



**RoboCup2004**  
**Rescue Robot League Competition**  
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www.robocup2004.pt

**RoboCupRescue - Robot League Team**  
**RFC Uppsala, Sweden**

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**Abstract.** The robot system designed by RFC Uppsala for the 2004 RoboCup Rescue Real League is a fully autonomous team of four robots. Based on ultrasonic sensor data, the robots cooperatively generate a map and mark victim positions. Employing wireless ad-hoc networking, communication between the robots is upheld even if contact with the network infrastructure is lost.

## **Introduction**

RFC Uppsala is a team from Uppsala University consisting of senior students taking the Master of Science program of Information Technology. Previous years RFC Uppsala has competed in the RoboCup Soccer Middle Size League, but this year the 20 weeks long project is aiming to develop a robot system designed for the RoboCup Rescue Real League. The experiences from previous year's projects are very valuable.

The goal is to develop a fully autonomous system consisting of four robots that have the ability to work as a team. The team should search the area and locate victims. Using ultra sonic sensors a map is generated to assist human rescue teams in their operation.

To develop effective search strategies a simulator where the robot software is evaluated has been constructed. This saves much time since experiments can be performed in a faster than real-time environment and parallel to the development of the hardware platform.

Another important feature of the system is the implementation of an ad-hoc network protocol that improves the systems performance in areas not covered by network infrastructure.

## 1. Team Members and Their Contributions

- Jakob Carlström            Advisor
- Per Halvarsson            Advisor
- Rasha Alshammari        Software developer
- Gustav Björcke            Software developer
- Marie Carlson             Hardware developer
- Carl Christiansen         Software developer
- Pär Johansson             Software developer
- Erik Jonsson               Hardware developer
- Jonas Jämtberg            Software developer
- Jonas Nilsson             Hardware developer
- Andreas Persson          Software developer
- Jon Rönnols                Software developer
- Mattias Seeman            Hardware developer
- Mathias Thore             Hardware developer
- Håkan Vindahl             Hardware developer

## 2. Operator Station Set-up and Break-Down (10 minutes)

The operator station consists only of a laptop with the human-robot interaction software installed and a small portable printer. Since the robots are fully autonomous the operator station is not be manned during the missions if there is no system failure forcing human operators to take manual control over the robots. The whole team of robots is controlled by, at most, one operator working on one laptop.

The robots are carried into the arena and be placed in a special formation in which the robots calibrate to a common reference system. This is the time critical part of the setup.

During initialization of robots there is a defined rank between members of the robot team. Highest ranking robot starts in the origin, and the other robots are set up in a pattern such that they know there position relative to the first robot.

## 3. Communications

The robots use WLAN communication with the 802.11a standard. The communication between the robots can be in two different modes, ad-hoc mode or infrastructure mode. In infrastructure mode the robots communicate through a base station which limits the range of operation.

In ad-hoc mode communication goes through the robots and the routing is changing depending on how the robots are located to each other. This makes the communication within the team more flexible in a sense, since the robots no longer are dependent on the base station to communicate with each other. Hence the robot can travel further away from the base station, but not too far away from each other. Ad-hoc network constrains prevent the robots from moving out of range from the other robots.

The protocol that is used for the ad-hoc mode is the LUNAR-protocol [1], developed at Uppsala University. LUNAR is a simple and robust self-configuring wireless ad-hoc routing system that creates an IP subnet illusion. It works well in the most common situations of wireless ad-hoc networking, namely small groups of less than 10 mobile nodes that are close enough.

#### **4. Control Method and Human-Robot Interface**

The team is designed to be fully autonomous, however there is a human-robot interface mainly used for development and debugging. During missions no human operator is needed unless some system fails.

The human-robot interface controls the whole team of robots from one laptop over the WLAN interface. Status of all subsystems for each robot is available from the human-robot interface and advanced functions for steering the robots are available. The operator can choose to control the robots exact paths, but also let the robots calculate their own paths and search behavior if that is preferred.

When in autonomous mode a planner runs on the robot that is selected as master at the current time, which robot that is master can change during the mission. If the master is lost another robot is appointed as master automatically. The planner allocates search areas for the robots in the team.

