# Mobile Autonomous Personal Emergency Response System Utilizing Face Detection

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## ABSTRACT

This paper outlines the design and implementation of the Fallen Angel, an autonomous mobile robot that can act as a personal emergency response system. Fallen Angel patrols the home avoiding obstacles while searching for someone who has fallen on the ground. Once a person is detected lying on the floor using face detection, it calls for help by sending preprogrammed text messages and e-mails to a list of predetermined emergency contacts.

## Keywords

Fall Detection, Autonomous, Mobile, Personal Emergency Response System, Face Detection, OpenCV

## 1. INTRODUCTION

There is a wealth of research conducted in the area of fall detection with a wide variety of different approaches. For example, some researchers use wearable devices that have sensors, such as accelerometers, to detect if the user has fallen [7]. However, this solution suffers from the disadvantage of requiring the user to constantly wear a potentially uncomfortable device. Others use stationary cameras to monitor the orientation of the human to determine whether they have fallen or not [11], [2], [4]. The disadvantage of this method is that many people may feel uncomfortable with having a network of cameras invading the privacy of their home. Falls have also been detected by using a sensor that measures the vibrations of the floor [1]. In this paper, face detection will be used as a means to identify fallen humans. The Fallen Angel uses a single camera mounted on a mobile robot to find fallen humans by detecting their faces. Unlike other vision based fall detectors, the single low to the ground camera on the Fallen Angel helps the user to still maintain their privacy.

The Fallen Angel was designed and built at the University of Florida for the Intelligent Machines Design Laboratory course (EEL 5666). The purpose of the robot is to assist the elderly and people with severe health conditions in achieving independent living. While the robot moves about the person's apartment, the robot will detect if the owner falls and will call for help.

Current commercial solutions to this problem are known as personal emergency response systems (PERS). In general, they consist of a radio transmitter, a console connected to a landline phone, and an emergency response center to monitor calls. The transmitter is usually the same shape and size of a small cell phone. It can be worn on a belt, around the neck, or carried in a pocket. When an emergency occurs, the user holds down the button on the transmitter which signals the console on the phone to dial an emergency number. The disadvantages of using such a product are that they require the user to be able to press a button. They also require that the user carries the transmitter with them at all times. By using a robot, this process can be automated so that a signal for help can be sent even if the user is incapacitated. Additionally, the Fallen Angel does not require the user to carry a radio transmitter or any other device.

## 2. FALLEN ANGEL SYSTEMS

The Fallen Angel consists of two main components. The first component is the mobile robot that uses an internet protocol (IP) camera to search for a fallen human. The second component is the laptop computer which conducts all of the vision processing as well as calling the outside world for help. This section will discuss how all of the electronic components are arranged and how they communicate with each other. A layout of how the various components of the system communicate with each other is shown in Figure 1.

