RoboCupRescue - Robot League Team
IUB Rescue, Germany

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Abstract. This paper describes the IUB rescue robot team 2004. The team is active since 2001 and it has competed in RoboCup 2002 in Fukuoka and RoboCup 2003 in Padua. The robots are semi-autonomous mobile robots providing streams of video and other essential data via wireless connections to human operated base-stations. In doing so, the autonomous functionalities enable a single operator to guide a set of robots working in parallel. All components of the robots, ranging from mechanics over computational hardware to all software levels have been to a large extent custom designed for the difficult task of rescue missions. Special highlights of the autonomous functionalities of the robots are localization and mapping in the unstructured environment of the rescue domain.

1 Introduction

IUB robotics is actively working in the domain of rescue robots since 2001. The team has already participated in RoboCup 2002 in Fukuoka and RoboCup 2003 in Padua [BCK04,BKR^{+}02]. The team ended on both occasions on a 4th place in the ranking. Furthermore, the team won in 2003 a technical award for its mapping capabilities [CKB04].

The IUB robots are based on complete in-house designs, ranging from the mechanics over sensors and actuators to the software level. This allows to optimize the designs for the particular tasks of rescue operations. The two main new types of rescue robots are the so-called papa- and mother-goose robots. These nicknames are derived from the fact that they can cooperate with a set of small autonomous robots called the ducklings.

The robots are based on the so-called CubeSystem designed for fast prototyping of robotic systems [BKS02,BKW00]. The center of the CubeSystem is the so-called RoboCube controller hardware [BKW98] based on the MC68332 processor. This ”universal” controller board with CPU, Memory and Flash, is supplemented by so-called base-boards to adapt the final architecture to the particular task, e.g., by incorporating power electronics that fit the ratings of the motors used in the robot. On the software side, the CubeSystem features a special operating system, the CubeOS [Ken00]. The CubeOS ranges from a micro-kernel over drivers to special high-level languages like the process description language PDL [Ste92]. For the data transfers between the robots and the operator station, we developed FAST-Robots (Framework Architecture

Fig. 1. Mother and papa goose entering the orange arena at the RoboCup 2003 competition.

for Selfcontrolled and Teleoperated Robots). FAST is an object-oriented network control architecture framework for robotics experiments in general [KCP+03]. It supports mixed teleoperation and autonomy [BK02]. Its features are the abstraction from the underlying communication system and its simplicity and flexibility towards modification and extension.

2 Team Members and Their Contributions

- Andreas Birk: Team Leader
- Stefano Carpin: Map Building and Localization
- Holger Kenn: Robot and System Programming
- Martijn Rooker: Adjustable Autonomy
- Viktoras Jucikas: Sensor Integration
- Danish Sheikh: Robot Mechatronics
- Max Pfingsthorn: User Interface

3 Operator Station Set-up and Break-Down

The IUB operators station is a highly integrated system. The GUI of the station is optimized to support adjustable autonomy in a dynamic way. In doing so, the information flow is modulated to minimize the amount of screen space while maximizing the utility of the data supplied to the operator. The necessary operator's console can hence be based on a laptop integrated in a rugged box, which hosts all interfaces and network equipment. The robots are also deployed from rugged boxes with integrated interfaces to the operators station.

4 Communications

Communications between the robots and to the operator's station is based on an adhoc network. The main physical backbone is based on glassfiber cables deployed by the robots. Furthermore, RF-LAN based on 802.11A is used as fallback in situations where the tethered solution has to be discarded. For short distance communications to the ducklings, low power RF-modules at 928 MHz might be used, a 802.11A based solution is tested at the moment.

5 Control Method and Human-Robot Interface

A single operator controls all robots working in parallel. The large sized robots are semi-autonomous, i.e., the operator specifies small, short-term tasks like move to a target location, which are autonomously carry out. The operator is in addition assisted by autonomous functionality like map-building, identification of victims via passive infrared and in the future via machine vision. The small ducklings are fully autonomous. Once they are deployed, they explore the environment to search for victims and for map building. In case a passive IR-sensor of a duckling reports a potential body, the robot emits an acoustic signal and opens a video-transmission to the operator to rule out false positives. In addition to the localization of victims, the ducklings contribute to the construction of the map.

