Cooperative Autonomous Robots
(with search and rescue applications)

Project Proposal

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I. Project Summary

The purpose of the senior design project is to design and implement cooperative autonomous robots for search and rescue applications. The robots will cooperatively search an unknown terrain for certain objects ("victims") that are located in the environment. The task will be accomplished with each robot cooperatively mapping the area and communicating with the other robot. The robots will communicate to each other an updated map, their current position, position of victims, and the possible need for help with saving victims. The project focuses largely on optimizing cooperative function of the robots. The goal is to demonstrate that they will be more effective and efficient completing a search and rescue task cooperatively, rather than independently. The measurables for this are as follows:

- Number of victims recovered
- Amount of total area mapped
- Execution time

II. Detailed Project Description

A. Functional Description

1. System Block Diagram and Function

The overall system block diagram is shown in Figure 1 and depicts the inputs to and outputs from 'N' identical robots. For each robot the outputs include the action of wheel rotation, movement, and tool manipulation. Tool manipulation will be the action of grasping the victim with a gripper located on the front of the robot. The inputs are tool feedback, data collected from the camera, sensor inputs, and user inputs. The camera and sensor inputs will be discussed in more detail in the next section. The COM inputs and COM outputs are digital signals transmitted via a wireless link. Finally, the robots will have a display panel to give the user updates and retrieve user inputs when necessary.

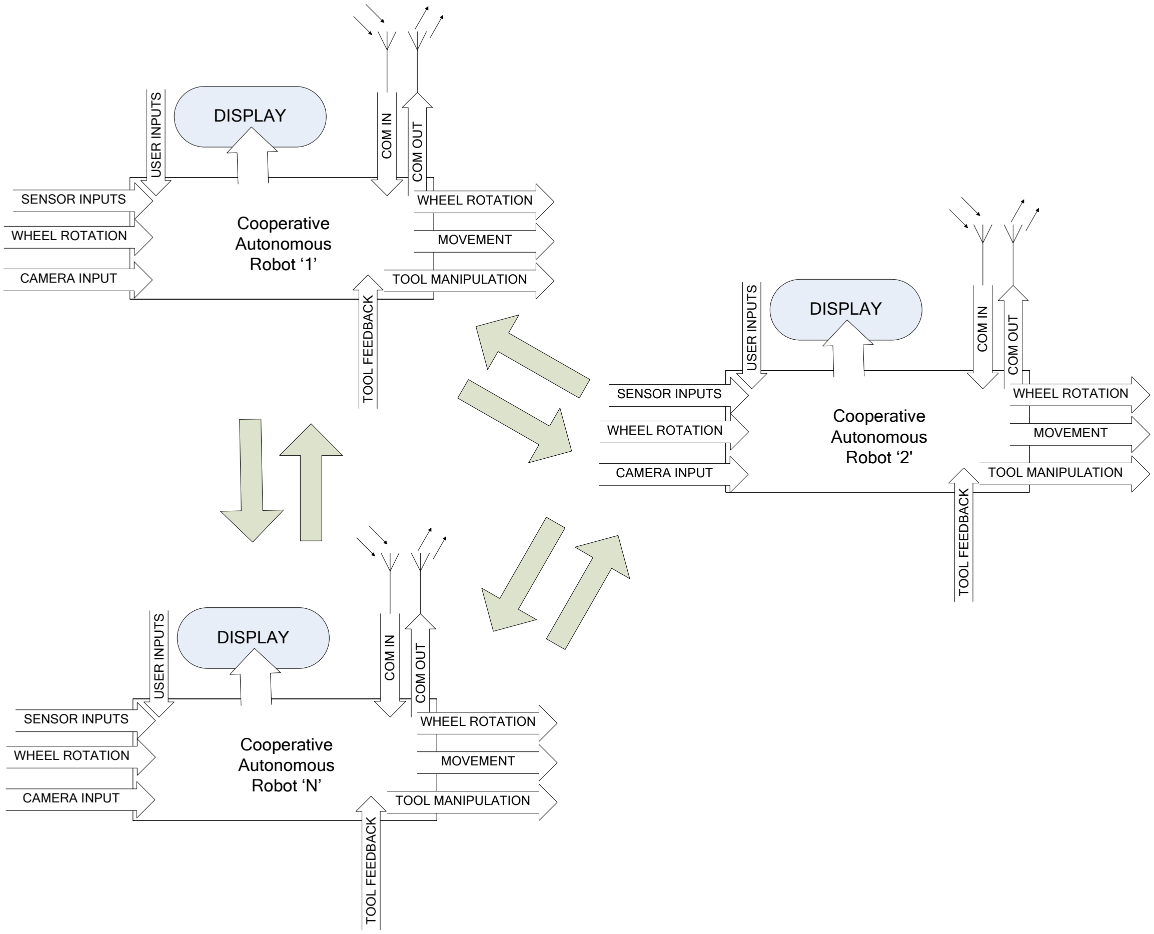

Figure 1 – Overall System Block Diagram

2. Detailed Block Diagram and Function for a Single Robot

A detailed block diagram for a single robot is shown in Figure 2 in which a microcontroller (denoted as CPU) will be utilized as the main component of the robot. It will process and control all inputs and outputs. Wireless COM links will be used for the communication between the robots. The following table shows the main inputs to and outputs from the CPU.

