Mobile Autonomous Robotic Sentry (MARS) with Facial Detection and Recognition

Tyler M. Lovelly
University of Florida, Dept. of Electrical & Computer Engineering
12315 Clarendon Ct
Spring Hill, FL 34609
+1 727.808.4376
tyler727@ufl.edu

Dr. A. Antonio Arroyo
University of Florida
Machine Intelligence Lab (MIL)
338 MAE-B, UF
Gainesville, FL 32611
+1 352.392.2639
arroyo@mil.ufl.edu

Dr. Eric M. Schwartz
University of Florida
Machine Intelligence Lab (MIL)
321 MAE-B, UF
Gainesville, FL 32611
+1 352.392.2541
ems@mil.ufl.edu

ABSTRACT
This paper outlines the design and implementation of the Mobile Autonomous Robotic Sentry (MARS) unit with facial detection and recognition capabilities. MARS patrols its surrounding area, performing obstacle avoidance and searching for human threats using facial detection. Once a threat has been identified, MARS will aim at its target and fire projectiles. In addition to facial detection, MARS can be trained to recognize specific faces and identify them as threats or non-threats.

Keywords
Mobile, Autonomous, Robotic, Sentry, Facial Detection, Facial Recognition, Eigenface, Principle Component Analysis

1. INTRODUCTION
MARS was designed and built for the Intelligent Machines Design Laboratory (IMDL) at the University of Florida. It was developed using various custom and commercial parts, some modified to fit the needs of the design. MARS uses infrared (IR) proximity sensors and DC motors connected to wheels to perform driving and obstacle avoidance. An Internet Protocol (IP) network camera and wireless router allow MARS to continually send images to a nearby laptop computer where image processing can be performed to detect and recognize faces. The laptop sends information back to MARS via wireless RF modules. MARS will receive information about the location of its target and commands to fire, at which point it will turn towards its target if necessary and trigger firing of an automatic dart shooter. The design, layout, parts, and behaviors of MARS are outlined in the following sections.

2. INTEGRATED SYSTEM & PLATFORM
The control board used for MARS is the Epiphany DIY robotics board from Out of the Box, LLC, shown in Figure 1, which uses an Atmel ATxmega64A1 microcontroller.

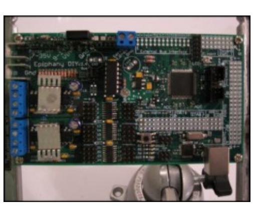

Figure 1. Epiphany DIY microcontroller board

The robot platform consists of two circular pieces of wood, approximately 30cm in diameter. These pieces are attached flat and parallel to each other, forming a two-piece platform onto which parts can be mounted. MARS is shown fully assembled in Figure 2.

Figure 2. Mobile Autonomous Robotic Sentry (MARS)

The parts and layout of the bottom piece of the platform are shown in Figure 3. The control board, which runs the C program that forms the basis of the robot's behavior, is mounted in the center. Three IR proximity sensors are mounted to the front of the platform, with the right and left sensors facing outwards to broaden the range which can be observed. Two DC motors are mounted to the upper sides of the platform, with a ball caster at the back for support. This allows for simple driving and turning movements. The main power supply is mounted behind the control board, and connected to a power routing board in order to simplify wiring and layout. Power is then routed thru an on/off switch and to the control board's power supply, motor drivers, and to the top platform. The control board also contains an Xbee wireless RF chip which allows for communication with a nearby laptop.

