RoboCupRescue - Robot League Team RescueRobots Freiburg (Germany)

Alexander Kleiner, Bastian Steder, Christian Dornhege, Daniel Meyer-Delius, Johann Prediger, Joerg Stueckler, Kolja Glogowski, Markus Thurner, Mathias Luber, Michael Schnell, Rainer Kuemmerle, Timothy Burk, Tobias Bräuer, and Bernherd Nebel

Institut für Informatik,
Universität Freiburg, 79110 Freiburg, Germany
http://www.informatik.uni-freiburg.de/∼rrobots

Abstract. This paper describes the approach of the *RescueRobots Freiburg* team. RescueRobots Freiburg is a team of students from the university of Freiburg, that originates from the former CS Freiburg team (RoboCupSoccer) and the ResQ Freiburg team (RoboCupRescue Simulation).
Due to the high versatility of the RoboCupRescue competition we tackle the three arenas by a a twofold approach: On the one hand we want to introduce robust vehicles that can safely be teleoperated through rubble and building debris while constructing three-dimensional maps of the environment. On the other hand we want to introduce a team of autonomous robots that quickly explore a large terrain while building a two-dimensional map. This two solutions are particularly well-suited for the red and yellow arena, respectively. Our solution for the orange arena will finally be decided between these two, depending on the capabilities of both approaches at the venue.
In this paper, we introduce some preliminary results that we achieved so far from map building, localization, and autonomous victim identification. Furthermore we introduce a custom made 3D Laser Range Finder (LRF) and a novel mechanism for the active distribution of RFID tags.

1 Introduction

RescueRobots Freiburg is a team of students from the university of Freiburg. The team originates from the former CS Freiburg team[6], which won three times the RoboCup world championship in the RoboCupSoccer F2000 league, and the ResQ Freiburg team[2], which won the last RoboCup world championship in the RoboCupRescue Simulation league. The team approach proposed in this paper is based on experiences gathered at RoboCup during the last six years.

Due to the high versatility of the RoboCupRescue competition we tackle the three arenas by a twofold approach: On the one hand we want to introduce a vehicle that can safely be teleoperated through rubble and building debris while constructing three-dimensional maps of the environment. On the other hand we want to introduce an autonomous team of robots that quickly explore a large terrain while building a two-dimensional map. This two solutions are particularly well-suited for the red and yellow arena, respectively. Our solution for the orange arena will finally be decided between these two, depending on the capabilities of both approaches at the venue.

1.1 Teleoperated 3D mapping (large robots)

We suppose that the orange and red arenas are only passable by making use of 3D sensors. Hence we decided to deploy large robots that are able to carry heavier sensors, such as a 3D Laser Range Finder (LRF). and are able of driving on steep ramps and rubble.

The robots are teleoperated by an operator that also has to create a map of the environment and to augment this map with locations of victims that are detected during navigation. Mapping and victim detection has to be assisted by the system as good as possible, since the navigation task of the operator is challenging on its own. Hence the system is designed to suggest plausible locations for scanning the environment with the 3D LRF, as well as to detect various evidences for the presence of victims, such as motion and heat, and indicate those to the operator.

1.2 Autonomous exploration of a team of robots (small robots)

We suppose that the yellow arena will be large and driveable by a team of small robots. The ”office-environment-style” of the yellow arena makes mapping comparable simple since 2D sensors suffice. Therefore we intend to deploy fast and agile robots that communicate with each other. Our idea is to simplify the 2D mapping problem by RFID tags that our robots distribute with a newly developed tag-deploy-device, as described in Section 10. In general, this has mainly two advantages for Urban Search and Rescue (USAR): Firstly, RFID tags provide a world-wide unique number that can be read from distances up to a few meters. To detect these tags and thus to uniquely identify locations, is significantly computational cheaper and less ambiguous than identifying locations from camera images and range data[1]. Secondly, travel paths to victims can directly be passed to human ambulance teams as complete plans that consist of RFID tag locations and walking directions. In fact, tags can be considered as signposts since the map provides for each tag the appropriate direction. Given a plan of tags, ambulance teams could find a victim by directly following tags, which is much more efficient than finding a path from a map. However, in order of being in one line with the rules, our team will also deliver hard copies of printed maps.

