A TECHNICAL SOLUTION OF A ROBOTIC E-LEARNING SYSTEM IN THE SYROTEK PROJECT

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Abstract: SyRoTek (a system for a robotic e-learning) is a robotic virtual laboratory being developed at Czech Technical University in Prague. SyRoTek provides access to real mobile robots placed in an arena with dynamically reconfigurable obstacles enabling variety of tasks in the field of mobile robotics and artificial intelligence. The robots are equipped with several sensors allowing students to realize how robots' perception works and how to deal with uncertainties of the real world. An insight to a technical solution of the SyRoTek project is presented in this paper.

1 INTRODUCTION

Having real mobile robots as an indivisible part of teaching robotics or artificial intelligence is advantageous due to their attractiveness for students. On the other hand, robots need to be continuously maintained in order to be used flawlessly. To resolve this issue and to minimize the maintenance cost, so-called virtual laboratories allowing remote access to real hardware equipment have been built in nineties. In robotics, first systems have been focused on manual tele-operation or manual goal assignment in the case of autonomous mobile robots. The further progress allows remote access to robotic actuators and sensory data and robotic hardware have been integrated into e-learning frameworks (Siegwart and Sauc, 1999; RedRover, 2006; Guimarães et al., 2003; Masár et al., 2004). This is also the case of the project *SyRoTek - System for a robotic e-learning*, which is focused on developing a virtual laboratory allowing remote access to a set of real mobile robots moving inside dedicated space called arena (Faigl et al., 2010).

In this paper, we provide an insight to the technical solution of the SyRoTek (Kulich et al., 2009), describe details of our designed robots, and an arena where the robots are placed and which allows a dynamic reconfiguration of obstacles. Students control the robots by their applications, and therefore robots and the whole system have to be robust enough to be used in a long-term without necessity of human manual interventions. Besides, a robot has to be able to autonomously navigate to the recharging station.

An overview of the SyRoTek realization is depicted in Fig. 1.

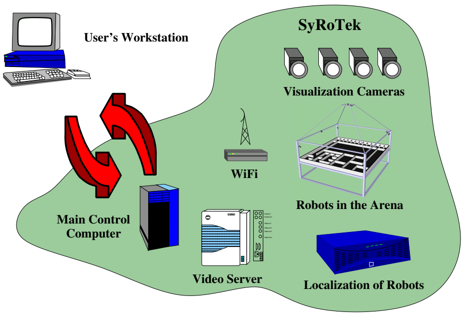

Figure 1: SyRoTek overview.

An user access to SyRoTek from his/her workstation is realized through the main control computer that is accessible from the Internet. A wireless communication infrastructure is used to connect robots with the main control computer. A visualization system with several cameras provides views to the real scene. A localization system based on a camera placed above the arena is used to estimate real position of the robots.

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The paper is organized as follows. Identified requirements steering the robot design are presented in the next section. Detailed description of the robot hardware is described in Section 3. The realization of the arena with moving obstacles, robots' docking stations and a global localization system are presented in Section 4. A remote user access to the robots is realized by the supporting computer that is directly accessible through the Internet, its role and concept of the user access to robots is briefly described in Section 5.

2 SYSTEM REQUIREMENTS

This section summarizes requirements affecting the SyRoTek system design. At first, it is worth to mention the system is designed as a multi-robotic, which requires enough available robots for collective tasks. Regarding to the expected scale of multi-robotic experiments, we have decided to create a system with 10–15 robots.

The available space about 10 m^2, restricts the maximal robot diameter to 20 cm in order to provide sufficient work area. A differential drive with two controlled wheels has been selected, offering sufficient maneuverability in narrow space. The maximal robot velocity in range 0.2–0.5 m/s is considered as sufficient.

The main goal of the SyRoTek system is to support education with real robots that will help students to realize how robots sense the environment and how to deal with uncertainties that are inevitable part of real world. In order to provide such experiences, variety of sensors are requested to be mounted at the robot body. The range-measuring sensors are the most typical sensors for basic robotic tasks. Also robot navigation based on image processing is becoming common nowadays, so a color camera has been included in the basic set of robot's sensor equipment. Rotating laser scanners (LIDARs) was selected as an optional equipment for more advanced tasks.