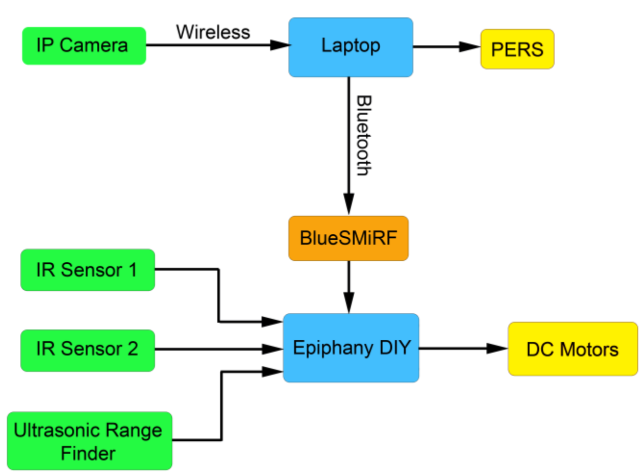


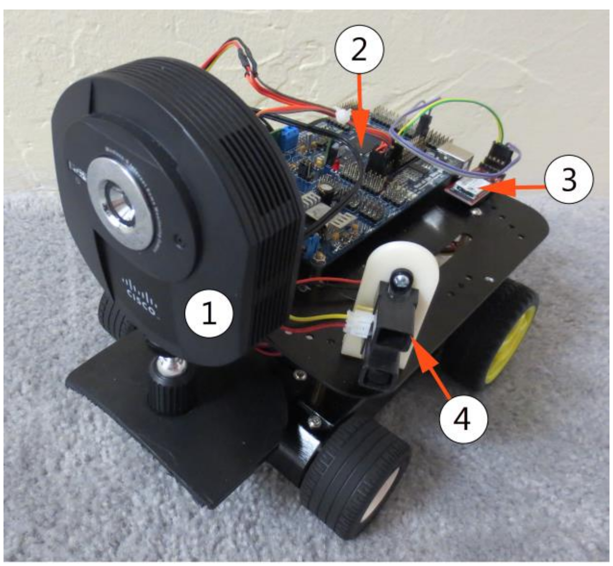

**Figure 1. Functional block diagram**

### 2.1 Integrated System

The IP camera, used for face detection, is mounted on the mobile robot and communicates with a router connected to the laptop computer via a wireless connection. Using an internet connection and custom designed software, the laptop computer is able to perform the same function as a PERS. The raw camera feed is sent to an OpenCV program for analysis. OpenCV is an open source library of programming functions for real time computer vision. The program checks the stream of images to see if it detects a face by searching for Haar-like features. OpenCV analyzes the information it receives and uses it to send commands from the laptop to the robot via a Bluetooth connection. The robot has a BlueSMiRF Bluetooth modem which allows it to receive the Bluetooth signal from the laptop. The BlueSMiRF has a direct connection to the Epiphany DIY embedded microcontroller on the robot. The Epiphany DIY board features an Atmel ATxmega128A1U microcontroller, which provides the intelligence behind the mobile platform. The board is also directly connected to the ultrasonic range finder and the infrared (IR) sensors. The board uses the information gathered by the sensors and the laptop to appropriately control the various actuators. During the search mode and obstacle avoidance behavior, the Epiphany DIY uses the IR and ultrasonic sensors to avoid obstacles while using the IP camera to search for a fallen human. Once a human is spotted, the laptop acts as a PERS and begins calling for help.

## 2.2 Mobile Platform

The mobile platform features a two-wheel drive system actuated by small DC motors. The platform consists of two main levels. The bottom level rests above the housing for the motors and provides space for the battery. In addition, a bracket is attached to the front of the bottom level and serves as the mount for the IP camera. All of the sensors and major electrical components are located on the top level. The Sharp IR sensors are mounted to the front of the top level via brackets. The ultrasonic range finder is mounted onto the base of the IP camera. The board is attached to the top level as well using plastic spacers. There is also room on the top level for the BlueSMiRF, which is attached with Velcro for ease of attachment and removal. The mobile platform is shown in Figure 2. Note that the ultrasonic sensor is not pictured in this figure.




1. IP Camera
2. Epiphany DIY embedded microcontroller
3. BlueSMiRF Bluetooth modem
4. IR Sensor

**Figure 2. Mobile platform of the Fallen Angel**

The IR sensor brackets, battery holder, and the wheel motor couplers were designed using a CAD program. Once the parts were modeled in the software, they were then printed out in ABS plastic on a Dimension SST 1200es printer.

# 3. POWER AND SENSORS

The Fallen Angel mobile platform features a variety of sensors, all energized by a single power source. In this section, the specifications of the sensors will be discussed in detail.

## 3.1 LiPo Battery

The Fallen Angel is powered by a single three-cell Zippy Flightmax lithium polymer (LiPo) battery. It features a capacity of 1500 mAh and a discharge rating of 20C. The LiPo battery powers everything on the mobile robot including the IP camera, Epiphany DIY board, speed controllers, and all sensors.

## 3.2 Ultrasonic Range Finder

An ultrasonic range finder is mounted on the front of the robot. It is a Maxbotix SEN-00639 and operates between 2.5 and 5.5 V. It consumes 2 mA, reads at a rate of 20 Hz, and features both analog and PWM output. For this project, only the analog output was used and provides a resolution of 3.94 mV/cm. It has a range of 0 to 650 cm with little to no dead zone. It is used in conjunction with the infrared proximity sensors for basic obstacle avoidance. An image of the ultrasonic range finder used on the Fallen Angel is shown in Figure 3.

**Figure 3. Ultrasonic range finder**

The ultrasonic range finder was characterized by placing a wall at a determined distance from it and reading the ADC value via a USB cable connecting the Epiphany DIY with the laptop. The software used to display the data coming into the computer was the X-CTU terminal. The same process was used to characterize the infrared proximity sensors. The results of the characterization of this sensor can be found in Appendix Figure 1.

## 3.3 Long Range Infrared Proximity Sensor

Two Sharp long range infrared GP2Y0A02YK0F sensors, shown in Figure 4, are mounted on the top level of the robot platform. They are located at the front left and right corners of the robot and are angled as shown in Figure 2. The sensors have a range of 20 cm to 150 cm, consume 33 mA, and require an input voltage in the range of 4.5 to 5.5 V. The sensors output an analog voltage that varies between .4 V (150 cm) to 2.8 V (15 cm). The results of the characterization of this sensor can be found in Appendix Figure 2.

