SYROTEK
On an e-Learning System for Mobile Robotics and Artificial Intelligence

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Keywords: e-Learning, Mobile robotics, Collective robotics.

Abstract: The paper deals with motivations and design leading to succeeding development of a system for remote learning of mobile robotics topics. Specifically, the designed SyRoTek system comprises a team of 12 tele-operated mobile robots acting in 24/7 maintenance-free environment equipped with charging docks and reconfigurable system of obstacles, all being observable and accessible via Internet. The SyRoTek system together with an attached e-learning environment it is aimed to provide the features real data gathering and real robot motion execution. The whole set-up is targeted on training purposes in basic and advanced courses in the field of Intelligent and Mobile Robotics and Collective Robotics as well as for test/verification purposes in a research domain.

1 INTRODUCTION

Robotics and autonomous systems have become an inseparable part of up-to-date IT solutions. As being applied more and more frequently in these days, need of training activities for these demanding technologies steadily raises. This situation forms conditions and requirements how to approach and optimize the training issue, respecting the nature of the robotics systems in question.

Autonomous robotics systems typically require applications of AI methods achieved through independent processing of perceived information, understanding the environment, and followed by autonomous reasoning and decision-making towards a self-derived or given goal.

Autonomous (or intelligent) robotics in the first place aims to design and develop systems with capabilities to operate the robot device under uncertainty - to handle unexpected situation or developments in the operating space of the system, changes of constrains of a task to be fulfilled, etc.

Moreover, as for a next level autonomy may be considered a system comprising multiple robot systems, where each of these is introducing its' own intelligence into a coexisting or even a cooperating team. The later concept leads to collective robotics tasks, whereas performance of such the system may substantially be improved through higher flexibility of the robots team, via better resource planning and assignment, more reliable and optimized environment sensing and other capabilities, which may be performed faster, in more robust way, being best optimized, and even sometimes done resolvable this way at all.

As it can be seen, majority of the afore mentioned tasks and their solutions are typically achieved on conditions, that the robot provides capability of autonomous processing of uncertain information, which a real environment satisfies. The uncertainty itself may be handled as a random process and therefore a simulation can be built up. Unfortunately, none of feasible random processes allow us to create an exhaustive simulator of real environments and sensors. Although some widely used systems offer a simulated environment and sensory simulations (e.g. Player/Stage/Gazebo system (Gerkey et al., 2003)), these do have a limited performance in certain situations and remain efficient only in early stages of an intelligent robot design and development phases.

Multiple experiences have shown, that precise simulation of sensor behaviour is an extremely hard

Kulich M., Faigl J., Košnar K., Přeučil L. and Chudoba J. (2009).
SYROTEK - On an e-Learning System for Mobile Robotics and Artificial Intelligence.
In *Proceedings of the International Conference on Agents and Artificial Intelligence*, pages 275-280
DOI: 10.5220/0001663102750280

task, which remains unsolvable very often. Therefore, existence of real senses, as sensory measurements from real environments can not ever be fully substituted by simulation.

The preceding finding leads to the idea, that research/development as well as teaching activities in the field of intelligent robotics can be performed on high quality level only and only if a real experimental platform is made available. This comprises mainly availability of real sensors being operated in real-world environments and providing realistic data. To move, orient and position the sensor in the environment a suitable carrier (mobile platform or actuator) is needed. Integrating both the previous issues together and adding some control algorithms we obtain a mobile robot, whereas the crucial control part (the data processing algorithms, reasoning and planning) can be executed either on-board such platform or off-board in an attached or remote computer. Having multiple such sensor platforms with some necessary control infrastructure (observation and caretaking system) we achieve a multi-robot system, which can be made ready either for local or remote control via Internet. As this setup is truly teleoperated, it can effectively create an experimental part of an e-learning system for the intelligent mobile robotics as well as collective robotics domains.

In this paper we present the SyRoTek system - a system for distance robotic learning which 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 behaviour of these algorithms on-line during real experiments.

SyRoTek mobile robots move inside a restricted area, which contains other elements like obstacles or objects related to objectives of the actually solved task. Moreover, several sensors (infrared, sonars, cameras, etc.) are used to gather information about the actual status of the play field and particular objects on it. Some sensors are placed on-board the robots, while others are 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, behaviour of the robots in the SyRoTek system can be modified, since the system allows to run own algorithms developed by the user.