Table 3-1
"CPU Inputs and Outputs"

Technology	Input / Output	Function
Power	Input	Powers all equipment on the robot
Camera	Input	Used to identify victim
Distance Sensors	Input	Ultrasonic sensors for realizing distances from walls and obstacles for mapping purposes
Wheel Rotation	Input	Sensors to aid in dead reckoning
Other Robot's Current Status / Objectives	Com Input and Output	Used by robot to cooperate effectively by assisting in victim rescue or searching

		unknown map locations based on the other robot’s current status and objectives.
Tool Sensors	Input	Used to prevent excess force being exerted by the grippers and to verify victim has been grasped
Updated Map	Com Input and Output	Robot sends and receives an updated map to or from the other robot(s) for merging
Power Electronics	Output	Includes wheel motors and tool control
Camera Control	Output	Control of a pan-mount fixture which allows 180° rotation of the camera

Using the inputs described above, the CPU will process all the information, as described in flowcharts in later sections, and, in turn, develop an updated map, update its status and high level objectives, and send all necessary information to the other robot(s). The high level objectives a particular robot may have include the following:

- Navigate the area
    - Search for victims
    - Map newly discovered boundaries/objects/obstacles
- Rescue victim
- Communicate
    - Ask for assistance from other robot(s) in rescuing victims
    - Inform other robot(s) of current status including failure (described later)
    - Send/Receive updated map

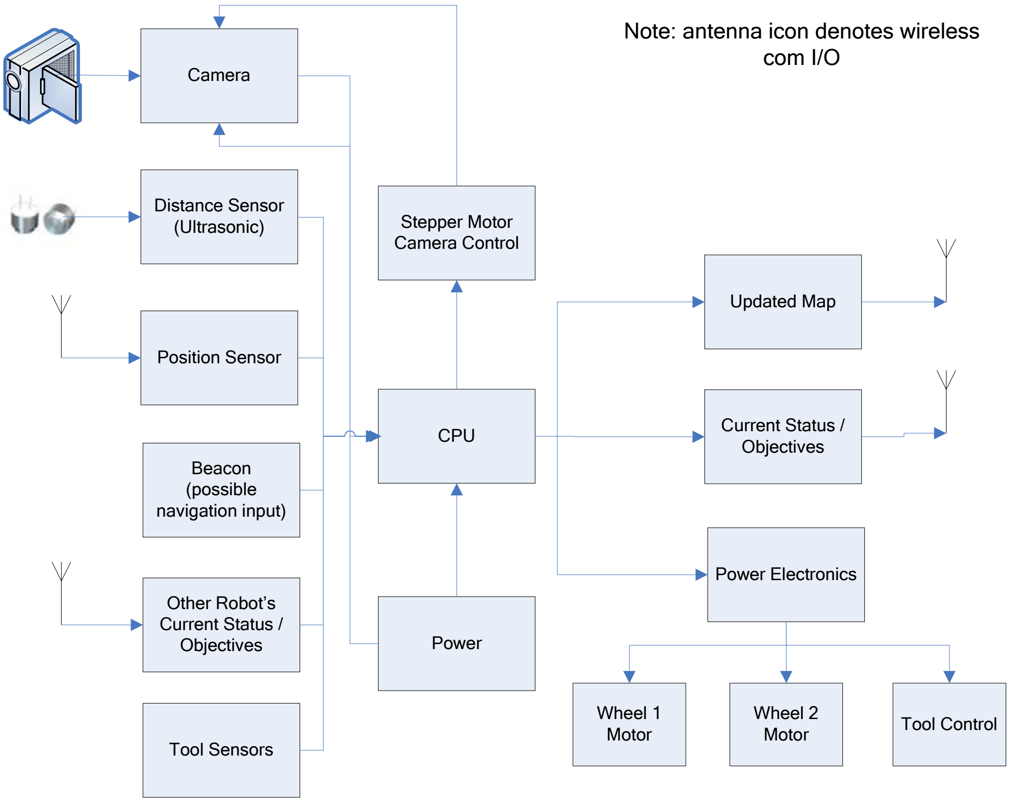

Figure 2 – Block Diagram of a Single Robot

3. Robot Modes

The Robot will have five main functional modes: Searching, Mapping, Communication, Rescue, and Failure mode. The robots will run in a Search, Map, and Communicate (SMC) pattern. The Rescue mode will only occur once a victim(s) has been found while in Search mode. The Failure mode is used to compensate for possible errors that could occur while in the other modes. A high level software flowchart is shown in Figure 3.