To effectively search the area the master allocates one section of the total area to each robot, when a slave robot has been allocated an area the local robot navigator calculates the path used to reach and search the given area. However, if the team is operating in ad-hoc mode, the slaves can not calculate their paths freely. Instead they are under influence of the master that makes sure that the ad-hoc communication network is upheld at all times.

#### **5. Map generation/printing**

The map is mainly generated from the ultrasonic sensors. The robot receives readings of angles and distances to the nearest obstacle for each angle from the ultrasonic

sensors, the points in the map at the given distance is calculated and marked as obstacles. All points between the robot and the obstacle are marked as free from obstacles. Data from the pyro-electric sensor are used to mark potential victims.

Statistical image analysis is used to improve the quality of the map and different colours are used to mark the obstacles. If the analysis shows that earlier discovered areas do not match the new data the main system is alerted of this and take actions to locate its own position to be able to correct data.

A global map consisting of the individual robots local maps are generated during the mission. Analysis and synchronization of the global map are distributed within the team to improve performance. When the server is reachable within the network analysis and synchronization can be done on the server to relieve the robots from some of the work

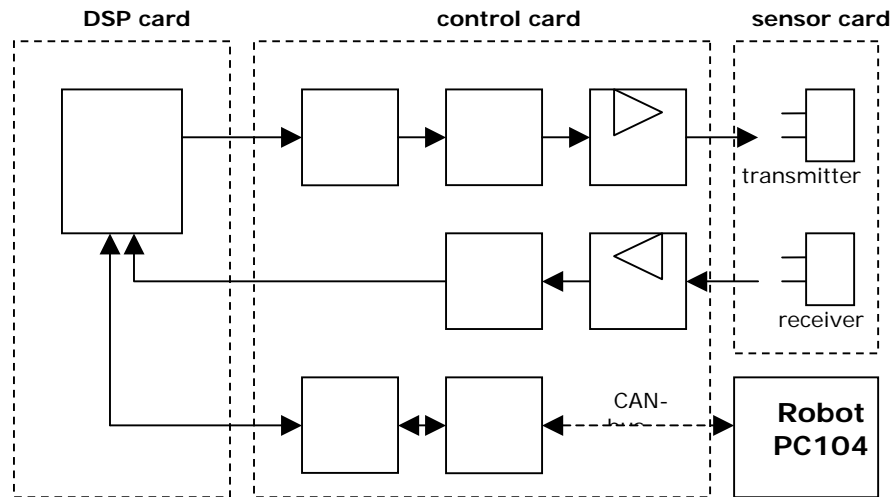
The server also analyzes the map with statistical methods and image analysis after the robots have finished their mission to enhance the quality even more before it is printed from the human-robot interaction software. Related previous work includes [2], [3] and [4].

## **6. Sensors for Navigation and Localization**

All the sensors are connected through a CAN-bus with a PC104 who gets the data and processes them.

### **Ultrasonic Sensors**

The robots have an array of active ultrasonic sensors mounted on the front of the robot. These return distances and angles to objects. Their purpose is to supply information necessary for mapping and navigation of the robots and also to enable them to avoid collision.



**Fig. 1.** The hardware for the ultrasonic sensors consists of a three cards

On the sensor card a transmitter array and receiver array are mounted. The transmitters emit bursts of 40 kHz sound when the control card issues a signal and the receivers listen for echoes. It is possible to control the direction of the ultrasonic beam by phase-shifting the transmitted signals. A sector of about 60 degrees in front of the robot can be searched. The ultrasonic system can measure distances ranging from 0.5 through 4 m.

The transmission of ultrasound is initiated by a DSP by sending a trigger signal to the control card. When an echo returns it is analyzed to detect if there were any reflections from objects. If an object is found, an angle and distance to the object is calculated by the DSP and then sent onwards to the robot through the CAN bus.

The CAN card handles the communication between the DSP and the CAN bus. The CAN bus receives information from the DSP via UART with information about the object that is detected by the ultrasonic system and send this information out on the CAN bus on to the main computer on the robot.

