SyRoTek – a system for robotic e-learning

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Abstract

The paper describes the SyRoTek ("System for robotic e-learning") project in general, its overall design, main hardware and software components and status of the project after one year of solution. The aim of the SyRoTek (http://imr.felk.cvut.cz/syrotek) project is to research, design, and develop novel methods and approaches for building a multi-robot system for distance learning. The foreseen system will allow its remote users to get acquainted with algorithms from areas of modern mobile and collective robotics, artificial intelligence, control, and many other related domains. Advanced users will be able to develop own algorithms and monitor behavior of these algorithms on-line during real experiments. The proposed system reduces a development process and allows a wide spectrum of both individuals and institutions to work with real robotic equipment.

Related work

The SyRoTek project is focused on building a system for distance learning. Many systems for controlling robots distantly as well as systems for e-learning were implemented during last decades.

First robotic projects enabling their users to share and control robots via Internet dealt with a single tele-operated robots. Many of these robots were operating many years so knowledge gathered during these years allows creating more advanced e-learning solutions.

One of the first robot controlled at distance and available to public was Telegarden [1] developed at University of Southern California. It has been running since 1995 and 9000 users registered to the system in first month of operation. Telegarden has a mechanism which informs its users about actual state of the system, and planned drop-outs. Moreover, the users can interact with each other via forum. Number of contributions in the forum shows that space for exchange experience among users is an inseparable part of an arbitrary e-learning system (see analysis in [2]). Users create their own community, manuals, documentation, tip&tricks which plays an important role for collective solving of problems.

Other system worth to mention is Bradford Robotic Telescope operated at University of Bradford [3]. The telescope is a part of an e-learning course of which goal is to popularize astronomy. In addition to open up a unique equipment to a broad public, the many research programs use telescope for research of galaxies, supernovas, and black holes. The system thus combines basic research with education by sharing limited sources.

Project RHINO [4] combines tele-operation with visualization. Robot RHINO (a robotic guide in a museum) is able to operate in two diverse modes. In the first one, the robot guides visitors which can interact with the robot and influence the tour. The second mode allows Internet users to control the robot and to view the museum at distance. Although main research goal of the project is to build an autonomous robots with cognitive functions education aspect plays an important role in both modes.

Robot Xavier [5] developed at Carnegie Mellon University is an autonomous robot operating in indoor environments of university hallways. Robot autonomy allows users to enter high-level tasks (e.g. go to a specified position), which are performed by the robot autonomously. After the task is done, an e-mail with a photo of target place is sent to the user. Concerning e-learning, an important part of the project was web interface designed with respect to deal with limited connection speed. The authors also discuss aspects related to operation time of robots. If the system should operate 24 hours/day and 7days/week then battery capacity, their charging and other hardware and software services must be designed with special attention.

Robotoy - a robotic arm with a gripper - developed at University of Wollongong allows it users to control it via web interface. The user can choose between two cameras from which it can see robot's working environment. Although the system is relatively simple, it contains all basic components of successful distant control. The robot is controlled in command regime, i.e. the user enters a command which is immediately fulfilled.

A notable part of such system is a simulator which introduces the robot to the user and allows the user to test robot's behavior and its responses to user's commands off-line.

Fig 1: Play field of AliceOnWeb project (adopted from [7])

One of the most complex robotic e-learning laboratories was developed at Swiss Federal Institute of Technology in Lausanne(EPFL). The RobOnWeb project [7] is focused on advanced robotic users. The authors define five fundamental services of web interface: chat, video, robot control, virtual robot representation, and logging. Moreover, an user registration system is introduced, which manages user's access to robotic hardware. Several configurations are parts of the project varying mainly in used robot platform and sensors: TeleRoboLab, AliceOnWeb, Koala on the Web, and Pygmaliion on the Web. TeleRoboLab is for example an environment monitored with several cameras, independent global localization system, Koala robots, and other controlled devices (movable doors, lights, etc.). Play-field in AliceOnWeb is realized as a small city with houses, streets, crossroads, and squares. Robots called Koala sized 22x21x20mm are localized using a camera placed above the play field.