2 Team Members and Contributions

- Team Leader: Alexander Kleiner
- Simulation and Behaviors: Christian Dornhege
- 2D Sensors and Localization: Johann Prediger
- 3D Mapping and Localization: Tobias Braeuer
- Controller Design: Johann Prediger, Joerg Stueckler
- Mechanical Design: Mathias Luber
- Victim Identification: Daniel Meyer-Delius, Daniel Hoefler, Markus Thurner, Timothy Burk

[1] Note that even for humans the unique identification of a location is hard, when for example exploring a large office building

– Teleoperation: Bastian Steder, Kolja Glogowski, Rainer Kuemmerle, Michael Schnell
– Advisor: Bernhard Nebel

These are all team members that contributed to the approaches introduced in this paper. The team which will finally be present at the venue is not decided by now, however, will consist of any subset from the upper list.

3 Operator Station Set-up and Break-Down (10 minutes)

Our robots are controlled from a lightweight laptop via a force-feedback joystick which all can be transported together in a backpack. It is possible for the operator to select between different robots as well as between different views/cameras from a single robot on the fly.

Our largest robot can be transported by a moveable case with wheels, whereas the small robots can even be backpacked. The whole setup and breakdown procedure can be accomplished within less than ten minutes, including to boot the computers, to check the network connection, and to check whether all sensors work properly.

4 Communications

Autonomous as well as teleoperated vehicles are communicating via wireless LAN. We use a D-Link DI-774 access point that is capable to operate in the 5GHz as well as in the 2.4GHz band. All communications are based on the Inter Process Communication (IPC) framework which has been developed by Reid Simmons [3]. The simultaneous transmission of multiple digital video streams is carried out by an error-tolerant protocol, which we developed based on the IPC framework.

Moreover, the small robots are equipped with radio modules that operate in the European 433MHz band with 10mW. This low-bandwidth communication is intended as a backup solution for short-range communication in case the wireless communication fails.

5 Control Method and Human-Robot Interface

The overall goal of our team is to build autonomous robots. We believe that this goal can possibly be achieved for the yellow arena, however quite unlikely for the red arena. Therefore our control approach is twofold: teleoperation in the red arena (large robots) and autonomous operation in the yellow arena (team of small robots) and a combination of both in the orange arena.

Teleoperation is carried out with a force-feedback joystick which is connected to a portable Laptop (see figure 1(b)). Besides images from the cameras mounted on the robot, the operator receives readings from other sensors, such as range readings from a LRF, compass measurements, and the battery state of the robot. Data from the LRF is used to simplify the operator's task of avoiding obstacles. The 3D force-feedback joystick indicates accurately the directions of incoming obstacle. This is carried out by

(a) (b)

Fig. 1. (a) The teleoperation window: range readings from a LRF (lower left corner), compass measurements (upper edge) , and the view of the surrounding area from an omni-directional camera (lower right corner) are overlayed onto the front view. (b) Force Feedback controller

applying a small force on the joystick that points into the opposite direction in which obstacles are detected. This feature makes it intuitively harder for the operator to drive into obstacles.

The Graphical User Interface (GUI) is realized by a similar approach as proposed by the RoBrno team at RoboCup 2003[7]. Images from video cameras are shown in full size on the screen and additional sensor information is overlayed via a Head Up Display (HUD). The operator might change the kind of information and the transparency (alpha value) of the displayed information via the joystick.

We designed a special omni-directional vision system that provides a complete view of the robot's surroundings. This is particularly important for the operator to avoid obstacle collisions while operating through narrow passages. Besides the omni-directional view, the operator can select between a rear-view and front-view camera. It is possible to select one camera as "active" camera. Images from the active camera are shown in full-screen to the operator, whereas images from all other cameras are sized-down and displayed as an smaller overlays on the screen (see figure 1 (a)).