### **Infrared Sensors**

The purpose of the active infrared sensors is to detect holes and steep slopes so that the robots can avoid them. They are also supposed to act as a complement to the ultrasonic system which operates from half a meter. The infrared sensors operate on

distances up to 80 cm. Therefore, the infrared sensors can enable collision detection and avoidance at close distances. The infrared sensors are placed in a way such that all directions around the robot are observed. Close to each tire, sensors are placed to prevent the robot from entering holes. Sensors are placed forwards, as a complement to the ultrasonic system, to detect obstacles. On the sides of the rear end of the robot sensors are placed to avoid collisions when the robot turns and also sensors facing backwards to prevent from collisions while reversing.

The sensors, which are analogue, work at distances from 10 cm to 80 cm. They report an output voltage that can be transformed into a distance. Each sensor is connected to an input channel on the AVR microcontroller. The microcontroller uses analog to digital conversion to read the output voltage value from an analogue infrared sensor. The controller calculates the distances that the output voltage values of the sensors correspond to and send distance reports on the CAN bus whenever the PC104 wants information.

### **Motor positioning calculation**

The electrical motors are controlled by a dedicated card, which also provides sensor data to the navigation system.

A Mega16 chip is mounted on the circuit board controller for the engines to take care of the pulses from the encoders and to make positioning calculation. The Atmel microcontrollers communicate through an i2c bus. The encoder information is being used to instantly adjust the motor speed and calculate the position of the robot. The solution with engine controller and encoder feedback on the same circuit board gives the possibility to drive the motors very exactly, which gives a very high precision in the movements of the robot.

The CAN messages to control the movement contain three parts: type of movement, speed and angle/distance/radius. The types movements are: go forward, go backward, turn left, turn right, rotate left, rotate right and stand still. From the engine controller CAN-messages containing position information is being sent continuously. The pace of position information packets being sent is controlled by how the robot is moving. The position packets can also be sent on demand.

## **7. Sensors for Victim Identification**

Pyro-electric sensors are used to provide a way for the robots to identify victims. The sensor provides accurate information on the horizontal end-points of a victim relative to the robot. To provide information of the distance between victim and robot two pyro-electric sensors are used.

The pyro-electric sensor is a passive sensor responsive to the wavelength of infrared light emitted by a warm human body. Since the sensor reacts to differences in

temperature between two areas, light from these two areas is focused upon the receptive areas of the sensor through a thin sliver of a Fresnel lens, and the sensor sweeps its surroundings mounted on a stepper motor.

The stepper motor is controlled by an AVR microcontroller, which also interprets the analog signal from the sensor. The AVR then in turn communicates the sensor findings to the robots main CPU over a CAN network.

A microphone is used to localize victims. This helps in finding hidden or entombed living humans, whose only way of telling where they are is through tapping or moaning.

Audio is continuously sampled through a single directional microphone facing forward. The audio stream is then processed for features distinguishing human voices and tapping sounds from background noises.

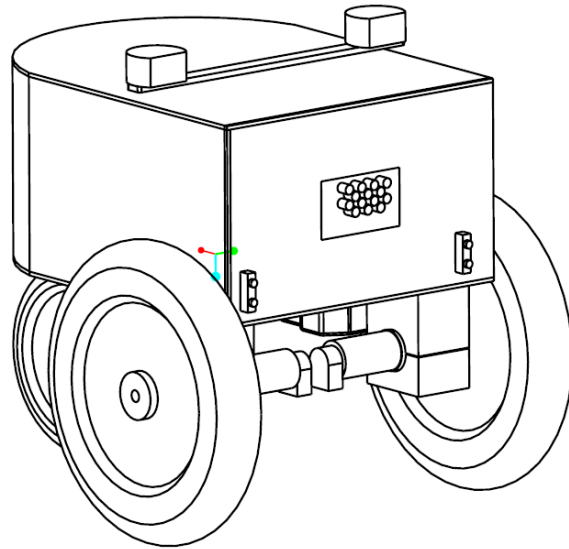
A standard web camera, connected by USB to robot CPU is used. The camera is used to document sites where victims are discovered to further help the rescue operation.