The sensor equipment requires appropriate computational resources that will allow simple sensory data processing on-board. A PC-compatible computer running operating system is highly desired for such tasks, as it will allow a comfortable maintenance and re-configuration.

Wireless communication device is needed onboard for transmitting sensor data, control commands, and software updates. IEEE 802.11 (WiFi) network modules allow a wide bandwidth, but their disadvantage is absence of the latency definition and eventual drop-outs in noisy environments with many wireless networks running alongside. This issue motivate us to use another communication module to control the robot, even at the cost of lower bandwidth.

The SyRoTek system is requested to run 24 hours a day with a minimal maintenance that is mainly related to autonomous robots charging. A minimal runtime for a charged robot is about two hours, which is derived from the duration of regular course lab. Many safety issues have to be solved as well, guaranteeing any part of the system cannot be damaged as a result of unexpected user action or internal failure.

3 ROBOTS

At the beginning of the SyRoTek project, several available robotic platforms were discussed whether they are applicable and meet identified requirements of the project needs. Many robots were rejected due to their size over 20 cm in diameter. Smaller robots mostly did not meet desired sensor equipment or had very poor options for extensions.

The most critical feature considered in the platforms evaluation is mechanism of the robot charging. All available robots considered are recharged with human attendance that would result in the need to adjust robot for automatic recharge. Considering the amount of necessary modifications of the considered robots in combination with its price, we have decided to design and manufacture a robot to serve our needs. The developed S1R robot is described in this section.

The most important component of the robot, influencing its design, are batteries and motors. Lithium-Polymer rechargeable cells were selected for the best trade-off between capacity and size. Required operation time on batteries results in need of about 50 Wh battery capacity. Monitoring of each cell individually is necessary during the charging of the lithium based battery, therefore a charger circuit has been embedded into the robot body.

Two Faulhaber 2224 motors with integrated gearbox and IRC encoder have been selected to meet the required differential kinematics. Two driven wheels are mounted directly to the motor gearbox axes. Outer casing of the chassis is a bumper of octagonal shape with rounded corners, as shown in Fig. 2.

On the top of the chassis, electronic modules are mounted. Three main electronic boards are

- power control and charger board (*power board*),
- motor control and sensor data acquisition board (*control board*) and
- on-board computer interface board with on-board computer (*OBC*) mounted on.

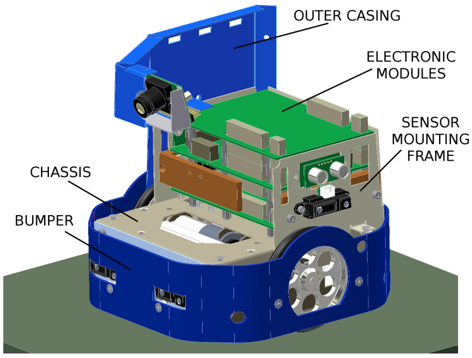


Figure 2: Main parts of the S1R robot.

A space in front of the robot is available for a replaceable sensor module (*front module*).

The top of the robot is covered by a lid with a unique pattern used for robot localization and identification.

3.1 Sensor Equipment

Robot sensor equipment is summarized in the Table 1.

The encoders together with designed wheels with radius 70 mm provide odometry information with resolution about 200 units per 1 millimeter of distance traveled. Actual motor currents are monitored and used for a simple collision detection if the robot is stucked and the motor current is increased.

The exteroceptive sensors include two infrared sensors directing forwards, mounted on chassis, and three additional sensors mounted on the sensor mounting frame. The additional sensors are directing to left, right and backwards. Above the left, right and rear infrared sensors, three sonars are mounted with the same directions.

A commonly equipped front module consists of three infrared sensors and three sonars, directing front and 45° left and right. Two *floor sensors*, each containing four reflectivity detectors, are mounted on the bottom of the robot.

3.2 Electronic Modules

Each electronic component is connected to the *on-board computer* (OBC) that provides the main access to the robot through wireless communication channels as shown in Fig. 3.

The power module provides battery maintenance and generation of on-board voltages. Embedded battery charger is able to charge the robot Li-Pol battery, when an external voltage is present. Voltage of each cell and the battery pack temperature is monitored permanently to avoid dangerous states and possible destruction of the pack.