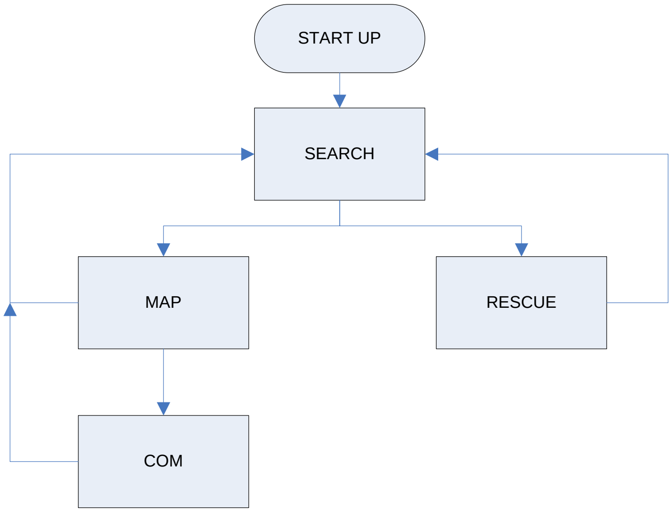

Figure 3 – High Level Software Flowchart

a. Search Mode

The robot will begin in Search mode, as shown in Figure 4. While in Search mode the robot will search a 1.5 meter radius from -90° to 90° relative to the front of the robot. While in search mode the robot will obtain a series of 5 pictures taken from an onboard camera. The camera will be attached to a pan-mount fixture that will rotate 45° between each picture. The pictures are analyzed using digital image processing (DIP) techniques to check for the right color, size, and shape of possible targets. The DIP algorithm will be able to confirm a victim within 1.5 meters. If a target is not found while in Search mode, the robot will continue to the Mapping mode

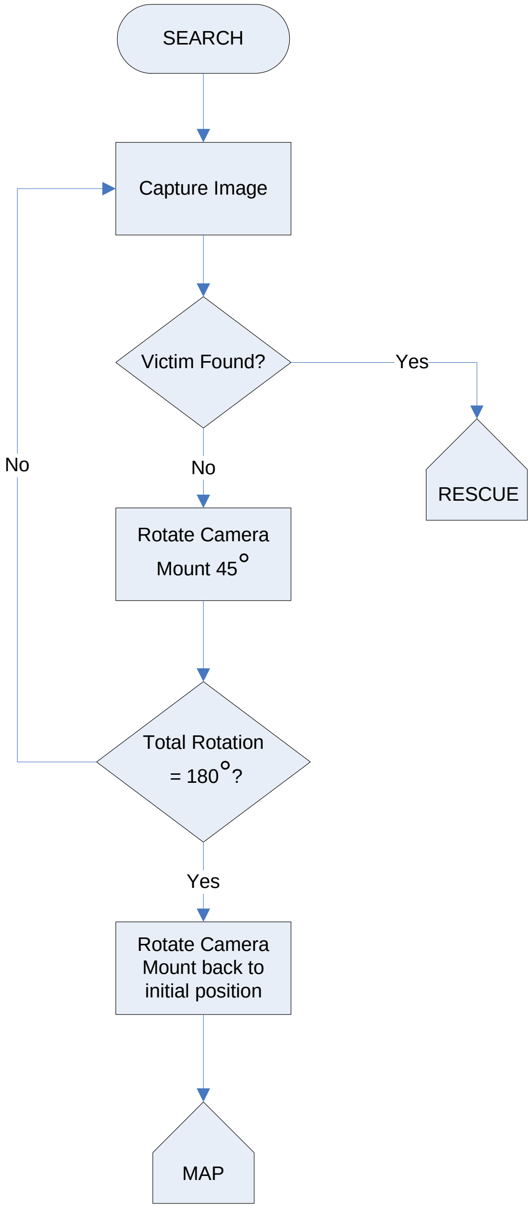

Figure 4 – Search Mode Flowchart

b. Mapping Mode

The second stage of the SMC pattern is to begin mapping. The Mapping mode can be seen in Figure 5. The robot will follow the right or left walls while in Mapping mode. The first robot will follow the right walls and the second robot will follow the left walls. Mapping different areas with each robot increase the searching efficiency. When starting the mapping mode, the robot will begin recoding its Cartesian coordinates and sonar data. The Cartesian coordinates will be recorded using sonar data, where possible, as well as a ‘Dead Reckoning’ approach. The sonar data is obtained from the ultrasonic sensors located on the front perimeter of the robot, as shown in Figure 6. The robot will follow the desired wall recording its distance and sonar measurements. The robot will travel 1.5 meters, at which point it will stop and enter Communication Mode and then Search Mode. If, while in motion, the robot reaches a wall, it will stop no closer than 50cm, rotate 90° and return to the Communication Mode and Search mode sequence.