The camera is mounted on the axis of the pyro-sensor swingarm and can be triggered by software, i.e. on victim discovery by the pyro-sensor.

## **8. Robot Locomotion**

As shown in figure 2 the robots are constructed with two front driving wheels and one rear wheel. The rear wheel follows the robot like the wheels on a shopping cart or a wheelchair. The positive effects of using just one rear wheel compared to two rear wheels is that the robot size decreases and have a smaller turning radius..

Two motors are used, one for each driving wheel. The robot turns by rotating the wheels driving wheels in opposite directions.



**Fig. 2.** Exterior view of a rescue robot

## **9. Other Mechanisms**

### **Motors**

The engine packs consist of a motor, model RE40 from Maxon. The motor is a 150 Watt, 48 Volt DC motor. A planetary gear head is mounted on the motor. The motor is also equipped with a Maxon encoder which gives an output of 500 pulses per turn on the motor. The engines are strong enough to drive a robot weighing 20kg over obstacles up to 75mm high without problems.

The engines are controlled by a one circuit board controller. The board is equipped with a can interface to communicate with other nodes on the robot. A microcontroller is being used to handle the can communication and to control of the motors.



## **10. Team Training for Operation (Human Factors)**

Since the system is fully autonomous minimal training is required for use. To operate the system a human-robot graphical interface is used where all robots can be controlled simultaneously. The interface is easy to use, but advanced functions for accessing robot subsystems for debugging purposes demands good knowledge of the system.

The operators do not need any extra training in addition to the normal testing before the competition. Tests includes however setup time and how to handle failure on the robot subsystems that might force an operator to take control of the team. We select the person to operate the system in case of failure of the autonomous system by timed test runs.

## **11. Possibility for Practical Application to Real Disaster Site**

Best chances for success are in buildings where ground obstacles are small. The system works perfectly without lightning since ultra sonic sensors are used for map building. The use of ad-hoc networking protocols gives the system ability to work in areas that is not covered by network infrastructure.

## **12. System Cost**

The system cost per robot is approximately 2800 euros. This does not include the operator station, which consists of a standard PC with an IEEE802.11a WLAN card and a printer. For further information see appendix A.

## References

- [1] Richard Gold and Christian Tschudin “LUNAR – Lightweight Underlay Network Ad-hoc Routing 2002”  
<http://www.docs.uu.se/docs/research/projects/selnet/lunar/>
- [2] Philip Althaus and Henrik I. Christensen “Automatic Map Acquisition for Navigation in Domestic Environments”, in Proceedings of the IEEE International Conference on Robotics and Automation, pp. 1551-1556, 2003.
- [3] Bing-Ran Zuo and I-Ming Chen “Predict Sonar Returns for Autonomous Robot Navigation in Unstructured Enviroments”  
<http://155.69.254.10/users/risc/Pub/Conf/00-c-icarcv-sonar.pdf>
- [4] Bing-Ran Zuo and I-Ming Chen “A Dynamic Reachability Test for Sensor-Based Navigation with Unknown Obstacle Boundaries”, in Proceedings of the IEEE International Conference on Intelligent Robots and Systems, pp. 2030-2035 vol 4, 2001

## Appendix A – Detailed System Costs

Number of items	Module	price/part excl. VAT (SEK)	tot price excl. VAT (SEK)	tot price (EUR)
<b><u>WLAN card</u></b>				
1	Orinoco Combocard Gold 802.11a/b Card-bus	650,00	<b><u>650,00</u></b>	<b><u>71,50</u></b>
<b><u>Web Cam/Microphone</u></b>				
1	Philips Toucam Fun II 30FPS 800x600 Pix Mic USB	550,00	<b><u>550,00</u></b>	<b><u>60,50</u></b>
<b><u>Ultrasonic Sensors</u></b>				
Sensor card:				
14	Polaroid 40LT10 part no. 626997	68,00	952,00	104,72
2	Receivers	56,00	112,00	12,32
	Total Sensor card		1 064,00	117,04
<b><u>Control card:</u></b>				
1	ADC	108,00	108,00	11,88
2	Transistor	13,80	27,60	3,04
1	Op Amp	10,20	10,20	1,12
1	Op Amp	5,32	5,32	0,59
1	AVR	55,80	55,80	6,14
2	Plug 4/4	14,60	29,20	3,21
4	Shift register	32,40	129,60	14,26