**Figure 4. Long range IR proximity sensor**

## 3.4 IP Camera

The IP Camera used for this robot is a Cisco Wireless N WVC80N IP camera. It communicates with a laptop computer using a Linksys wireless router. The camera is used in conjunction with OpenCV to detect if a human has fallen on the floor. The IP camera records video at 2 frames per second (fps) with a resolution of 320 x 240 pixels. There is a tradeoff between the speed it takes to process an image and the quality of the image. At higher frame rates, the laptop was unable to process the images fast enough to function in real time. At lower frame rates, another issue presented itself. The way the program prevents against false positives is by checking whether or not a face is detected in three consecutive frames. If the frame rate was reduced to 1 fps, it would take a minimum of three seconds in order for the laptop to confirm that it had found a fallen human and then signal the robot to stop. By this time, the robot may no longer have the camera fixed on the fallen human. This is important because in future iterations of the design, the robot will display live video and audio feed of the fallen human to the emergency contacts. An image of the IP camera used on the Fallen Angel is shown in Figure 5.


**Figure 5. IP camera**

## 3.5 BlueSMiRF

A BlueSMiRF Silver Bluetooth modem, shown in Figure 6, is mounted on the robot as a means for the laptop to communicate directly to the robot. It has an operating range of 3.3V to 6V with a maximum transmission distance of 18 meters.


**Figure 6. BlueSMiRF silver Bluetooth modem**

## 3.6 LiPo Battery Monitor

Whenever using a LiPo battery, it is important to monitor the battery voltage so that it does not drop too low. If the voltage drops below a certain threshold, it may become irreversibly damaged. This particular battery monitor is designed for the three-cell LiPo battery which is used to power the robot. The characterization of this battery sensor is described in Table 1.

**Table 1. Characterization of the LiPo battery monitor**

| | |
|---|---|
| Blue light shines | 11.1V and higher |
| Blue light flashes | 11.1V ~ 10.2V |
| Red light shines | 10.2V ~ 9.9V |
| Red light flashes and beeps | Below 9.9V |

# 4. ACTUATORS

The primary actuators of the Fallen Angel are two ServoCity DC micro gear motors. These 12 volt motors are used to provide the robot with basic mobility and have a max speed of 130 rpm. They have a stall torque of .35 N-m and a stall current of 1600 mA. The robot is driven by the front two wheels while the back wheels are free spinning. Steering is achieved using differential drive between the front right and front left wheels. The motors were chosen for their small size and ease of mounting to the mobile platform. An image of one of the motors can be seen in Figure 7.

**Figure 7. DC motor**

# 5. BEHAVIORS

The three main behaviors of the robot will be discussed in detail in the following sections. Figure 8 shows a summary of the decision making process the robot goes through in order to determine which behavior to exhibit.

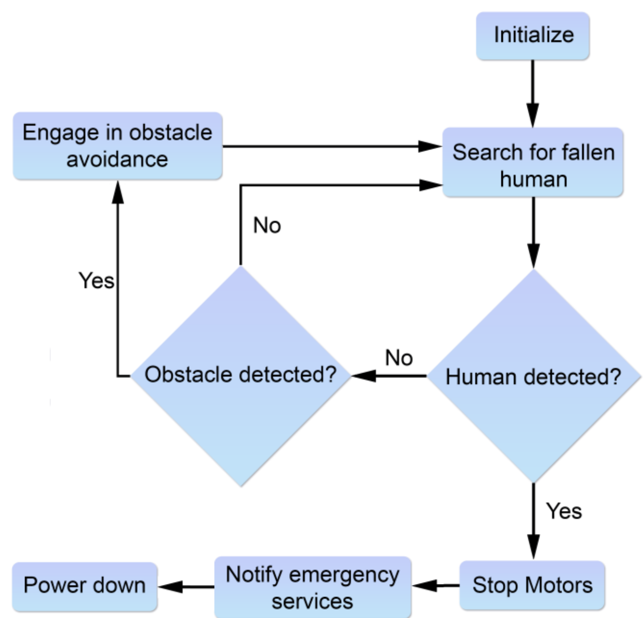



**Figure 8. Behavioral block diagram**

## 5.1 Search Mode and Obstacle Avoidance

Once the robot is activated, it will begin navigating the home looking for a fallen human. Until it discovers a human, it will engage in a search behavior. While searching for a human, the robot will use its infrared and ultrasonic sensors to do basic obstacle avoidance. If one of the IR sensors detects that an object is within a certain threshold of the robot, it will reverse the direction of the opposite side's motor to cause the robot to veer away from the object. If both IR sensors detect that an object is within a certain threshold, or if the ultrasonic sensor senses an object directly in front of it, it will back up for a set amount of time and then turn in a random direction. It is important to feature randomness whenever designing an obstacle avoidance behavior for a mobile robot. The nondeterministic behavior will help prevent the robot from becoming trapped.