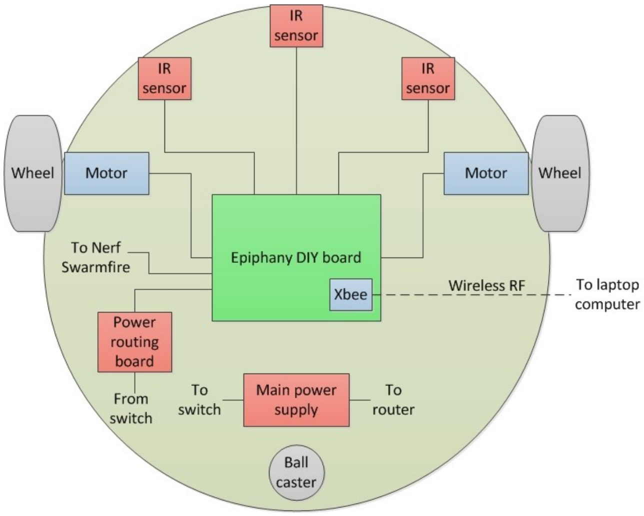

Figure 3. MARS platform bottom piece layout

The parts and layout of the top piece of the platform are shown in Figure 4. An IP camera is mounted front and center and tilted upward in order to maximize its field of view to include faces of people standing upright and several meters away. It uses its own power source and is connected via Ethernet to a wireless router which allows transmission of images to a nearby laptop computer. The router is powered by the main power supply on the platform below. A Nerf Swarmfire automatic dart shooter is mounted in the center facing forward and on an upward angle in order to best target any threats it must fire upon. The top platform also contains the on/off switch for the robot.

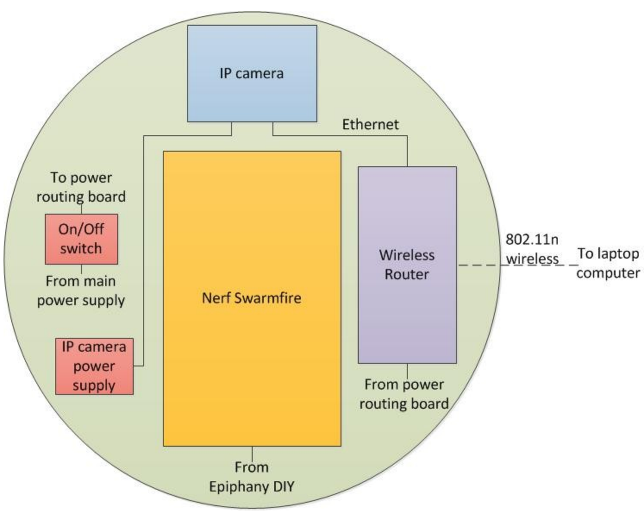

Figure 4. MARS platform top piece layout

A nearby laptop computer, which runs the C++ program used for image capturing and processing in order to detect and recognize faces, is shown in Figure 5. It captures images from MARS thru its connection with the wireless router and sends commands and targeting information back using an Xbee wireless RF chip, connected via an Xbee USB dongle.

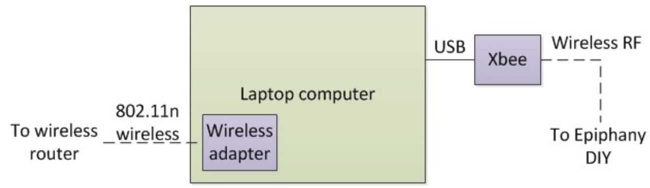

Figure 5. Laptop computer connectivity

The main power supply consists of eight rechargeable AA batteries, shown in Figure 6 with rechargeable battery packs, connected in series in an 8-AA battery holder. These were chosen because of adequate battery life and because their combined voltage suited power requirements for the control board, DC motors, wireless router, and Nerf Swarmfire. The battery holder is mounted to the platform using Velcro which allows easy removal and reattachment when recharging batteries.

Figure 6. ReVive Refresh Pro series AA smart chargers with truCELL 2700 series rechargable AA batteries

3. DRIVING & OBSTACLE AVOIDANCE

MARS drives using two DC motors attached to wheels and mounted to the bottom piece of the robotic platform, with a ball caster at the back for support. The motors and metal mounting brackets are shown in Figure 7. Motors were selected based on relatively small current draw, adequate torque to support and move the weight of the robot, and appropriate RPM for driving speed requirements.

(a) **(b)**

Figure 7. (a) 75:1 metal gearmotors, 75 RPM, 80mA free-run, 2.2A stall, 85 oz-in (6.1 kg-cm); (b) 25D mm metal gearmotor brackets

The wheels were chosen based on their size and ability to be mounted to the motors with mounting hubs, shown in Figure 8.

(a) (b)

Figure 8. (a) 70x8mm wheels; (b) Universal Aluminum mounting hubs for 4mm shaft, 4-40 holes

The motors are connected to the motor drivers on the control board, where driving can easily be controlled using Pulse Width Modulation (PWM). Turning can be done by simply running one motor backwards. The longer one motor runs backwards, the farther MARS turns in its respective direction. Therefore, variable turning behavior can be accomplished.