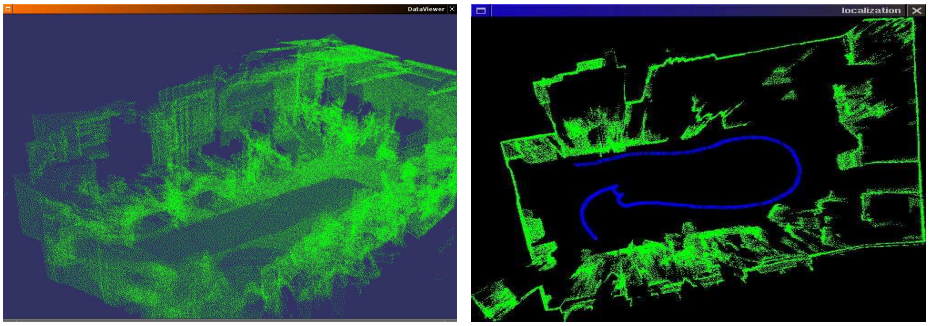
Besides teleoperation, the operator has to construct a map of the arena. Optimally, map generation takes place automatically in the background and the operator has not to care about. However, since 3D scanning needs time, the operator has at least to initiate this process manually in order not to be disturbed while navigating. Our system indicates good locations for taking 3D scans to the operator and displays the result of the matching process on the screen. At any time, the operator is able to access the current 3D model of the environment. This is helpful if, for example, lighting conditions are bad. Additionally, the resulting map can also be used by a path planning algorithm for recommending an optimal path to the operator's current destination.

Autonomous control of robots is one of the most challenging goals in robotics, which we are planning to achieve at least in the yellow arena. For this purpose we

are going to utilize techniques that we have already applied successfully in the *F2000* league [6]. However, the autonomous control of robots in RoboCupRescue requires a very detailed world model in 2D, or even in 3D if approaching the orange arena. In the orange arena, conventional control methods for autonomous robots might fail since they are tailored for operation in the plane with specific ground properties (e.g. a soccer field). Hence we are currently working on control methods that can be executed with respect to different conditions of the ground.

6 Map generation/printing

Our team develops simultaneously two different approaches for mapping and localization. The choice for two localization approaches is due to the versatility of rescue arenas: The yellow arena has to be explored and mapped as fast as possible, likewise in 2D, whereas the orange and red arena can only be mapped by making use of 3D sensors. Hence we plan to deploy fast and numerous robots for autonomous 2D exploration and a larger one, equipped with a 3D scanner, for the automatic, operator assisted generation of maps.



(a) (b)

Fig. 2. A 3D map generated from various scans in our lab (a). A 2D Map generated from the 3D map (b). The location of the robot while mapping is shown by a blue trajectory.

On the one hand, we are working on an automatic map generation software that processes data from a 3D LRF based on the ICP scan registration method that recently has been proposed by the *Kurt3D* team[4] to the rescue league. Therefore, we constructed a new system for taking 3D scans, which is described in Section 7. A preliminary result of the successful registration by the ICP method of 3D scans taken in our Lab is shown in figure 2 (a) and a 2D localization within this map is shown in figure 2 (b).

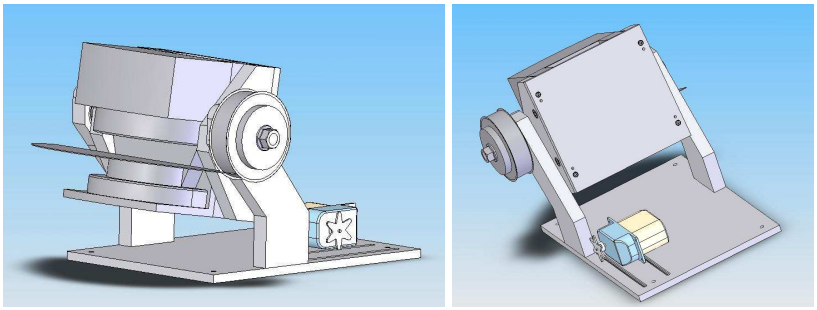
On the other hand we are working on a method for the autonomous multi-robot mapping supported by the active distribution of RFID tags. For this purpose we constructed a special aperture, further described in Section 10, that can be triggered to release tiny RFID tag into the environment. Tags are detectable by a RFID reader that can be mounted on any robot. The deployment of tags, the sensing of environmental structure, the absolute orientation and odometry, and evidence of victim whereabouts are communicated between the robots. From this information, each robot is able to integrate a world model, which is consistent with those of the other robots, whereas the

RFID tags, which are detectable with nearly no noise, are supporting the alignment of the individual maps build by each robot.