1	DC/DC converter	350,00	350,00	38,50
1	Oscillator	74,30	74,30	8,17
1	AVR CAN	151,00	151,00	16,61
1	CAN interface	33,40	33,40	3,67
1	Circuit board	200,00	200,00	22,00
	Total Control card		1 174,42	129,19

**CAN-card:**

1	CAN controller	20,00	20,00	2,20
2	Optocoupler	44,80	89,60	9,86
1	CAN transceiver	33,40	33,40	3,67
1	Reset circuit	24,80	24,80	2,73
1	AVR Microcontroller	165,00	165,00	18,15
1	RS-232 sender/receiver	23,30	23,30	2,56
1	Circuit board	100,00	100,00	
	Total CAN-card		456,10	50,17

**DSP-card:**

1	ADSP-21065L SHARC, EZ-LAB	2 500,00	2 500,00	275,00
	Total Ultrasonic		<b><u>5 194,52</u></b>	<b><u>571,40</u></b>

**IR**

CAN-card:

1	AVR Microcontroller	185,00	185,00	20,35
1	CAN controller	20,00	20,00	2,20
1	CAN transceiver	33,40	33,40	3,67

1	Reset circuit	24,80	24,80	2,73
2	Optocoupler	44,80	89,60	9,86
8	SHARP IR sensor	44,25	354,00	38,94
	Total IR		<b><u>706,80</u></b>	<b><u>77,75</u></b>

#### **Tires**

3	Tires	300,00	<b><u>900,00</u></b>	<b><u>99,00</u></b>
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#### **Motors**

2	DC-motor	1 200,00	2 400,00	264,00
2	Planetary Gear	1 065,00	2 130,00	234,30
2	Pulse sensor	410,00	820,00	90,20
2	Assembly set	36,00	72,00	7,92
	Total motors		<b><u>5 422,00</u></b>	<b><u>596,42</u></b>

#### **Chassis sheet**

1	Work + material	600,00	<b><u>600,00</u></b>	<b><u>66,00</u></b>
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#### **Motor sockets**

1	Work + material	800,00	<b><u>800,00</u></b>	<b><u>88,00</u></b>
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**Batteries**

2	Batteries	861,00	<b><u>1 722,00</u></b>	<b><u>189,42</u></b>
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**Battery charger**

1	Charger	2 000,00	<b><u>2 000,00</u></b>	<b><u>220,00</u></b>
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**Battery sockets**

2	Holds	100,00	<b><u>200,00</u></b>	<b><u>22,00</u></b>
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**Pyro-electric sensor**

2	Operational amplifier	5,82	11,64	1,28
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2	Rail-to-rail op	7,72	15,44	1,70
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2	Pyroelectric IR-sensor (Nippon Ceramic)	49,90	99,80	10,98
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2	Fresnel lens (Nippon Ceramic)	45,60	91,20	10,03
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2	Stepper motor driver (Allegro)	45,30	90,60	9,97
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1	Stepper motor	512,00	512,00	56,32
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	Total Pyro		<b><u>820,68</u></b>	<b><u>90,27</u></b>
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**RFC-CAN cards**

3	Cards	312,50	937,50	103,13
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1	Extras	500,00	500,00	55,00
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	Total RFC-CAN		<b><u>1 437,50</u></b>	<b><u>158,13</u></b>
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**CPU (sponsored prices)**

1	Hectronic H6023 PC/104 motherboard	2 547,00	2 547,00	280,17
1	SODIMM 128MB	448,00	448,00	49,28
1	CompactFlash 128MB	409,00	409,00	44,99
1	Hectronic H7006 CAN-card PC/104	350,00	350,00	38,50
1	Hectronic H4008 PCMCIA-reader PC/104	738,00	738,00	81,18
1	Cables	300,00	300,00	33,00
1	Assembly – testing	150,00	150,00	16,50

Total CPU **4 942,00** **543,62**

**TOTAL SYSTEM COST** **25489,40** **2 803,83**