Obstacle avoidance can be performed using the three IR proximity sensors mounted to the front of the bottom piece of the robotic platform. The IR sensors are attached to small pieces of wood which are mounted to the platform using Velcro, allowing the sensors to be easily adjusted to suit different driving environments. The sensors chosen, shown in Figure 9, were selected due to their appropriate range of detection for the robot's obstacle avoidance purposes.

Figure 9. Sharp GP2D120XJ00F IR proximity sensors, 3-30cm range

The IR sensors are connected to analogue-to-digital converters (ADCs) on the control board. While MARS is driving, it is constantly reading values from these sensors. If the reading shows an obstacle is in the way, there is a slight 50ms delay and the reading is checked again. This removes false positives due to random spikes in readings from the sensors.

Once an obstacle has been detected, MARS will turn to avoid it and continue driving. The direction and length of its turn are determined by the combination of readings from the three sensors, shown in Table 1. This gives MARS dynamic obstacle avoidance behavior in order to safely navigate and patrol its surroundings.

Table 1. Obstacle avoidance turning behavior

Left obstacle	Center obstacle	Right obstacle	Direction	Time (ms)	Rotation (°)
No	No	No	Forward	∞	0
Yes	X	Yes	Right	3500	180
X	Yes	No	Right	1750	90
No	Yes	Yes	Left	1750	90
No	No	Yes	Left	500	25
Yes	No	Yes	Right	500	25

4. IMAGE CAPTURING & PROCESSING

MARS captures images using an IP network camera, which is modified to be powered by four AAA batteries connected in series in a 4-AAA battery holder, mounted with Velcro for easy battery replacement. The IP camera is connected via Ethernet to a wireless router. The router is modified to be powered by the main power supply. The IP camera and wireless router are shown in Figure 10.

(a) (b)

Figure 10. (a) Cisco-Linksys WVC80N IP camera; (b) Belkin N150 Wireless-N router

This allows images from the IP camera to be captured by any device which is on the same secured wireless network. A nearby laptop computer connected to the network continually captures images in order for facial detection and recognition to be performed.

The IP camera is configured to continually take low quality 320x240 MJPEG video at 4 frames per second. This setting is adequate for facial detection and recognition purposes and allows image frames to be captured from the video stream and processed at a steady rate with minimal lag. Due to a short initialization delay when first establishing the connection to the network video stream, the first 150 frames captured are not processed in order to remove any initial lag.

To prevent against false positives, a face must be detected in three consecutive frames in order to be valid. With facial recognition operating, only every third frame in which a face is detected is analyzed and compared to known faces in order to remove extra lag caused by facial recognition processing.

These configurations allow for an effective and rapid image capturing and processing system.

5. FACIAL DETECTION

The facial detection system uses the OpenCV library's cascade classifiers for facial and eye detection. These classifiers are trained and encoded with information about contrasts between regions in the image relating to features of the class being detected, in this case faces and eyes [1] [2].

When a frame is captured, it is first converted to grayscale and its histogram is equalized in order to normalize brightness and increase contrast in the image. A cascade classifier for faces is used to detect faces in the frame. A cascade classifier for eyes is then used with the segments of the images containing faces to detect eyes within faces.

Faces can be detected at both close up and far standing range in normal indoor lighting environments. It was found that detection of eyes was unreliable at far range and therefore only facial detection is used to determine robot behavior. Faces and eyes in each frame are circled and displayed in real time, shown in Figure 11.

(a) **(b)**

Figure 11. (a) Facial and eye detection at close range; (b) Facial detection at far standing range

6. FACIAL RECOGNITION

The facial recognition system is based on an OpenCV implementation of the eigenface technique, based on Principle Component Analysis (PCA) dimensionality reduction [3] [4].

In the eigenface technique for facial recognition, faces are projected in a PCA subspace that is more easily analyzed than the original image space due to reduction of dimensionality. Eigenvalues are generated which represent the “distance” between two faces in the PCA subspace. If this distance is below a certain threshold, the faces are said to match.