From the collected information a topological map emerges, which can be passed to a human operator. The topological map consists of RFID tags as vertices and navigation directions and lengths as edges. The map is augmented with structural and victim specific information. Human ambulance teams that are also equipped with a RFID tag reader might find the locations of victims more efficient than directly from a 2D/3D map, since RFID tags can be used as signposts. However, also conventional maps can be printed by our system and handed out to the human team.

7 Sensors for Navigation and Localization

As already stated in the previous section, our team has started to develop a 3D LRF device for the automatic mapping of rescue arenas. A model of the sensor can be seen in figure 3. The LRF sensor is rotated by a strong servo motor that allows a fast and accurate vertical positioning of the device. As can be seen from figure 3, the device can be rotated by more than 200 degrees. This allows to take 3D scans from the front as well as from behind the robot. The design of this system differs from the design of other 3D scanners in that it is capable of collecting sparse data from a large field of view rather than dense data from a small field of view. We believe that the sparse data collection will improve the speed of 3D mapping and the larger field of view will lead to a larger overlap of scan points, which in turn, will increase the robustness of the scan registration process. Robust scan registration is the basis for autonomous[2] mapping.

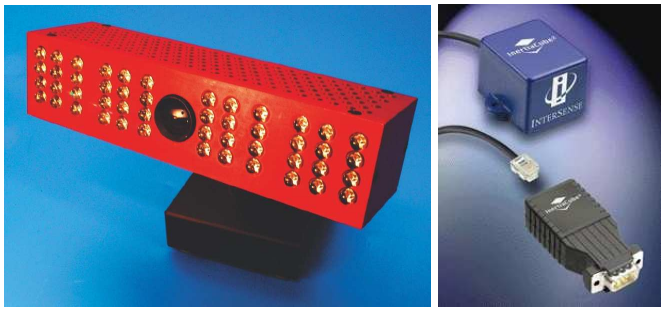


(a) (b)

Fig. 3. A hand-made 3D Laser Range Finder (LRF) device, shown from the front (a), and shown from the back (b).

Also the autonomous exploration of robots requires an accurate modeling of the environment. In RoboCupRescue this environment is three-dimensional and thus requires highly developed sensors for the navigation tasks. As can be seen in figure 7(a), Section 9, our base for autonomous operation is equipped with 9 infrared and 3 ultrasonic sensors. Furthermore, we added a compass, an acceleration sensor, and two wheel-encoders for counting the revolution of each wheel.

[2] Note that we distinguish *automatic mapping* from *autonomous mapping* in that the latter also includes the task of autonomous navigation



(a) (b)

Fig. 4. The 3D camera "SwissRanger" from CSEM (a), and the accurate orientation sensor "InertiaCube2" from InterSense (b).

These sensors provide sufficient information on the structure of 2D environments. However, in order to explore autonomously 3D environments, higher sophisticated sensors are necessary. Therefore we are planning to detect local 3D structures, such as ramps and stairs, with a 3D camera (see figure 4 (a)), and to track reliably the 3D orientation (yaw, roll and pitch) of the robot with a 3DOF sensor from InterSense (see figure 4 (b)).

8 Sensors for Victim Identification

Victim identification is crucial for both autonomous operation and teleoperation. The latter can be simplified by augmenting video streams with useful information gathered by image processing techniques or sensors that detect motion, heat, or CO_2 emission.

We utilized the Eltec 442-3 pyroelectric sensor to detect the motion of victims. This sensor can measure changes of the infrared radiation over time. Therefore the sensor has to be in motion in order to detect heat sources. For that purpose we mount the sensor on a servo which allows a rotation of nearly 180 degrees. Due to the high thermal sensitivity of the sensor, changes of the background radiation are detected as well, which lead to a noise contaminated signal. In order to separate the useful signal from noise, some filtering techniques are used. Preliminary tests have shown that it is possible to safely detect human bodies within a distance of four meters.