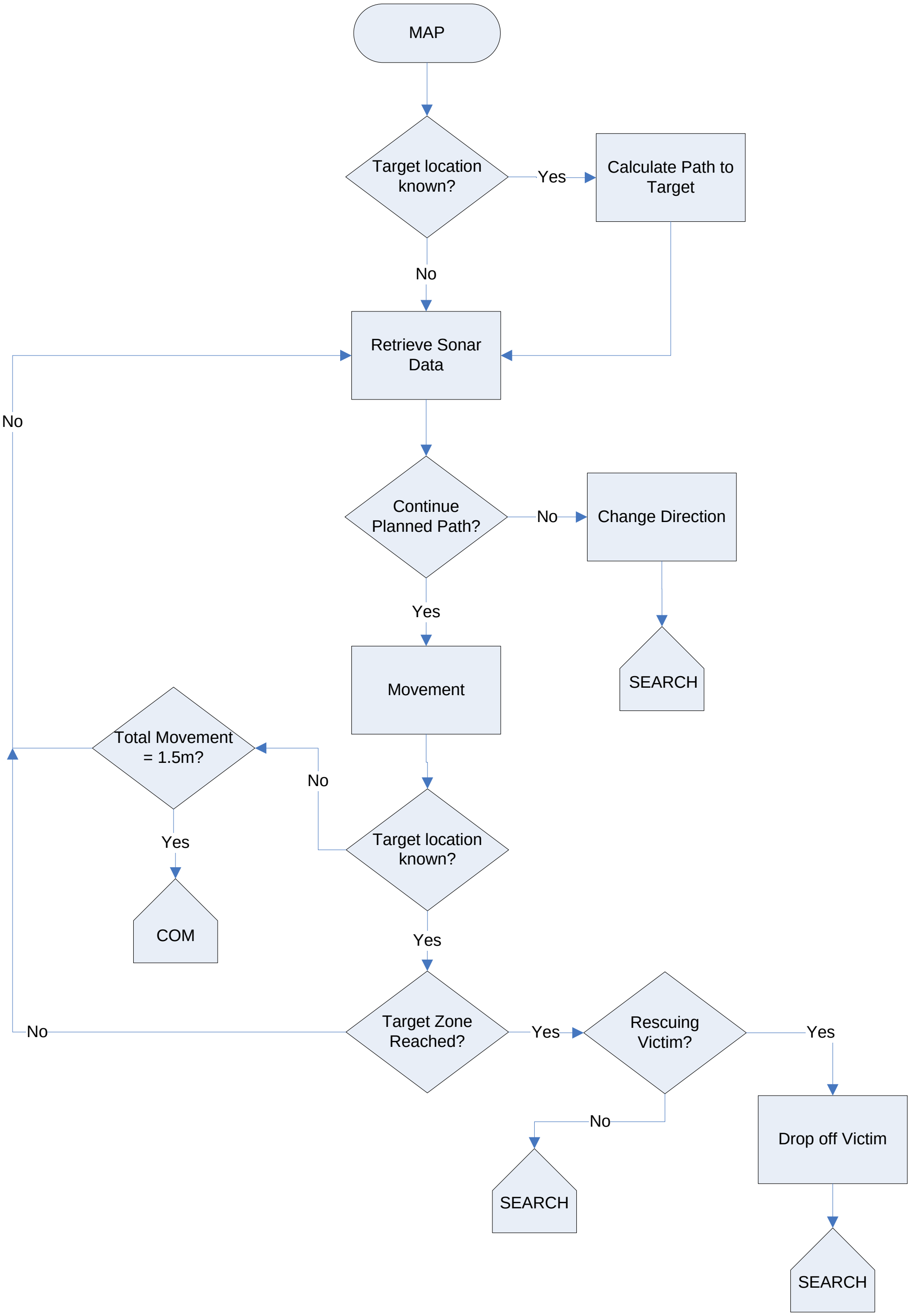

Figure 5 – Mapping Mode Flowchart

Figure 6 – Ultrasonic Sensors on the Robot

c. Communication Mode

The Communication mode is used to send or receive new information about objectives or mapped data. While in communication mode, the robot will send and receive map information, ask for help, or respond to requests from the other robot. At this point, it has not been decided whether the robots will connect directly to each other or if a third stationary computer will be used for addition processing power and communications. Once all of the communication has been completed, the robot will return to the respective mode. In most cases it will complete the cycle and move into the Search Mode. If the robot receives a request to help retrieve found victims, the robots will enter a decision based auction. In a decision based auction, the robots perform appropriate algorithms, which are functions of their current status and objectives, to determine which objective each robot will be assigned (Sariel, 2005). The flowchart for the Communication mode is shown in Figure 7.