Offline training is used to process a large set of training images of a known person’s face. It is best to use training images taken from varying ranges and lighting conditions and to take a large sample from the same lighting environment in which MARS will be operating. Several examples are shown in Figure 12. The PCA subspace information for each of the training faces is stored in an XML file to be referenced later.

Figure 12. Training faces in 40x40 format, taken from varying ranges and lighting conditions

When a face is detected in a frame, the segment of the image that contains the face is resized to 40x40 and saved. This resizing has several advantages. It causes image segments from faces detected at varying ranges to scale in size and quality, allows the eigenface algorithm to work with consistently sized images, and reduces processing time and image dimensionality by working with a small image size.

Once the resized face image segment is saved, the eigenface algorithm tries to recognize the face by comparing it to all known faces saved during training. An eigenvalue is returned which represents the “distance” between the face and the known face for which it matches best. If this value is below a certain threshold, the faces are considered a match and the person has been recognized.

MARS can classify known faces as threats or non-threats and use this information to determine firing behavior.

7. TARGETING & FIRING

The laptop computer sends commands to fire back to MARS via Xbee wireless RF modules, shown in Figure 13.

(a) **(b)**

Figure 13. (a) Xbee Explorer USB dongle; (b) Xbee wireless RF chip

A minimum delay of 10 seconds is required between sending commands in order to prevent MARS from going into a constant firing loop while operating in large crowds.

When a face is detected, its horizontal location in the frame is used to determine the location of the threat for targeting purposes. This information is sent back to MARS along with the firing command. When MARS is told that its target is on the left or right side of its field of view, it will turn in the correct direction to aim at its target before firing.

MARS fires foam darts at its targets with a Nerf Swarmfire dart shooter, shown in Figure 14. This dart shooter was chosen due to its automatic firing mechanism and its ability to hold up to 20 darts.

Figure 14. Nerf Swarmfire dart shooter

The dart shooter is modified in order to reduce size and weight. The entire back segment is removed and much of the casing is stripped. This also allows access to the internal electronics, which is necessary in order to interface it with the control board.

The automatic firing mechanism of the dart shooter is operated by a DC motor which rotates the barrel and activates a spring plunger to fire darts. The trigger and safety simply switch power to this motor to trigger firing. These switches are removed and the motor is connected directly to a motor driver on the control board, powered by the main power supply. This gives MARS the ability to start and stop automatic firing as needed.

8. CONCLUSION

MARS accomplishes all of its original design goals, producing a mobile autonomous sentry unit with facial detection and recognition capabilities.

MARS provides a proof of concept for any mobile autonomous machine that has behaviors based on image processing, in particular facial detection and recognition. This can expand beyond sentry units to functions ranging from criminal identification to search and rescue.

Future development of MARS will focus on several key areas. Range of obstacle detection sensors should be improved and more sophisticated driving behavior developed, incorporating fuzzy logic to produce smooth navigation and turning. A permanent light source should be mounted to MARS, providing consistent light towards its field of view in order to more reliably detect and recognize faces in varying lighting environments. Accuracy of targeting behavior should be increased by mapping threat locations in image frames into more detailed targeting commands.

More information about MARS, including source code, can be found online [5].

9. ACKNOWLEDGMENTS

My thanks to Dr. Arroyo and Dr. Schwartz for offering students an exciting and interactive learning environment.

10. REFERENCES

[1] *Face Detection using OpenCV,* OpenCV Wiki, Aug. 25, 2011, opencv.willowgarage.com/wiki/FaceDetection

[2] *Cascade Classifier,* OpenCV 2.4.0 documentation, opencv.itseez.com/doc/tutorials/objdetect/cascade_classifier/cascade_classifier.html

[3] Hewitt, R., *Seeing With OpenCV – A Five Part Series,* SERVO Magazine, Jan. - May 2007, T & L Publications, Inc, www.cognotics.com/opencv/servo_2007_series/

[4] *Simple face recognition using OpenCV,* The Pebibyte, Jan. 21, 2011, pebibyte.wordpress.com/2011/01/21/simple-face-recognition-using-opencv/

[5] *Mobile Autonomous Robotic Sentry (MARS),* plaza.ufl.edu/tyler727/imdl/