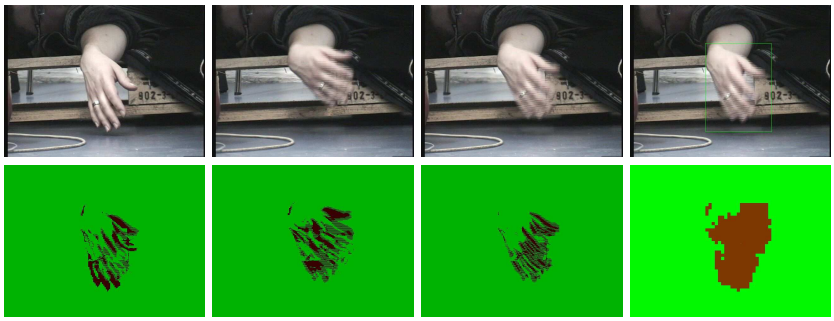


Fig. 5. Series of pictures that demonstrates motion detection based on noise reduced difference images.

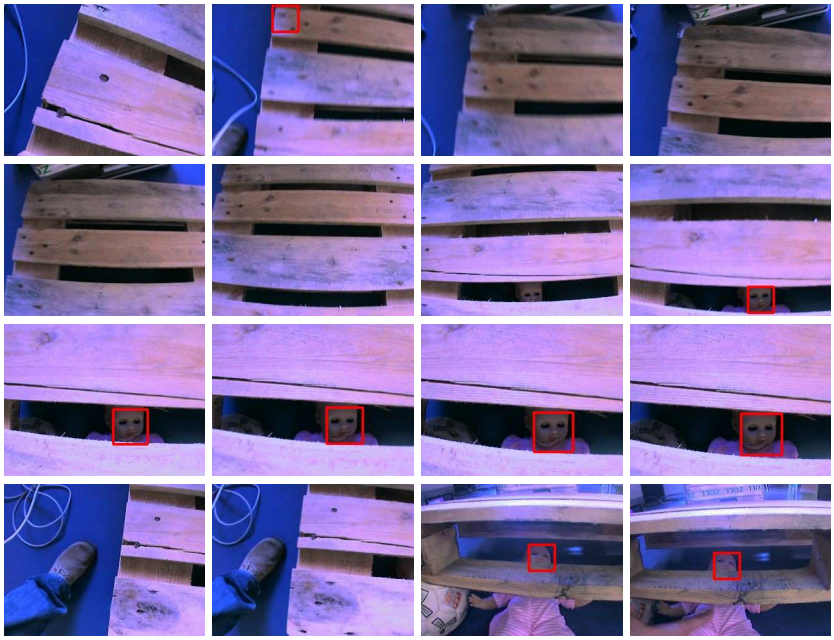


Fig. 6. Series of pictures that demonstrates victim face detection based on ADABoost with simple features.

Moreover, we examine image processing techniques for victim detection. In contrast to the RoboCupSoccer domain, there is no color coding within RoboCupRescue. This means that image processing algorithms have to be capable of dealing with the full color space, rather than with a small subset of pre-defined colors, such as for example, the ball color and the field color.

We utilized a fast approach for detecting motion within video streams which is based on the analysis of differences between subsequent images. After filtering the difference information from noise, a clustering is calculated that is used for estimating the probability of human motion. The whole process is shown by the image series in figure 5.

Besides motion, victims can also be detected from single video images by their faces or fingers. Although this detection is hard under varying illumination conditions and different view angles, a recent approach, originally introduced by Viola and colleagues [5], produces also in the rescue domain promising results, as can be seen in figure 6. This approach combines the classification results of multiple, simple classifiers by ADA boosting[1], which is contrary to former approaches that favored one complex model for the classification.

9 Robot Locomotion

Locomotion is carried out by three different robot platforms (not necessarily one for each arena). In figure 7 all robots that will be deployed are shown. Figure 7(a) shows a fast and agile robot that will be used for the autonomous team exploration. Figure 7(b) shows a larger robot that is equipped with a LRF for mapping and obstacle avoidance,

(a) (b) (c)

Fig. 7. Three of our robots: (a) an autonomous and agile robot, (b) a teleoperated, large robot that can drive ramps, (c) a teleoperated, large robot that can drive on rubble.

and multiple cameras in order to provide a good overview to the operator. Figure 7(c) shows a toy-robot that is capable of climbing a pallet as shown in the figure. The latter two robots are supposed to be controlled by an operator.