6 Map generation/printing

The map is computer drawn and printed. The map is based on a probabilistic occupancy grid, i.e., it shows the free space and obstacles as gray values. A hall-way for example is shown as white floor and red walls, black depicts unknown territory (figure 2).

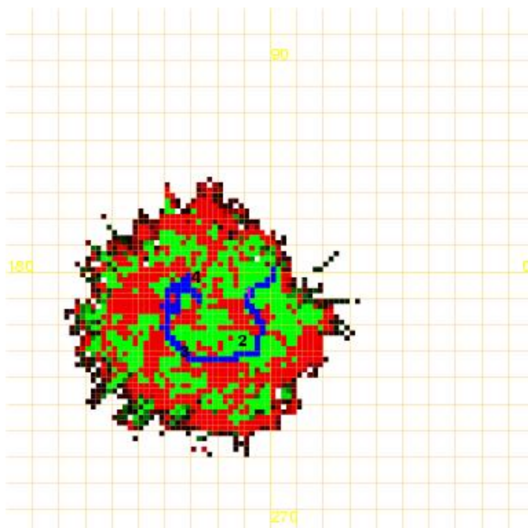

Fig. 2. A map of the arena based on data from the localization sensors and the laser scanner.

The results in respect to mapping in 2003 are described in some detail in [CKB04]. In current work, simultaneous localization and the fusion of several maps from different robots is implemented.

7 Sensors for Navigation and Localization

The robots are equipped with a low-cost laserscanner from Hokuyo Automatic, the PB9-11. It covers 162 degrees in 91 steps up to a depth of 4m. This sensor is the main tool for gathering obstacle data.

The bases are in addition equipped with several one-dimensional obstacle sensors, namely

- coarse range Ultrasound Sensors

    - from Polaroid
    - with a long range, i.e., up to 10 m, wide scan angle of 60 deg
  - high precision Ultrasound Sensors
    - from Baumer Electric
    - with a medium range, i.e., up to 7 m, narrow scan angle of 10 deg
  - active InfraRed Sensors
    - from Sharp
    - with a short range, up to 0.7 m, narrow scan angle of 10 deg

These sensors are ideal for simple control behaviors like wall-following to autonomously negotiate long corridors.

To estimate the absolute orientation of robot, two digital compasses are used. The first one is based on the Philips KMZ51 IC. It has an I2C interface and it is directly connected to the CubeSystem. The second compass is from Honeywell. Its RS232 interface is serviced by the onboard PC.

The motors of both robots are equipped with high resolution quadrature encoders from HP. The software modules of the CubeSystem not only use this data for control, but also for odometry and dead-reckoning to estimate the robot's pose. In doing so, the data from the compass is used for a leaky update of the orientation estimation via odometry. By this, the performance of dead-reckoning gets significantly improved. This can be explained by the fact that the odometry based estimation of orientation severely suffers from cumulative error and hence significantly drifts. The absolute orientation measurements of the compass compensate this drift.

8 Sensors for Victim Identification

The main sensors for victim detection are USB cameras from Philips. The cameras are high resolution with 1280x960 pixels. The main advantage of these sensors is that they are low-cost. In the standard configuration, papa goose is equipped with 4 and mother goose with 2 of these cameras.

The IUB 2003 rescue team was fortunate to use in addition a very special sensor for victim detection, namely a thermal camera. The Flir P60 thermacam has a uncooled, high resolution Focal Plane Array (FPA). Its 320x240 elements provide temperature information in a range of -40^{o}C to 120^{o}C with 0.08^{o}C resolution. The color to temperature map can be changed such that the related image highlights only spots with human body temperature. During the competition, the rented sensor turned out to be very useful as it helps to spot victims under conditions where normal visual feedback completely fail. For 2004, a Flir A20 is bought. This camera is less expensive than the P60, but it provides only resolutions of 160x120 pixels.