## 5.2 Face Detection

The IP camera mounted on the front of the robot sends its raw video feed to a laptop running OpenCV. The camera is oriented low enough to the ground so that it is only able to detect the faces of people who are lying on the ground. The OpenCV program detects faces in real time by searching for Haar-like features using the Viola-Jones method [9]. The laptop displays the video from the IP camera on its screen in real-time and also draws a red bounding box around the area of the image where a face has been detected. A sample frame from the OpenCV face detection program is shown in Figure 9. This figure also shows the robustness of the face detection algorithm in that it can detect the face of a person even when their eyes are closed. The program is also capable of detecting multiple faces at the same time, but since the robot is designed for individuals who live independently, it is assumed that under normal operating conditions only one face will be detected at a time. When a face is detected in three consecutive frames, the laptop sends a message to the robot via Bluetooth to stop driving and keep the camera fixed on the person.

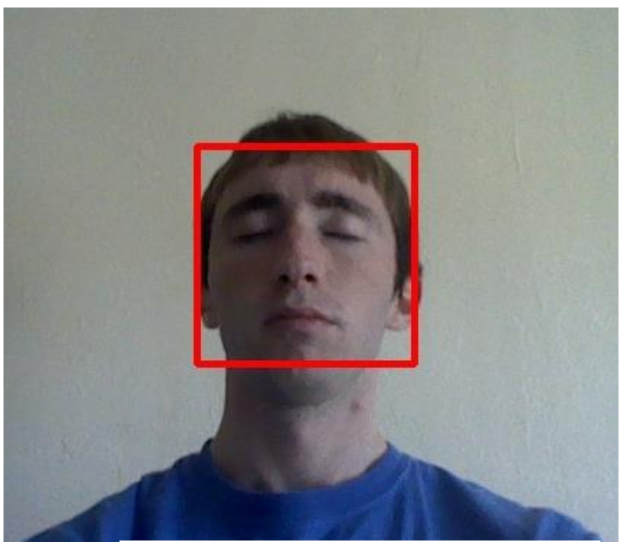


**Figure 9. Sample frame from the face detection program**

The first iteration of the face detection program had the drawback that it could only find a face if it was oriented in the upright position. In order to compensate for this and make the overall face detection more robust to orientation of the fallen human's face, the raw feed from the camera is rotated both 90 degrees clockwise and counterclockwise. These additional two images are then processed through the face detection program. This allows the program to find faces in three orientations, upright and rotated 90 degrees clockwise and counterclockwise. The last two are particularly useful since when someone falls on the ground, they are more likely to have their head oriented in one of those positions rather than being upright. A sample frame of the program detecting a rotated face is shown in Figure 10.

Since rotating the original image clockwise and counterclockwise requires the program to process three images instead of one, the frame rate of the camera had to be lowered from six fps down to two fps. Even after this adjustment, the lag in the vision processing still presented an issue. To compensate for this residual lag, the maximum drive speed of the mobile robot was slowed down slightly, giving it the ability to function in real time with a more robust face detection program. With the ever-increasing rate at which the speeds of computing are improving, this limitation is likely to be resolved in a few years.

**Figure 10. Rotated face detection**

In addition to the face detection algorithm's sensitivity to the orientation of the face, there are some other cases in which the algorithm becomes less effective. One case is when the user is wearing glasses and there is a light shining directly on them. The glare in the glasses can make it more difficult for the program to detect the face. Another case is when the face is partially or even completely obstructed, such as in the case when the owner of the robot has fallen face down. In order for the Fallen Angel to function properly, it is assumed that the face of the person it is looking for is oriented properly and that the entire face is viewable. Admittedly this is a restriction; however a method to resolve this limitation is discussed later in this paper.

## 5.3 Personal Emergency Response System

For Fallen Angel, the laptop computer will perform the same function as a PERS. The laptop features 4 gigabytes of RAM and runs a 64-bit version of Windows 7. As soon as the IP camera and the OpenCV program detect a human lying on the floor, the laptop will send a signal to the robot via a Bluetooth connection. Once the robot receives confirmation that it has found someone, it will stop moving. At the same time, OpenCV launches a Visual Basic simple mail transfer protocol (SMTP) application that sends a prewritten message to a predefined list of e-mail accounts. The message is also sent to a predefined list of phone numbers via a text message. Once the message is sent, an audial confirmation is given by the laptop using a text-to-speech algorithm. This provides confirmation to the fallen person that a call for help has been sent. In the e-mail, a photo of the fallen person is attached. This allows the recipients to verify the authenticity of the emergency. Additional information including demonstration videos, code, and CAD renders can be found at the Fallen Angel's official website [3].