System introduction

The aim of the SyRoTek project is to research, design, and develop novel methods and approaches for building a multi-robot system for distance learning. The foreseen system will allow its remote users to get acquainted with algorithms from areas of modern mobile and collective robotics, artificial intelligence, control, and many other related domains. Advanced users will be able to develop own algorithms and monitor behavior of these algorithms on-line during real experiments. The proposed system reduces a development process and allows a wide spectrum of both individuals and institutions to work with real robotic equipment.

The main components of the robotic platform – mobile robots – are expected to move inside a restricted area, which will also contain other elements like obstacles or objects related to objectives of the actually solved task. Moreover, several sensors (infrared, sonars, cameras, etc.) will be used to gather information about the actual status of the play field and particular objects on it. Some sensors will be placed on-board the robots, while others will be stand-alone getting global overview of the play field status. The user will be able not only to observe gathered data using Internet interface, but also control the robots in real-time. Unlike existing e-learning robotic systems developed in the world in which the user can only tele-operate robots, behavior of the robots in the SyRoTek system can be modified, while the system allows to run own algorithms developed by the user.

Overall design

Implementation of the system can be divided into realization of hardware components (robots and play field) and software which communicates with hardware in a defined way in order to control it. It is expected that different kinds of support tools (both commercial and open source) will be used during software development. Discussion about tools to be used for particular sub-tasks as well as target platforms is an inseparable part of SyRoTek software design.

10 main components (objects) constituting the system were identified with respect to the state of the art in robotics, e-learning, and relative domains (see figure 2). Majority of e-learning systems is oriented to a distant user. Objects realizing interface with the user can be therefore considered as a core of such systems. *Web interface* which is user’s front-end gate to the system is one of these objects. *User’s computer* represents user’s work space. The user has access from its computer to web interface, learning materials, he is able to observe situation on the play field, send commands to control robots. The goal of *Environment visualization* is to visualize actual play-filed situation to the user. It is realized by a set of video streams which are produced by cameras monitoring the play field.

The inseparable part of electronic form of distance education is learning material as well as exercises for practical verification of acquired knowledge. With respect to the process how this material is created and to the fact that learning material is independent from existence of its web presentation, *Exercises and instructions* is a standalone object.

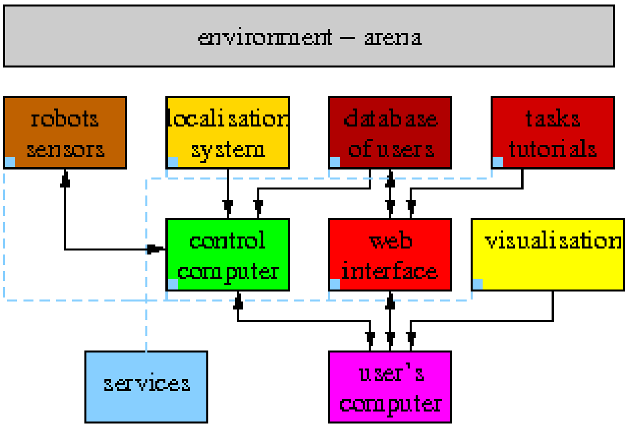

Fig 2: General concept and main SyRoTek modules

It is expected that a number of SyRoTek users will be large and thus there must be a system for user administration. The aim of *Database of users* object is to manage information about SyRoTek users (their login data, status of all exercises, actually solved experiment, sensory data and visual streams from experiments, etc.). Moreover, the object handles a booking system for user's access to play field, particular robots, sensors and cameras.

The robots move in a defined space (play field) called *Arena*. For successful pursuing of robotic tasks, harmless robot control, navigation of a robot to the docking station, obstacle avoidance, and for automatic evaluation of user's solution of exercises it is needed to determine positions of robots. Localization is performed by the *Localization* object by processing image from a camera located over the arena.