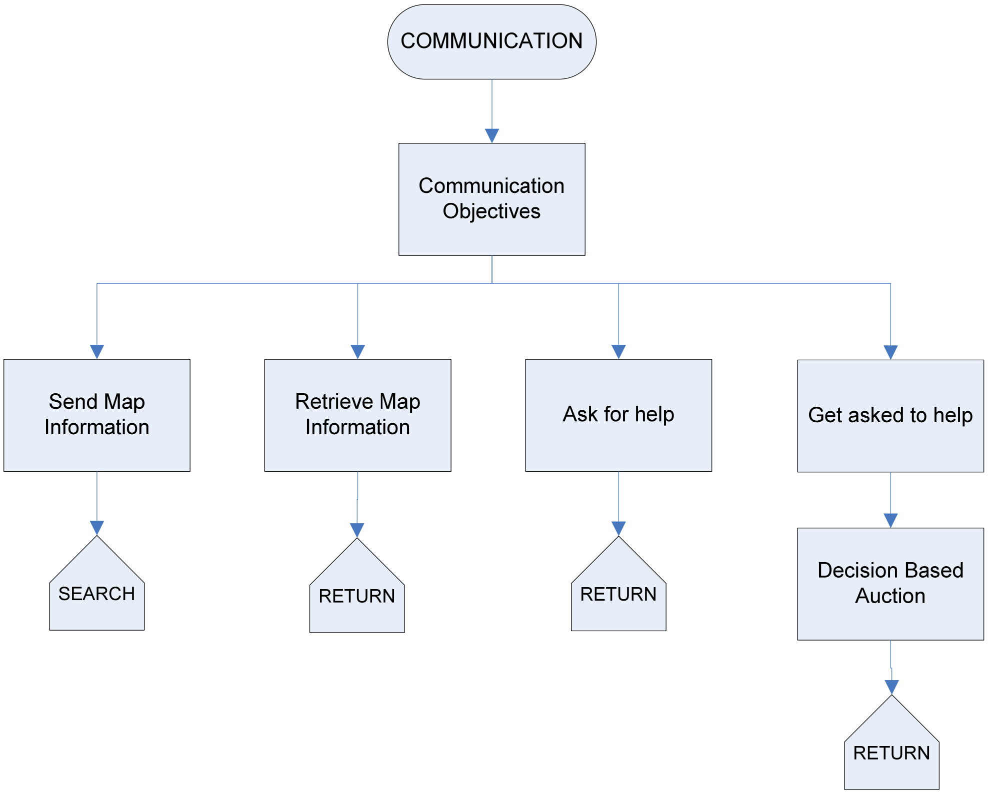

Figure 7 – Communication Mode Flowchart

d. Rescue Mode

The robot will continue to run this SMC pattern until a victim is found during Search mode. Once a victim has been found, the robot will go immediately to Rescue mode. The Rescue mode is detailed in Figure 8. The robot will use information provided by the Digital Image Processing (DIP) algorithms to determine the approximate angle and distance of the victim with respect to the robot. The robot will begin to center with respect to the victim. Once the robot has the victim directly in sight, it will begin to approach the victim. The camera will continue to provide information via DIP to assist the robot to maintain its position. When the robot is positioned correctly, a gripper will be used to grab and lift the victim. If the gripper used provides feedback about the force applies, the software will ensure that the proper amount of force is applied to grab, but not crush the victim.

When the victim is secured by the robot, the robot will begin to return to base. While a victim is being returned the robot will go into a designated Mapping mode. In this function, the robot will travel along an optimum path, based on the overall map generated to that point, to return to base. It will continue to make distance and sonar measurement to ensure its following this optimum path. The robot will continue to communicate while returning to base. In this mode, the robot's first priority is to return the victim.