# 6. CONCLUSION

In conclusion, the Fallen Angel provides several advantages to currently available commercial personal emergency response systems. The first advantage is that it does not require the user to carry around a radio transmitter which can be invasive and uncomfortable. Commercial PERS also require that the user is capable of pressing the button on the transmitter in order to function properly. This leads to the second advantage of the Fallen Angel over commercial PERS. Fallen Angel can detect if someone has fallen, even if they are no longer conscious. The third advantage is that the user can decide who should receive the emergency texts and e-mail messages. The text messaging and e-mail feature can potentially result in a faster response time to the typical call to the local police department or a 911 call center by adding neighbors to the robot's contact list. Additional information such as, "I am allergic to aspirin." may be added to the e-mail and text messages. For best results, it can be used in conjunction with a traditional PERS in order to ensure the greatest chance for a successful rescue.

## 7. FUTURE WORK

One of the disadvantages of using face detection as a means for the robot to detect a fallen human is that it is sensitive to the orientation of the person's face. If the individual lands in a face-down or face-up orientation, there would be no way for the robot to detect that they have fallen. As shown in [10], one way to resolve this issue is to instead have the robot detect for body profiles of people who have fallen and are lying on the ground.

When things in the household are normal and there is no emergency, there is no reason for the robot to be active. One way for the robot to decide when to start searching the home is to use a loud sound as a trigger to activate the robot. This is possible by using a microphone to monitor the sound level in the home. However, using this method, it would be difficult for the robot to differentiate between a crash of thunder and someone falling on the ground. Another possible solution is to just have the robot make periodic searches of the house. Or perhaps an even better solution would be to integrate the Fallen Angel to a vacuum cleaning robot, so that it cleans the house as it searches for a fallen human. Ideally, a number of trigger solutions could be implemented and left to the user to decide which is most appropriate for their home.

One final improvement that could be made to the robot is the ability to view the feed from the robot's IP camera remotely. A link could be provided in the preprogrammed e-mail so that the user could view and listen to the victim in real time to get a better grasp of the situation.

## 8. AKNOWLEDGEMENTS

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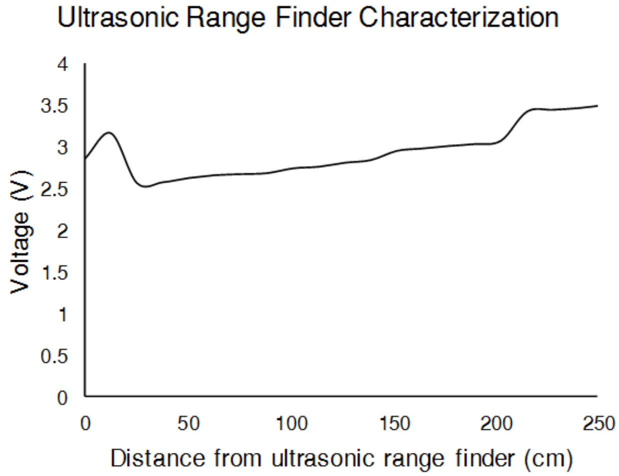
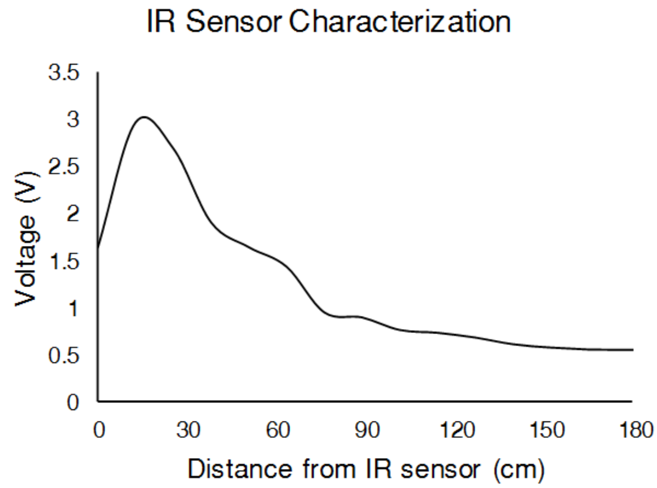
## 10. APPENDIX




**Appendix Figure 1. Ultrasonic range finder characterization**




**Appendix Figure 2. IR sensor characterization**