Control computer provides user's access to shared SyRoTek hardware – it distributes sensor data to the user and transmits control commands to the hardware. It is not always possible or required to perform experiments with real robots (during debugging, when robots are already reserved by other users, etc.). Control computer therefore allows running the task in the simulator. From user's point of view, the simulator works equally to the real system – the user can send the same control commands and gets simulated sensor data and video streams.

The SyRoTek system is designed to run in 24/7 regime. The aim of the *Services* object is to provide functionality for distant administration of the system. The object incorporates connections to other objects, gathers information from them and creates log files about all activities of currently connected user, and statistics about system load. Moreover, the object is responsible for backup of the system and its recovery in case of failures.

Arena

As mentioned above, Arena is a space, where the robots perform their actions. There are antipodal demands on arena size. The larger the play field the more complex tasks can be solved, robots can move more freely, more users can solve their assignments, etc. On the other hand, for localization system based on camera, it is needed to overview the whole Arena – the larger the area, the higher the camera should be placed and the higher resolution it has to have. Moreover, Arena has to be situated in current classrooms, which also determines its size. As a compromise, the size was chosen to approx. 350x380cm including docking station (see fig. 3). It is expected, that obstacles placed on Arena will be of two kinds. While fixed obstacles are designed to be stationary during longer periods of time (weeks), movable obstacle can change their position by moving up and down (the obstacle can have different heights or can totally coincide with plane of Arena).

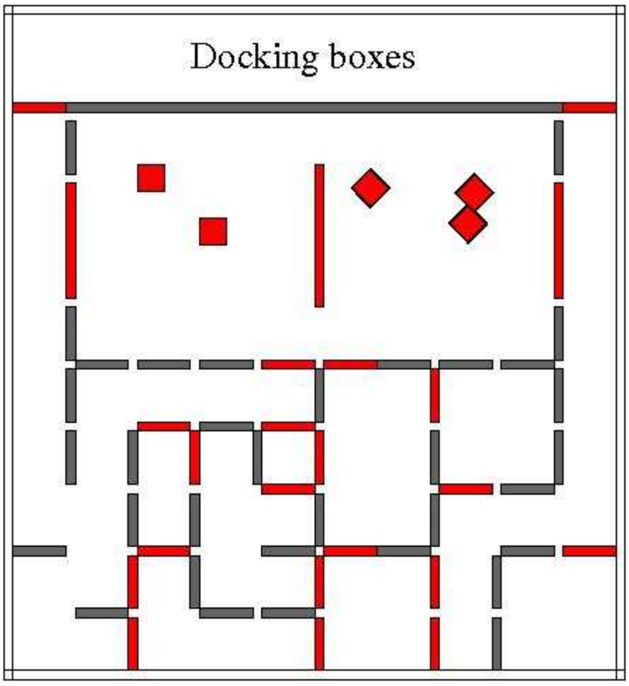

Fig 3: Design of Area. Movable (pop-up) obstacles are highlighted with a red color.

Robots that currently perform no assignment are situated in docking boxes. This is an area separated with barriers from the place where the robots normally solve their tasks.

Robots

A robot is an autonomous mobile platform that gathers information about its surrounding environment, preprocesses this information and sends it to the user or user application. The user then generates control commands which are executed by the robot. The robot has to guarantee maximal safeness of its movements with respect to user's needs, access rights, and skills.