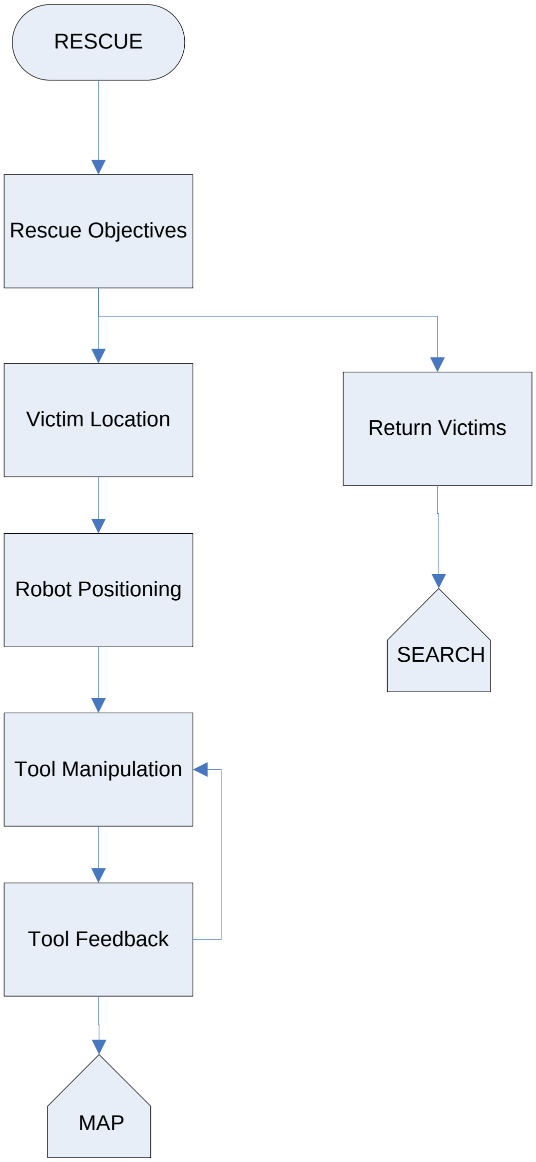

Figure 8 – Rescue Mode Flow Chart

e. Failure Mode

The failure mode is shown in Figure 9. This mode will be triggered if there is a map error, the robot becomes immobile, there are communication issues, or if an unknown error occurs. If there is a mapping error caused by a discrepancy between the two robot’s maps, the robot in Failure mode will remove the corrupted map data, retrieve the correct map form the other robot, and then attempt to return to the base. If the robot becomes immobile it will inform the other robot of its error status. If the communication system fails, then the robot will retrace its route back to the starting point. If an unknown error occurs, it will return back to the base and communicate to the other robot that an unknown error has occurred. If this is the case, the other robot will attempt to complete the task without the aid of the other robot. A message will be displayed on the screen detailing any error that occurs while in operation.

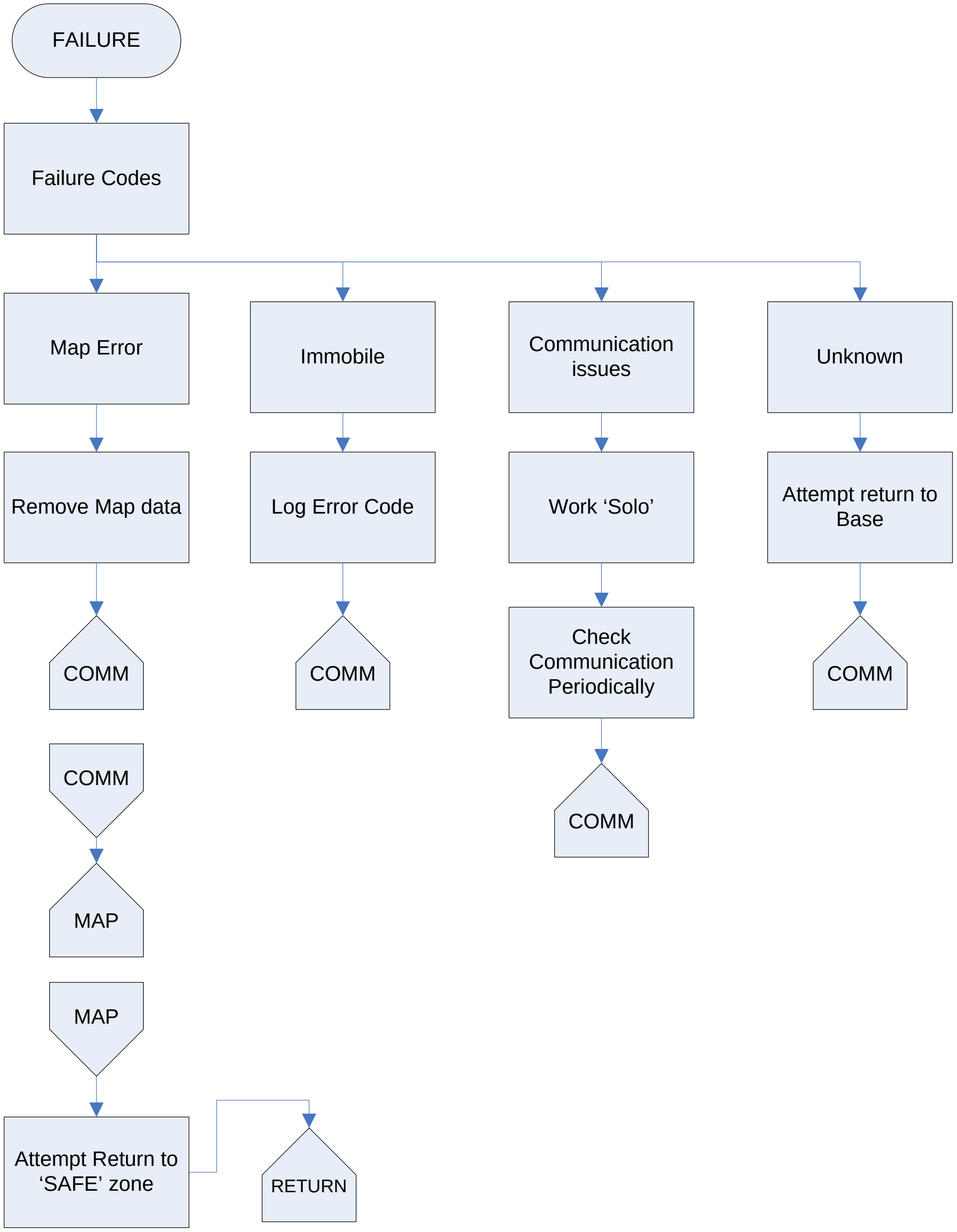

Figure 9 – Failure Mode Flow Chart

B. Functional Requirements

1. System Requirements

There are a wide variety of environments that could be encountered in search and rescue applications. This project will be constrained to an environment in which the autonomous robot will be able to maneuver through and map the environment with a good chance for success. The characteristics of the environment will be limited by the following.

