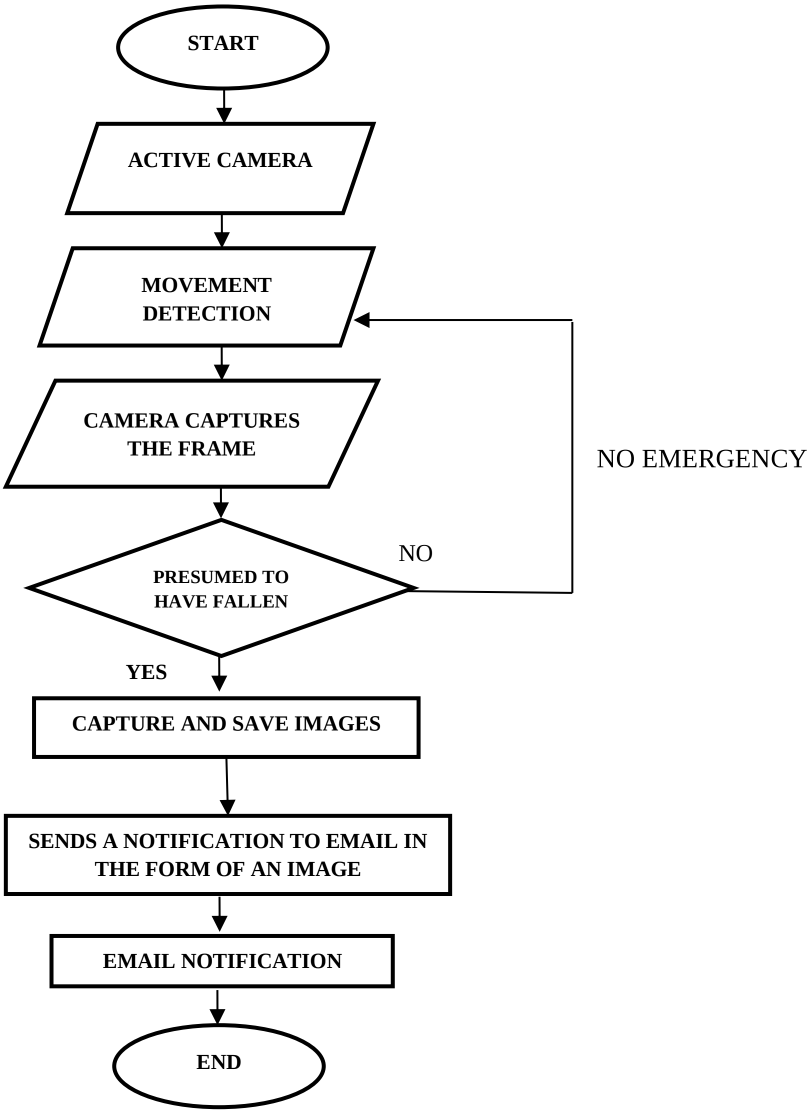

Figure 1. Flowchart of the fall detection system

As shown in Figure 1, the initial stage in the fall detection system flow was the camera taking and storing the initial frame (boundary box). In this stage, the already active camera detects objects in the room. If a human object was present, the camera captured the object through the frame (boundary box) to detect the object's movement. This initialization, allowed the camera to distinguish between two different objects. The only objects recognized in this programming were human objects.

Next, the camera took a new image. At this stage, the camera was already active and detected the movement of human objects in the room. If a movement was suspected to be a fall, it captured the initial image of the detected object or frame (boundary box) in the camera. This would be a reference to guide through the process. When the object in the frame experienced a falling movement, the frame detected the ratio between the number of objects and the speed at which they were moving. If the ratio between the number of objects and the speed of object movement satisfied the falling movement, the camera captured the image. This stage occurred when the camera captured a frame (boundary box). After the camera captured the image of falling objects, it saved them to the Raspberry Pi. In this initial frame, the camera only detected human movement. Even when there were multiple objects, the camera could still detect human objects with different frames (boundary boxes). The frame (boundary box) the camera captured was then stored as a reference for the following command [25].

The final stage was to send an email notification on the captured image. At this point stage, a real-time notification was sent to the user-specified email address. After the image was stored in the Raspberry Pi, it was sent to the desired email address specified in the programming. In this research, we used gun mail when sending from Raspberry Pi.

To prepare the devices for this research, the first step was to prepare Raspberry Pi and Raspberry Pi camera and ensure the availability of the necessary resources. Next, the Raspberry Pi camera was installed in the designated slot on the Raspberry Pi. Then, a Wi-Fi dongle was installed in the USB slot of the Raspberry Pi to ensure internet connectivity, as the device had problems receiving networks wirelessly and via a LAN cable. A mobile phone charger with a DC 5V voltage was used to power the Raspberry Pi, and a remote desktop was activated using VNC on the PC. The PiCam Raspberry Pi module was activated via the terminal and moved from the home directory to the directory where the program files were stored [26]. They then ran the fall detection program using Python, which allowed the Raspberry Pi camera to detect human objects through the boundary box according to the research objectives [27].