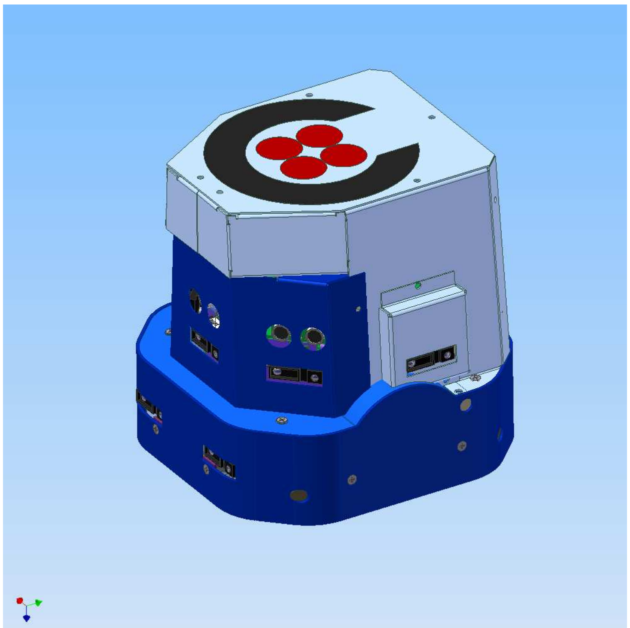

Fig 4: Sketch of SyRoTek mobile robot - covered version with sensors

Essential parts of the robots include drive units (engines), sensors, computers, batteries, and electronic modules for robot charging. Furthermore, the robots are equipped with wireless communication modules that allow robots communication with other robots and components of the system (robot control server).

Robots have two controlled wheels on its sides (differential kinematics) with two supporting balls in front and rear providing the robot stability. This construction determines usage of the robot on solid flat ground only.

Computational performance is provided mainly by two computers: *on-board computer* (Gumstix Verdex with XScale PXA270 processor, running RT Linux operating system) and single-chip microprocessor based *control computer* (processor Hitachi H8S/2639). On-board computer provides a communication with the user and other SyRoTek objects and executes user applications and top-level service functions. Control computer is responsible for controlling robot drive units, gathering and distribution of chassis sensor data, computing odometry and provide basic robot movement functions (e.g. velocity control or trajectory following). The engine current senses are analyzed by the control computer, providing information about higher force against the movement direction, indicating possible collision with an obstacle.

There are other microprocessor computers in the robot, responsible mainly for controlling replaceable sensors. Most important amongst them monitors and controls the battery charging and management module. This particular processor is continuously measuring battery voltage, estimates remaining charge based on actual current consumption and is responsible for detecting dangerous states, possibly leading to battery damage. With regard to the safety of the robot running without continuous human supervision, several thermometers are monitored, allowing avoiding heat damage or fire in case of serious accident. Additionally, this module contains power regulators supplying whole robot with the demanded voltages and allows to connect and disconnect some electrical parts of robot from the power supply.

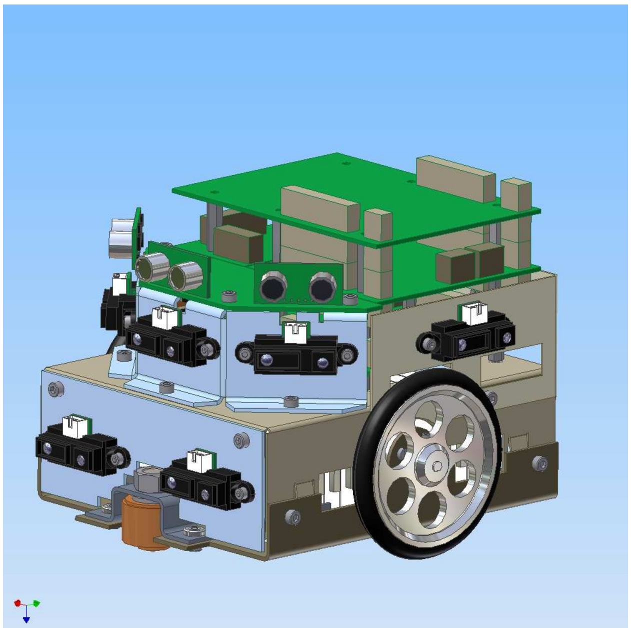

Fig 5: Sketch of SyRoTek mobile robot - view without a cover

The robots are designed taking modular principles into account, which allows flexible reconfiguration of robots and placement of various sensors on them. The modularity is taken into consideration in hardware frame construction, electronic modules, even the software design, while it is most significant is the sensor replacement-ability. To typical sensors used belongs: incremental odometry, infrared distance sensors and sonars. Extended configuration of the robot include laser range-finder, accelerometers, compass, internal/external thermometers, and cameras.