Table 1: Robot sensors.

Sensor	**Type**
Chassis sensors:	
IR range sensors	5× Sharp GP2D120
Sonars	3× Devantech SRF10
Compass	Devantech CMPS03
Accelerometer	Freescale MMA7260Q
Camera	CmuCam3
Other sensors:	
Floor sensor	2× 6-detector lines
Front sensor:	
IR range sensors	3× Sharp GP2Y0A21Y
Sonars	3× Devantech SRF10
Laser rangefinder:	Hokuyo URG-04LX

The main function of the control board is to control robot motors and collect data from the chassis sensors. It is based on the Hitachi H8S/2639 microcontroller with embedded hardware counters for the quadratic encoders. This processor provides odometry based estimation of the robot position within its local coordinate frame.

The OBC (Gumstix Overo Fire with OMAP 3530 at 600 MHz) represents the main computational power of the robot. Beside UART, SPI, I^2C, and USB communication interfaces, it provides on-board 802.11g wireless network module.

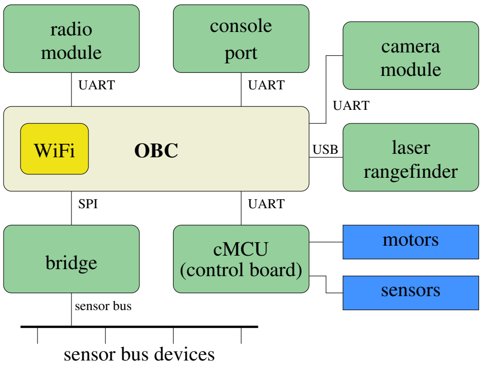


Figure 3: OBC connections to modules.

The radio module, dedicated to transmit real-time control commands and low-data-rate sensor data between the robot and an external control computer, is based on the Nordic nRF24L01 chip, allowing full-duplex communication at speed over 100 kbps.

3.3 Inter-module Communication

Having several modules and variety of used sensors, a unified approach to connect as much sensors as possible has been highly desirable. The I^2C bus has been selected as the primary communication bus between the most electronics modules. We created so called *sensor bus* by adding 2 lines to the standard I^2C, allowing module reset and firmaware update. The unified communication protocol simplifyes module implementation.

A sensor bus communication protocol is datagram-based and it basically follows common I^2C communication based protocols. A fixed length datagram header that may be eventually followed by a variable size data message is used. A publisher/subscriber schema is also used for sensors readings to avoid polling based on the request/response schema.

A microcontroller of each sensor-bus compliant module has a boot-loader code implemented, allowing remote firmware update over the sensor bus. This feature has proven to significantly speed up development process.

3.4 Power Consumption

As we require maximal operating time while robot is powered from batteries, minimization of the power consumption of individual components is crucial.

An average consumption of the motors is considered under 500 mW. The most power consuming component is the OBC module, with consumption about 2 watts with the WiFi module running. The consumption of most remaining electronic components is about 10–40 mA at 5 V per processor or module. Total consumption of all these devices and sensors is between 2–3 watts in full operation mode. The total power consumption of all these components is comparable to the consumption of OBC, so proper power management is advisable, considering that all devices are not necessary to run all the time.

When a laser rangefinder front module is used, the power consumption rise significantly, by approximately 3 watts, resulting in operation time drop by 30–50%.

Overall parameters of the robot are summarized in Table 2. The robot operation time has been experimentaly measured when the robot was performing a IR-sensor based obstacle avoidance.

Table 2: Robot parameters.

Robot parameter	**Value**
Length × Width × Height	174 × 163 × 180 mm
Weigth	about 2 kg
Maximal velocity	0.34 m/s
Odometry resolution	200 samples/mm
Battery type	Li-Pol (6 cells)
Battery voltage (nominal)	22.2 V
Battery capacity	2400 mAh (53 Wh)
Total power consumption	about 5 Watts
Robot operation time	about 8 hours
Robot charging current	2 A
Computation power	ARM CPU @ 600 MHz

4 ARENA

The SyRoTek arena (see Fig. 4) is an enclosed space dedicated for robots.