System scheme
In general, the working principle of the fall detection system using Raspberry Pi in this research was to use Raspberry Pi 3 Model B, a Pi Camera, an internet connection, and also an android smartphone as a data communication tool between the user and Raspberry Pi. This way users could receive notifications in the form of images sent via email. Figure 2 shows a system diagram of the system design overview.

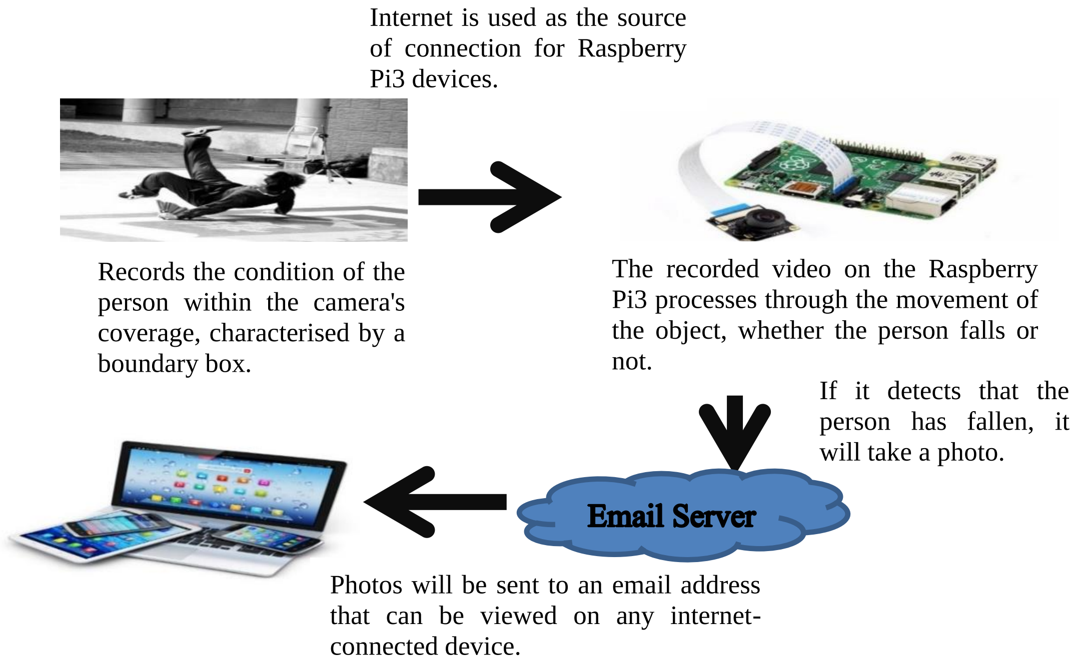

Figure 2. System overview

Figure 2 shows the simulation of the human fall detection system indoor, and the images could be sent to a predetermined user. To send an email, the device had to be connected to the internet. The following stages were applied to the room area plan and the distance of the camera to the detected object. First, the camera captured the monitored object with a monitoring distance of 1.5 m and a camera height of 1.5 m. In the second stage, the camera that captured the image processed it on Raspberry Pi. If it was detected the image contained a falling object, the image was stored in the Raspberry Pi. If no falling motion was detected, the camera continued to monitor the movement of the detected object [28]. In the third stage, the image that had been stored in the Raspberry Pi was sent to the specified user via email. The last stage involved the user who was to receive an email being informed of a falling object in the room by receiving an email notification from Mailgun sent by Raspberry Pi.

RESULTS AND DISCUSSIONS

This section discusses the test results of the designed and built system. The system test consisted of testing the detection of falling people and sending image data of falling people via email. The aim of the test was to determine whether the system's work process functioned as expected. In Figure 3 and Figure 4, it can be seen that the Raspberry Pi camera detected human objects through the boundary box.

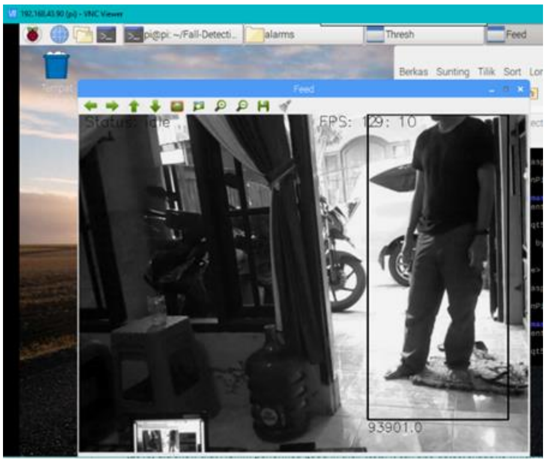

Figure 3.

Figure 4. Pi camera detected a human object

When the Raspberry Pi camera detected a significant movement of the detected human object, the boundary box marked the area of the falling object with a cross line, as shown in Figure 5 below.

Figure 5. Raspberry Pi camera detected two objects

After the Raspberry Pi camera detected a human falling, the program sent the image to the specified recipient's email, as shown in Figure 6.