It is expected that no more than eight robots will operate concurrently on the play field with the area of approximately 10 m^2 at the same time. Moreover several (4-8) robots can be prepared in the docking station which limits robot size to 18cm.

Robot design is depicted on pictures [4] and [5**]**. The first picture shows fully covered robot while the second one

shows robot without the cover parts. Both pictures show the basically equipped robot – with two low-mounted infrared range sensors in front direction and three infrared sensors pointing to both sides and rear. There are three sonars mounted just above the infrared sensors. At the robot bottom there are two rows of light-reflectance sensors measuring a color (or rather reflectivity) of the floor under the robot, allowing it for example to detect painted line on the ground.

The front part of the robot is designated for replaceable sensor modules, where the basic module contains three infrared sensors pointing forward and 45 degrees to both sides and three sonars mounted above in the same directions. The replaceable modules currently under a design include laser range-finder module, and CMUcam camera module [9].

All robot sensors, except some chassis sensors mentioned before, and some control modules (e.g. power control module), are connected using so called *sensor bus*. Physical layer of the sensor bus is formed by I^2C bus extended by two signals for device reset and programming mode setting which is particularly useful during the development, when devices are re-programmed remotely. Transport layer of the sensor bus involves fixed-length datagrams with ability to append variable-length data. There are basically two methods of gathering sensor data: polling (active requesting each data) and subscription (autonomous data sending by the source with specified interval). The communication protocol allows to use both methods depending on the data character in order to achieve maximal bus throughput.

Robot has two wireless communication channels used for different purposes. There is wireless network card (WiFi) mounted on the on-board computer, used mainly for the program upload and maintenance. Because the latency of the WiFi may not be sufficient for the real-time controlling of the robot, there is second radio channel based on the Zigbee communication modules. This control channel is used for high-priority data whose latency is crucial, but their volume is relatively low – control commands and sensor data. It is obvious that data from the sensors like cameras or laser range-finders, providing higher amount of data, will need WiFi for the transmission on the central control server because of low channel capacity of Zigbee.

Because of continuous operation without human supervision robots have to be re-charged autonomously. This implies necessity of the re-charging station, where robot may charge its batteries when it successfully docks in. There are more possibilities how to transfer energy from the station to the mobile robot. Probably most common and often used design with metallic contacts may suffer by contact damage caused by long-time attrition and pollution. This lead us to development of non-metallic transfer of the energy using the magnetic inductance. Because of the losses in energy transmission there is necessity for precise robot docking, achieved by robot and station shape, robot localization and motion control.

Assignments

An important part of the project is to put together a collection of assignments that users (students) can solve with the system. The assignments sectioned into several categories. Students should be introduced to the system at first, so several simple assignments demonstrating basic functionality and features of the system were designed.

Second category of assignments leads students to implement simple robot control like reactive control, dead reckoning, basic teleoperation, etc. Solving other assignments introduces control theory and advanced control algorithms, and basic principles of navigation (controllers, filters, wall following, planning algorithms, etc.) to students.

After the student copes with the techniques mentioned above, it can solve more complex single-robot tasks, like mapping, localization, simultaneous localization and mapping, exploration, inspection, etc. Advanced users then will be able to solve these tasks using multiple robot that cooperate. Moreover, it is expected that the system will serve as a test-bed for many artificial intelligence algorithms.

Conclusion

The paper presents the state of SyRoTek project after first year of solution. An exhausting study of current state of the art in robotic e-learning was originated during this year. The study deals with teleoperation, software technologies and frameworks, Internet and web interfaces, hardware components, sensors, and mobile robots that can be potentially used in the project. Based on the study, overall design of the system was sketched together with main its components and their functionalities. Moreover, SyRoTek robots were designed and their first functional prototype was built.

Activities for the next year concern mainly to final design and production of 12 mobile robots, design and implementation of fundamental software functionalities of robots an the control computer. Furthermore, the assignments will be specified in more details, as well as a concept of user's access to the system will be designed.

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