The robot working space is a flat area of dimension 3.5 m × 3.8 m with an outer barrier 18 cm tall. Additional 13 cm tall obstacles are placed inside (see Fig. 5). Some obstacles can be remotely retracted, while the rest of them is fixed, however all obstacles can be manually removed.

4.1 Robot Charging Docks

For each robot in the arena a dedicated docking space is allocated, where a recharging mechanism is available. A space of docks is separated from the working space and robots are exclusively controlled automatically in this part of arena.

Several technical solutions of charging connector were discussed during the system design phase, with respect to contact resistance, durability and maintenance-free. Among other solutions a wireless power transfer was tested and rejected mainly due to necessity of very precise docking.

The final solution uses two flexible contacts (see Fig. 6), pushed by springs against gilded metal pads on the bottom of the robot. Two contact pads on each contact are used to measure the contact resistance. Each dock provides 2-Ampere power supply, allowing the robot to fully recharge in about 1–2 hours.

4.2 Reconfigurable Obstacles

The arena was designed to be reconfigurable without need of human attendance. This feature was achieved

Figure 4: The SyRoTek arena and robots.

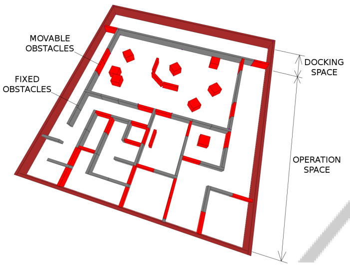


Figure 5: Obstacle configuration in arena.

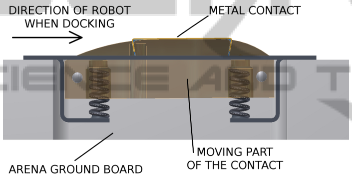


Figure 6: Charging contact detail, side view.

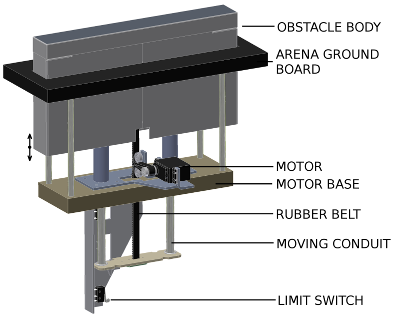


Figure 7: A moving obstacle design.

by installing several moving obstacles, allowed to be retracted under the surface, which is schematically shown in Fig. 7. When a mechanism of moving obstacles was designed, an operation noise and budget limitations were the main criteria. As a noise generated by the moving obstacles is nonneglible, frequency of the arena reconfiguration should be minimized.

4.3 Robot Localization

A robot identity together with its position and orientation is estimated using an image processing method. A grayscale camera (Unibrain Fire-i 820b) mounted above the arena working space provides an image in which patterns on the top of robots (an example is shown in Fig. 8) are recognized. The graph in the Figure 9 shows a result of a convolution-based localization function on a sample image. It is obvious that function maxima representing robot positions are very distinctive, alowing robust localization under various light conditions. An achieved accuracy of the localization is about 3 mm in position estimation and 5° in robot orientation.

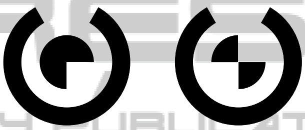


Figure 8: An example of robot identification/localization patterns.

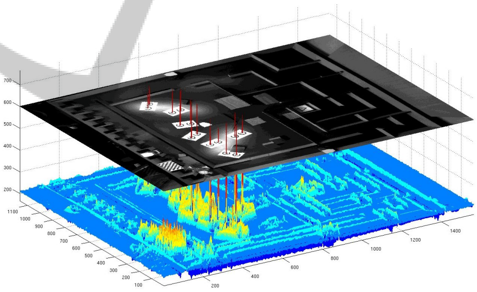


Figure 9: Result of a robot localization algorithm.

5 USER ACCESS

The user access to SyRoTek is realized through *control computer* accessible from the Internet. It consists of web pages with information about system, courses and supporting materials, and an user application controlling robot, running at the control computer.