- An off the shelf robotic platform that has limited mobility due to its size and motor capabilities.
- The ability to detect a ‘victim’ using a camera and DIP
- Available testing areas at Bradley University.

Each mode of the robot shall have its own requirements. The requirements of the robot are shown in Table 12-1.

Table 12-1
“System Requirements of the Robot”

Completion Time:

- The Robot will be able to map and search a 1.5x10 meter open hallway in less than 3.4 minutes.
- The Robot will be able to map and search a 9x9 meter open room in less than 18.5 minutes.

Mapping Mode:

- Each robot shall map walls, obstacles and boundaries with an accuracy of 5 cm.
- The accumulated position error shall be less than 5 cm for every 3 meters mapped.
- Each robot shall return the victim at a speed greater than .8 meters per second.
- Each robot shall return to the entrance of the room within 1 meter accuracy.
- Each robot shall be navigate a 1.5 meter sector in less than 10 seconds (assuming no victim is found)
- Each robot will be able to make a 90° turn in less than 5 seconds.

Search Mode:

- Each robot shall search a sector of 1.5 meters in less than 20 seconds.
- Each robot shall locate a victim within a distance of 1.5 meter in a 45° section.

Rescue Mode:

- Each robot shall be able to identify a victim in less than 5 seconds.
- Each robot shall be able to navigate and grasp a victim in less than 30 seconds.

Communication Mode:

- The max range for communication is 70 feet

The requirements shown in Table 12-1 are subject to change upon testing of the robotic platform and appropriate software. The largest limitations of the robot are the speed at which the robot can move, the operating time of the pan-mount fixture, the effectiveness of the camera and DIP software, and the use of sonar data to create an accurate map.

The camera and DIP software limit the length of each sector that will be searched. The camera and software will be able to detect a ‘victim’ at distances no greater than 1.5 meters. If the quality of the camera or DIP software increases, the distance that the robot could travel will increase. Moving farther distances before returning to Search mode will increase the overall speed of the robot.

The maximum speed of the robot, while in Mapping mode, is limited by the maximum speed of the platform and the ability to record accurate sonar information while moving. The 10 second time to map a 1.5 meter sector is determined by the time it takes to start and stop moving and the maximum speed the robot while traveling the 1.5 meters. The maximum time for the system to complete the Searching mode is limited by the camera and DIP software. It has been determined that the pan-mount fixture and software will be able to complete a series of five pictures at 45° increments in less than 20 seconds.

Mapping and Search modes are the biggest factors on the time it takes to complete the desired task. The robot will be able to search and map a 1.5 meter section every 30 seconds. The time it takes to completely map and search a room depends on the complexity of the environment and the number of victims found. Every victim found will add an additional 30 seconds when securing the victim and the time it will take to return the victim to the starting point. The robot will be forced to travel at a slower speed when approaching a victim or targeted zone. This is due to the path planning and positioning that will require accurate movement by the robot.

2. Hardware Specifications

The P3-DX robotic platform was chosen for this project. The Specifications of the robot are shown below in Table 13-1. The specifications for the desired web camera are shown in Table 14-1.

Table 13-1
“Robot Platform Specifications”

Max Speed	1 meter/sec
Number of sonar range finders	8
Range of sonar	15cm to 5 meters
Angle of sonar sight	180°
Swinging radius	32 centimeters
Traversable slope max	25%

Table 14-1
"Camera Specifications"

Camera resolution	640 X 480 pixels (color)
Camera minimum focal distance	3 cm
Camera mount field of vision	180°
Angles pictures will be taken from	180 °, 135 °, 90 °, 45 °, and 0 °

3. Software Specifications

The running time for the software has yet to be determined. The digital image processing and map generation will consume the most CPU cycles. However, at the time of this document preparation, it appears that time constraints due to platform motion will be dominant constraint.

III. Experimental Work and Proposed Scheduled

C. Work Completed to Date

A large amount of research has been conducted to ensure this project becomes operational. At this point in time, the largest amount of research has been in the areas of mapping and digital image processing. Additional research has been done on communication, decision based auctions, and the P3-DX platform.

A program called MapViewer 2.0 uses sonar information to create a digital map. MapViewer 2.0 was created by Shane O'Sullivan who graduated with a masters in mobile robotics from the University of Limerick, Ireland. The program creates a map based on data from ultrasonic sensors and the robots relative location to its starting point. This program will allow maps to be created easily by the two robots. With the aid of this program, creating maps and planning paths should be able to be achieved with relative ease.

The other focus of research has been on using digital image processing to accurately find a 'victim' from a distance no greater than 1.5 meters. The DIP will use a series or combinations of several techniques to properly identify a 'victim'. Some of the methods for detecting a victim are edge, color, and shape detection. Although it has not been determined at this moment what methods the DIP software will use, all of the methods are being researched.