10 Other Mechanisms

Figure 8 shows the prototype of a novel mechanism for the active distribution of RFID tags. The mechanism can easily be mounted on a robot or a R/C car and can be triggered by setting the appropriate angles of a servo motor. The servo motor opens a small opening that releases a $1.3cmx1.3cm$ small chip, carrying the RFID tag. The chip can be detected by a RFID tag reader that has to be mounted on the vehicle. Since the tags are transported on the robot within a metal box, they are only detectable after being released. By this it can be guaranteed that a tag has been released by the mechanism successfully. The shown device is capable of holding 50 tags, which we plan to improve towards a capacity of 100. Tags once deployed by robots can easily be collected by a vacuum cleaner.

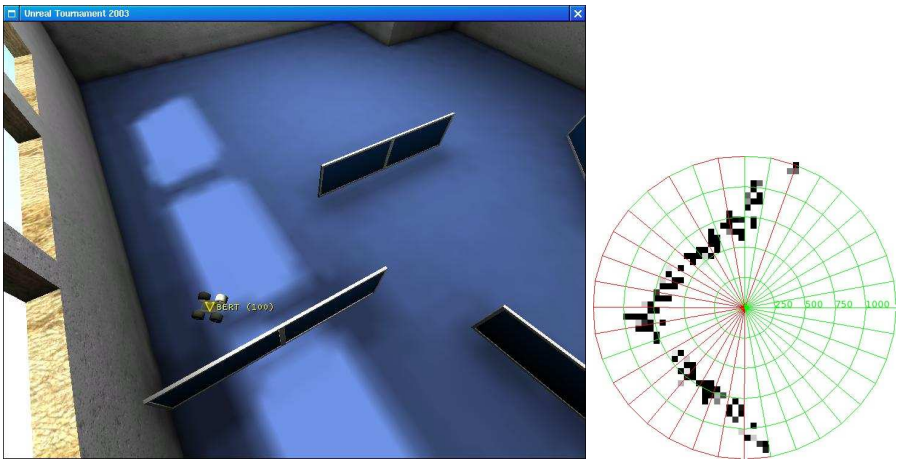
(a) (b) (c)

Fig. 8. A novel mechanism (a) for the active distribution of RFID tags (b). The mechanism in action while mounted on a R/C car (c).

11 Team Training for Operation (Human Factors)

The teleoperation of rescue robots requires a long period of training, since communication delays but also the restricted field of view have to be learned by the operator. We plan to perform regular competitions between our team members in order to determine the person most suitable for teleoperation. Competing members will have to build challenging arenas in order to make the current operators task more difficult.

Furthermore, a large amount of practicing is necessary for training a team of autonomous robots. Since this is a very tedious task, we decided to utilized the USARSim simulation system, which is based on the Unreal2003 game engine (see figure 9(a)). The simulation of the robots is crucial in order to speed-up the development of multi-agent behaviors as well as providing data for learning approaches. Figure 9(b) shows an occupancy grid and Vector Field Histogram (VFH) of one of our robots simulated in the yellow arena.



(a) (b)

Fig. 9. Robot simulation with USARSim, based on the Unreal2003 game engine (a) and the corresponding Vector Field Histogram (VFH) for obstacle avoidance (b).

12 Possibilities for Practical Application to Real Disaster Site

Our team has no experience with any practical application in the context of real disaster sites. Anyway, we are confident that some of the techniques utilized by our team are likely helpful for supporting real rescue teams.

A mobile device for the automatic generation of 3D maps might be very helpful if, for example, rescue teams have to decide optimal locations for starting excavations. The generated maps could also be used for providing a better view of the situation in the field to an outside operator/instructor.

Our approach of autonomous exploration with RFID tags might be very helpful in case the disaster site is large and little blocked with rubble, such as the yellow arena.

Since our robots are small and cheap, they can be a real benefit to an human team that could focus more on victim healing and transport.

13 System Cost

Generally, our philosophy is to provide solutions that are good as possible but also cheap as possible. Hence some of our robots are based on R/C cars that can be bought for less than 100 USD. The following three tables list the approximate costs of each robot type. A detailed description of each robot part that we use, is found in the appendix.