Well-known and widely used the Player framework (Gerkey et al., 2003; Player, 2010) has been selected as the main user application interface. Although the Player provides a flexible interface to control mobile robots, it does not support user authorization to particular sensors. In an e-learning system, the authorization is mandatory because in a certain task, particular sensor is not allowed to be used by the user. It is the main reason why a *robot access module* called *robacem* was developed, representing a robot at the control computer. The player server connects to the robacem using specific player driver called *syrdriv*.

Particular options of the user's application access to the robot are shown in Fig. 10.

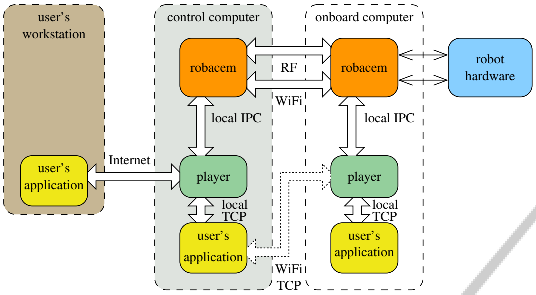
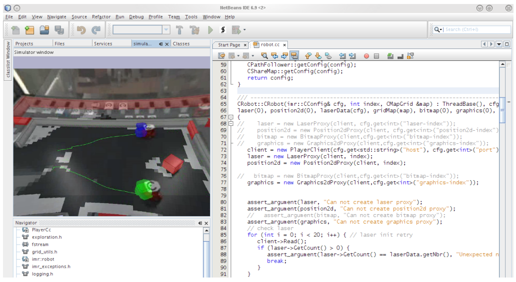


Figure 10: User's application access to robot.

The player server provides an abstract layer hiding particular hardware details. Moreover, the *Stage* simulator (Vaughan, 2008) may be used, allowing application development without real hardware.

In SyRoTek, a dedicated visualization component is being developed to provide a visualization tool. The component is based on modified Stage simulator (version 3.x) that is enhanced to support showing video streams on-line or from recorded files. It can be used as an independent visualization application or as a plug-in for some of Integrated Developing Environment, e.g. Netbeans , see Fig. 11. The application allows on-line visualization using current sensory data transmitted from the SyRoTek control computer and live streams from visualization cameras.



```
   CPathFollower::getConfig(config);
   CShareMap::getConfig(config);
   return config;
}

/// ------------------------------------------------------------------------
CRobot::CRobot(imr::CConfig& cfg, int index, CMapGrid &map) : ThreadBase(), cfg
laser(0), position2d(0), laserData(cfg), gridMap(map), bitmap(0), graphics(0),
{
//    laser = new LaserProxy(client, cfg.get<int>("laser-index"));
//    position2d = new Position2dProxy(client, cfg.get<int>("position2d-index")
//    bitmap = new BitmapProxy(client,cfg.get<int>("bitmap-index"));
//    graphics = new Graphics2dProxy(client,cfg.get<int>("graphics-index"));
   client = new PlayerClient(cfg.get<std::string>("host"), cfg.get<int>("port")
   laser = new LaserProxy(client, index);
   position2d = new Position2dProxy(client, index);

//   bitmap = new BitmapProxy(client,cfg.get<int>("bitmap-index"));
   graphics = new Graphics2dProxy(client,cfg.get<int>("graphics-index"));


   assert_argument(laser, "Can not create laser proxy");
   assert_argument(position2d, "Can not create position2d proxy");
   //   assert_argument(bitmap, "Can not create bitmap proxy");
   assert_argument(graphics, "Can not create graphics proxy");
   // check laser
   for (int i = 0; i < 20; i++) { // laser init retry
      client->Read();
      if (laser->GetCount() > 0) {
         assert_argument(laser->GetCount() == laserData.getNbr(), "Unexpected n
         break;
      }
   }
```

Figure 11: The SyRoTek visualization component within the integrated developement environment.

6 CONCLUSIONS

The development of the SyRoTek project is still in progress. However, the prototypes of educational robotic platform S1R were already tested and robots are now manufactured. Several experiments with collaborating robots in the arena have been performed to verify the concepts and to test a developed hardware and firmware. An other important part of the SyRoTek project consists of web pages with supporting materials and courses, guiding students (users) how to use the system and how to create an application to control a real mobile robot. Even though this part is still under development, it is expected that a trial application of SyRoTek will be opened for users from July 2011.

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