D. Tentative Work Schedule

Table15-1
"Tentative Schedule"

Date(s)	Objectives / Milestones	*Group Member*
4th Dec. – 22nd Jan.	Break. 'C++ for Dummies' Start working/testing P3-DX platform. Write software to export sonar/position information.	Bryan / Rob ALL Adam / Austin Adam / Austin
23rd Jan. – 06 Feb.	Software Development Mapping Movement Algorithms Searching Imaging	 Austin Adam Bryan Rob
07th Feb. – 20th Feb.	Integrate Software and hardware Basic movement and path planning Ability to create 'raw' maps Begin testing 'finding a victim' Purchase 2nd Robot? *Basic communication	 Adam Austin Bryan / Rob Dr. Huggins Bryan
21st Feb. – 06th Mar.	Test Software/Hardware Ability to create detailed maps Advanced movement and path planning Be able to find victim in 1.5 m. radius *Advanced communication	 Austin Adam / Bryan Rob Bryan
07th Mar. – 20th Mar.	Integrate all Software with Hardware Create, use, and combine maps Utilize maps for movement and targeted path planning 'Rescue victim' *Optimization of two robots *Decision based Auctions	 Austin / Bryan Adam Rob Rob / Bryan Austin / Adam
21st Mar. – 03rd Apr.	Debug Hardware and Software Begin test runs Have Software finalized Analyze strengths and weaknesses DEBUG	 Bryan /Rob ALL Austin / Adam ALL
04th Apr. – 17th Apr.	Debug Hardware and Software Optimize successes and minimize problems Repeated test runs Bring everything together DEBUG	 Austin / Adam Bryan / Rob ALL ALL
18th Apr. – end of semester	Finalize Project DEBUG Prepare final report, all other documentation, and presentation materials	ALL ALL ALL

IV. Standards and Patents

E. Patents

Table 16-1
"Patents applicable to S.A.R.A."

7,089,084	Search robot system
7,085,624	Autonomous machine
7,082,350	Robot system
7,069,124	Robotic modeling of voids
7,066,291	Robot system
7,054,716	Sentry robot system

F. Standards

Table 16-2
"Standards applicable to S.A.R.A."

ISO 10218-1:2006	Robots for industrial environments - Safety requirements - Part 1: Robot
AS 2939-1987	Industrial robot systems - Safe design and usage (FOREIGN STANDARD)
EN ISO 14539	Manipulating Industrial Robots - Object Handling with Grasp-Type Grippers - Vocabulary and Presentation of Characteristics
MIL-STD-2045-13501 NOT 1	INFORMATION TECHNOLOGY DOD STANDARDIZED PROFILE INTERNET ROUTING BETWEEN AUTONOMOUS SYSTEMS BORDER GATEWAY PROTOCOL (NO S/S DOCUMENT)
ISO/TR 21730:2005	Health informatics -- Use of mobile wireless communication and computing technology in healthcare facilities -- Recommendations for the management of unintentional electromagnetic interference with medical devices

V. Bibliography

P3-DX
http://robots.mobilerobots.com/
Camera
http://hitony.en.alibaba.com/product/50128782/51251378/PC_Camera/Webcam.html
Map Viewer
http://mapviewer.skynet.ie/
Self-Mapping Mobile Robot Capstone Project by Stephanie Luft
http://cegt201.bradley.edu/projects/proj2006/mapbot/

Sariel, S and Balch, T, 2005. Real Time Auction Based Allocation of Tasks for Multi-Robot Exploration Problem in Dynamic Environments. http://www.cc.gatech.edu/~sariel/publications/AAAI_workshop_2005_sariel.pdf

VI. Equipment List

One P3-DX mobile robot, a laptop, and camera have been purchased and are ready to test. A digital compass, pan-mount fixture, and gripping tool will be purchased on a later date. Once all items have been purchased specifications will be made available. All future specifications are pending the test results. Table 17-1 denotes the equipment that the project will require.

Table 17-1
"Equipment List."

Items Required
ActiveMedia P3-DX mobile robot (X2)
Onboard Laptop (X2)
Digital Compass (X2)
Pan Mount Fixture (X2)
Camera (X2)
Gripping Tool (X2)
Appropriate connectors for listed equipment
MATLAB, Visual Studio, and/pr another type of software development system

VII. Project Summary

Cooperative autonomous robots will be used to search an unknown terrain, map the environment, and locate and save victims. Using wireless communication, the robots will be able to maximize results by cooperating with each other. Due to this cooperation, areas will not be covered twice and robots will have the ability to assist each other in recovering victims. Upon implementation of the final design of this project, the goal is to demonstrate that having cooperative autonomous robots perform a search and rescue task is more effective than robots operating independent of each other. Benefits include more victims saved, more area covered, and a faster execution time. In the case of search and rescue applications, the benefits previously mentioned are all keys to a successful operation.