Name	Part	Price in USD	Number	Price Total in USD
Robot Base		50	1	50
Micro Controller	MC9S12DG256	120	1	120
IR Sensor	GP2D12	12	9	108
Sonic Sensor	SRF08	53	3	159
Compass Sensor	CMPS03	53	1	53
Flex Sensor FLEXS		18	2	36
Pyroelectric Sensor	R3-PYRO01	64	1	64
Odometry Sensor	R238-WW01-KIT	60	1	60
Acceleration Sensor	ADXL202	100	1	100
Radio Modul ER400TRS		45	1	45
WLAN Adapter	ADL-AG650	77	1	77
CPU Board	speedMOPSlcdCE	390	1	390
RFID Reader Medio S002		370	1	370
Sum:			1	1582
Sum Total:			3	**4746**

Table 1. Costs for *Team of small robots*.

Name	Part	Price in USD	Number	Price Total in USD
Robot Base	Pioneer II	4000	1	4000
FireWire Camera	Sony DFW-V500	1000	4	4000
FireWire HUB		60	1	60
LRF LMS200		4000	1	4000
LRF 3D Extension		500	1	500
Laptop	MP-XP731DE	1900	1	1900
Sum Total:			3	**14460**

Table 2. Costs for *Large Robot I*.

Name	Part	Price in USD	Number	Price Total in USD
Robot Base	Tarantula	99	1	99
FireWire Camera	Sony DFW-V500	1000	2	2000
FireWire HUB		60	1	60
Laptop	MP-XP731DE	1900	1	1900
Sum Total:			3	**4059**

Table 3. Costs for *Large Robot II*.

References

1. Y. Freund and R. E. Schapire. Experiments with a new boosting algorithm. In *International Conference on Machine Learning*, pages 148–156, 1996.
2. A. Kleiner, M. Brenner, T. Braeuer, C. Dornhege, M. Goebelbecker, M. Luber, J. Prediger, J. Stueckler, and B. Nebel. Successful search and rescue in simulated disaster areas. In *Proc. Int. RoboCup Symposium '05*. Osaka, Japan, 2005. submitted.
3. Reid Simmons. `http://www-2.cs.cmu.edu/afs/cs/project/TCA/www/ipc/ipc.html`, 1997.
4. H. Surmann, A. Nuechter, and J. Hertzberg. An autonomous mobile robot with a 3d laser range finder for 3d exploration and digitalization of indoor environments. *Journal Robotics and Autonomous Systems*, 45(3-4):181–198, 2003.
5. P. Viola and M. Jones. Robust real-time object detection. *International Journal of Computer Vision*, 2002.
6. T. Weigel, J.-S. Gutmann, M. Dietl, A. Kleiner, and B. Nebel. CS-Freiburg: Coordinating robots for successful soccer playing. *IEEE Transactions on Robotics and Automation*, 18(5):685–699, 2002.
7. L. Zalud. Orpheus - universal reconnaissance teleoperated robot. In *Proc. Int. RoboCup Symposium '04*. Lisboa, Portugal, 2004. To appear.

14 Appendix

NUMBER: 1
KEY PART NAME: MC9S12DG256
PART NUMBER: CARDS12DG256
MANUFACTURER: Elektronik Laden
COST: 120 USD
WEBSITE: http://www.elektronikladen.de/cards12.html
DESCRIPTION: Micro Controller mit 256KB Flash, 4KB EEPROM, 12KB RAM

NUMBER: 2
KEY PART NAME: IR Sensor
PART NUMBER: GP2D12
MANUFACTURER: Sharp
COST: 12 USD
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: IR Sensor

NUMBER: 3
KEY PART NAME: Ultra Sonic Sensor
PART NUMBER: SRF08
MANUFACTURER:
COST: 53 USD
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: Ultra Sonic Sensor

NUMBER: 4
KEY PART NAME: Compass modul
PART NUMBER: CMPS03
MANUFACTURER:
COST: 48 USD
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: Compass

NUMBER: 5
KEY PART NAME: Flexsensor Age Inc.
PART NUMBER: FLEXS
MANUFACTURER:
COST: 18
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: Sensor that detects deformation

NUMBER: 6
KEY PART NAME: Pyroelectric sensor package
PART NUMBER: R3-PYRO1
MANUFACTURER: Acroname
COST: 64 USD
WEBSITE: http://www.acroname.com/robotics/parts/R3-PYRO1.html
DESCRIPTION: Sensor that detects human motion

NUMBER: 7
KEY PART NAME: Odometry
KEY PART NAME: Two Wheel Servo Encoder Kit
PART NUMBER: R238-WW01-KIT
MANUFACTURER: Acroname
COST: 60 USD
WEBSITE: http://www.acroname.com/robotics/parts/R238-WW01-KIT.html
DESCRIPTION: Sensor that counts wheel revolution