To detect breath, Vaisala CO_2 probes are used. The sensor requires careful data analysis, but it seems to be useful for alerting the robot of victims in its vicinity.

Last but not least, microphones are used on the robots to identify and to locate victims via sound.

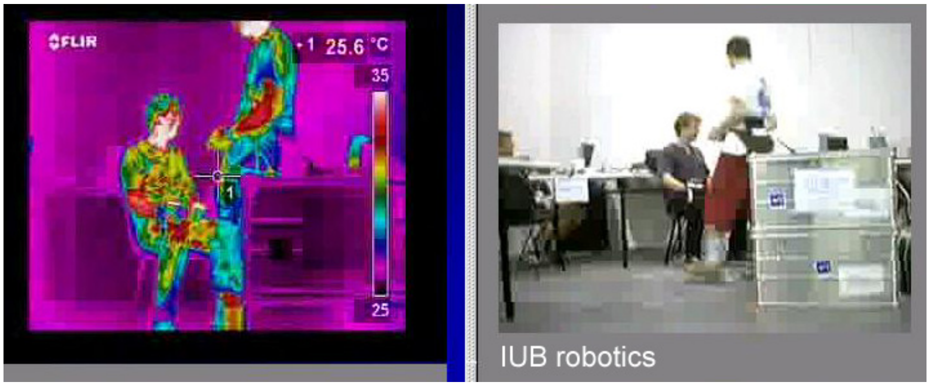

Fig. 3. A typical image from the thermal camera (left) and a normal camera (right).

9 Robot Locomotion

Papa goose is the main type of robot used in the IUB rescue robots team. It has a 6-wheeled base that is equipped with substantial onboard computation power and various sensors. Its locomotion system is an improved version of a previous designs used in the 2002 RoboCup competition in Fukuoka and 2003 in Padua. The 3 wheels of each side are driven via belts and a motor-unit connected to the axis of the rear, respectively front wheel on the left, respectively right side of the robot. The motors have 90 W power each and they are equipped with HP quadrature encoder with 500 pulses per channel.

The main design goal for mother goose was to shrink the size of the robot compared to papa goose. This mainly had consequences for the on-board PC, which has to be an embedded solution which fits the size and power constraints. Furthermore, the opportunity to explore an other locomotion system was used and a tracked drive was designed. For the 2004 competition, a completely new track version was designed which is based on significantly enlarged track-wheels.

10 Other Mechanisms

One of the robots carries a camera arm based on servos, which can be extended for overview scans or to move close to victims for inspecting them.

11 Team Training for Operation (Human Factors)

The goal of the IUB team is to get within the next two years to a status where the overall system can be launched and used by rescue workers who have undergone hardly any training for the system. Crucial issues are the turn-key start-up of the robots and an intuitive user-interface of the operator's console. For this purpose, all software components are integrated in a general framework that supports adjustable autonomy.

For testing and training purposes, a rescue arena has been set up at IUB. The arena is based on a high bay racking system. This allows to have a large floor-space and many different levels. The arena has a footprint of 5.60m by 4.70m and it is approximately 6m high. It has 3 main floors and several intermediate floors, which are interconnected.

12 Possibility for Practical Application to Real Disaster Site

As mentioned before, the goal for the IUB team is to get systems that can be used in the field within the next two years. The most crucial aspects toward this goal are ruggedness of the equipment and usability. In respect to ruggedness, a cooperation with a design company has been started to investigate the necessary steps. For usability, the according adaption and improvement of the robot programs and the user interface is already on its way. First tests in the IUB arena in cooperation with professionals from rescue organizations are planned for this year.

13 System Cost

The costs for each bare robot with control and locomotion system plus on-board PC is in the order of 8,000 Euro. The most expensive single sensor is the Flir A20 therma cam with 16,000 Euro. The standard sensor load of each robot costs in the order of 4,000 Euro. Some detailed information on components and suppliers is located at

- `http://robotics.iu-bremen.de/CubeSystem/`
- `http://robotics.iu-bremen.de/RoboWiki/`

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