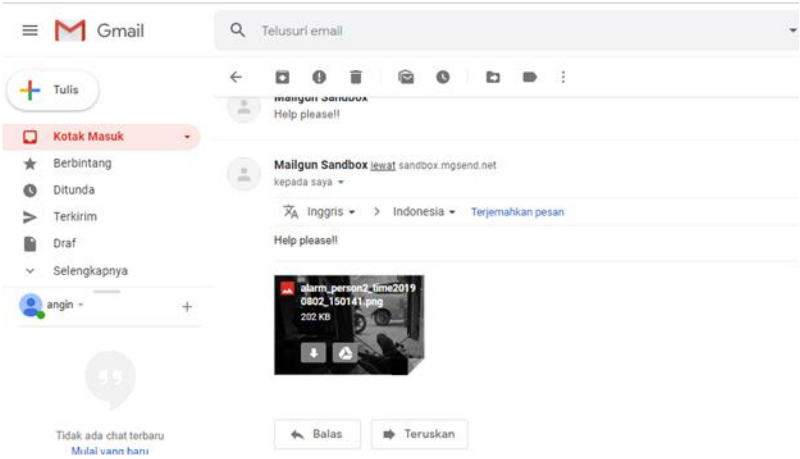

Figure 6. Display of incoming email notifications to recipients

From the results of the experiments, sufficient light intensity, at least around 79 lux, was required to detect the movement of a fall on the human object. The height of the camera was installed to detect approximately 1-1.5 meters at a distance of two meters from the observed human object. The Raspberry camera was also able to detect two objects at once. This fall detection program adhered one condition: when humans detected the object and did not move, it was detected as falling. The accuracy of this system was influenced by light, as seen in Figure 7.

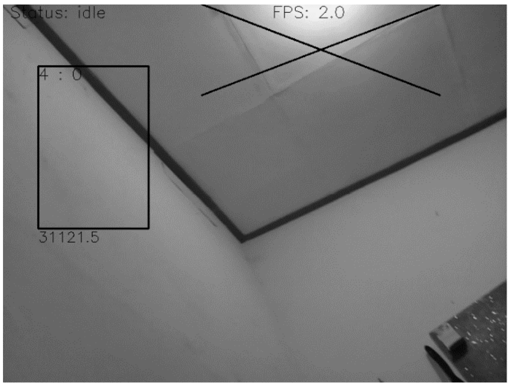

Figure 7. Detected light during falls

From the experimental images, we found that light affected the accuracy of the fall detection system. A possible explanation for this might be because at some point a light that was too bright was considered to be a human object.

Table 1.

Activity	Fall Detected	No Fall Detected
Sent	True Positive= 8	False Positive= 2
Not Sent	False Negative= 3	True Negative= 5

After collecting data with "sent" and "not sent" parameters, the results obtained by the true positive data (detected falls and sent) were 8, true negative by 5, false positive by 2, and false negative by 3. Based on the data in ther table, the calculation can be done as follow:

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \Rightarrow \text{Accuracy} = \frac{8+5}{18} \times 100\% = 72.22\%$$

$$\text{Sensitivity} = \frac{TP}{TP+FN} \times 100\% \quad \Rightarrow \quad \text{Sensitivity} = \frac{8}{11} \times 100\% = 72.72\%$$

$$\text{Error} = \frac{FP+FN}{TP+TN+FP+FN} \times 100\% \quad \Rightarrow \quad \text{Error} = \frac{2+3}{18} \times 100\% = 27.77\%$$

Results of test presented in tabular form show accurate data. For the fall detection system, the results of test with data showed that the system accuracy was 72.22%, sensitivity 72.72%, and error 27.77%. Accuracy refers to the correct predicted data (true positive and true negative) in all data. By summing the sent fall data with the undelivered fall data and dividing it by the whole data.

Then, the sensitivity of the delivery data detected by the system falls detected (true positive) divided by the total delivery data, resulting in 72.72%. Some of the data tested was fall data that was not detected by the system and was not sent. This was influenced by several factors, among others. The first factor was changes in light intensity in the room. The tests we author conducted used natural light such as sunlight and lights. Dim light could decrease light intensity, which could affect data transmission and the system's sensitivity to detect falling objects. The second factor was the movement of the falling object. The parameters used to detect the movement of falling objects were the maximum movement, minimum movement, and movement time. If there was a fall on the minimum and maximum movement, the object’s counting frames moved continuously, while for the movement time, if there was a fall, the object did not move for a very long time, and then the system detected the fall. The last factor was the internet connection, which was essential when sending data via email. The speed and stability of the internet connection may affect the speed of the data transmission process from the system.

The non-fall detection data where a fall was detected (false positive) had a 27% error, which was equivalent to 2 data. This occurred when the fall detection system detected a non-fall as a fall. The system continued to send data. I tis possible that this occurred due to the detected object’s significant movement.

CONCLUSION

Based on the discussion and results of the research, Raspberry Pi can be used to optimize a fall detection system as an early warning system to improve the quality of life of elderly people by sending notifications to specified recipients when it detects falls. The camera can detect two objects, and the detection is carried out in a room with sufficient light.

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