NUMBER: 8
KEY PART NAME: Acceleration Sensor

PART NUMBER: ADXL202
MANUFACTURER: Analog Devices
COST: 100 USD
WEBSITE: http://www.analog.com/library/analogDialogue/archives/35-04/ADXL202/
DESCRIPTION: Sensor that detects acceleration and tilt into two direction

NUMBER: 9
KEY PART NAME: Radio modul 433MHz - LPRS
PART NUMBER: ER400TRS
MANUFACTURER: Easy Radio
COST: 45 USD
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: Modul for radio transmission of RS232 signals

NUMBER: 10
KEY PART NAME: Robot Base
PART NUMBER:
MANUFACTURER:
COST: 50 USD
WEBSITE:
DESCRIPTION: Differential drive toy robot

NUMBER: 11
KEY PART NAME: DWL-AG650
PART NUMBER:
MANUFACTURER: D-Link
COST: 77 USD
WEBSITE: http://www.dlink.de
DESCRIPTION: IEEE 802.11a/b/g PCMCIA Card

NUMBER: 12
KEY PART NAME: DI-774
PART NUMBER:
MANUFACTURER: D-Link
COST: 160 USD
WEBSITE: http://www.dlink.de
DESCRIPTION: IEEE 802.11a/b/g Access Point

NUMBER: 13
KEY PART NAME: CPU Board
PART NUMBER: speedMOPSlcdCE
MANUFACTURER: Kontron
COST: 390 USD
WEBSITE: http://www.kontron.de
DESCRIPTION: PC104 733MHz Board, runs under Linux

NUMBER: 14
KEY PART NAME: RFID Reader
PART NUMBER: Medio S002
MANUFACTURER: Ades
COST: 370 USD
WEBSITE: http://www.ades.ch
DESCRIPTION: Universal RFID Reader

NUMBER: 15
KEY PART NAME: InertiaCube2
PART NUMBER:
MANUFACTURER: InterSense
COST: ca. 1800 USD
WEBSITE: http://www.roboter-teile.de
DESCRIPTION: Modul for radio transmission of RS232 signals

NUMBER: 16
KEY PART NAME: FireWire Camera
PART NUMBER: Sony DFW-V500
MANUFACTURER: Sony
COST: 1000 USD
WEBSITE: http://www.ccddirect.com/online-store/scstore/p-114100.html
DESCRIPTION: Sony FireWire Camera

NUMBER: 17
KEY PART NAME: FireWire HUB
PART NUMBER: IEEE 1394 6-PORT REPEATER
MANUFACTURER:
COST: 60 USD
WEBSITE: www.conrad.de
DESCRIPTION: FireWire HUB

NUMBER: 18
KEY PART NAME: 3D Camera
PART NUMBER: SwissRanger
MANUFACTURER: CSEM
COST: ca. 7000 USD
WEBSITE: http://www.swissranger.ch
DESCRIPTION: 3D Camera

NUMBER: 19
KEY PART NAME: Robot Base
PART NUMBER: Pioneer II
MANUFACTURER: ActiveMedia

COST: ca. 4000 USD
WEBSITE: http://www.activmedia.com
DESCRIPTION: Robot Platform

NUMBER: 20
KEY PART NAME: Robot Base
PART NUMBER: Tarantula Toy Robot
MANUFACTURER:
COST: 99 USD
WEBSITE: http://www.amazon.com
DESCRIPTION: Robot Platform

NUMBER: 21
KEY PART NAME: LRF
PART NUMBER: LMS 200
MANUFACTURER: Sick
COST: 4000 USD
WEBSITE: http://www.sick.de
DESCRIPTION: Laser Range Finder

NUMBER: 22
KEY PART NAME: LRF 3D Extension
PART NUMBER:
MANUFACTURER: Uni Freiburg
COST: ca. 800 USD
WEBSITE:
DESCRIPTION: Device for rotating a LRF

NUMBER: 23
KEY PART NAME: JVC Laptop
PART NUMBER: MP-XP731DE
MANUFACTURER: JVC
COST: 1900 USD
WEBSITE:
DESCRIPTION: Laptop