The remainder of the paper is structured as follows. The next section gives a brief overview of existing robotic systems for e-learning. In section 3, main ideas and architecture of the SyRoTek system are presented. Robots developed and play-field are described in section 4 and 5 respectively. Finally, typical assignments solvable by the system are briefly introduced in section 6.

2 RELATED WORK

The SyRoTek project is focused on building a system for distance learning. Many systems for remote robot control 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 teleoperated 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 robots controlled at distance and available to public was Telegarden (Telegarden, 2008) developed at University of Southern California. It has been running since 1995 with 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 (Kahn et al., 2005)). Users create their own community, manuals, documentation, tips&tricks which play an important role for collective solving of problems.

Other system worth to mention is Bradford Robotic Telescope operated at University of Bradford (Telescope, 2008). 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 (Rhino, 2008) combines teleoperation 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 (Simmons et al., 2000) 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 7 days/week then battery capacity, their charging and other hardware and software services must be designed with special attention.

Robotoy (Robotoy, 2008) - 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 behaviour and its responses to user's commands off- line.

One of the most complex robotic e-learning laboratories was developed at Swiss Federal Institute of Technology in Lausanne (EPFL). The RobOn-Web project (Siegwart and Sauc, 1999) 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 Pygmalion 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.

3 SYSTEM DESIGN

The SyRoTek system comprises of ten main components (both software and hardware) which are depicted on figure 1, and which will be described in the following paragraphs.

Majority of e-learning systems is oriented on 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.

Learning materials as well as exercises for practical verification of acquired knowledge are inseparable parts of each modern e-learning systems. With respect to the process how this material is created and maintained and to the fact that learning material is independent from existence of its web presentation, *Exercises and instructions* is a standalone object.

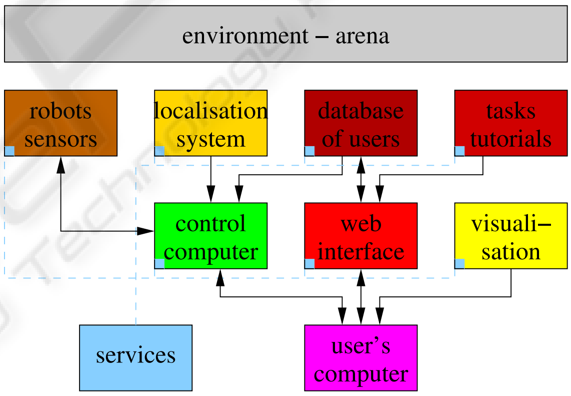

Figure 1: General concept and main SyRoTek modules.

It is expected that a number of SyRoTek users will be large and thus 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.

4 ROBOTS

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

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 belong: incremental odometry, infrared distance sensors and sonars. Extended configuration of the robot include Hokuyo laser range-finder, accelerometers, compass, internal/external thermometers, and cameras (CMUcam, see (CMUcam, 2008)).

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. Moreover, the robots are equipped with other processors responsible for controlling sensors and monitoring robot status (batteries, temperature,charging, etc.)

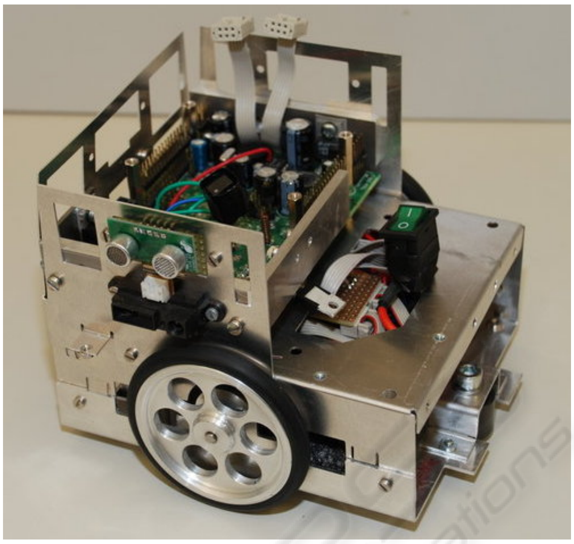

Figure 2: A robot without a cover and sensors.

Robots have two wireless communication channels used for different purposes. Wireless network card (WiFi) mounted on the on-board computer is used mainly for the program upload and maintenance. Because the latency of the WiFi may not be sufficient for the real-time control of the robot, radio channel based on the Zigbee communication modules is used for high-priority data whose latency is crucial, but their volume is relatively low – control commands and sensor data (except camera).

An uncovered robot without sensors is depicted on figure 2.

5 ARENA

As mentioned above, Arena is the 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).

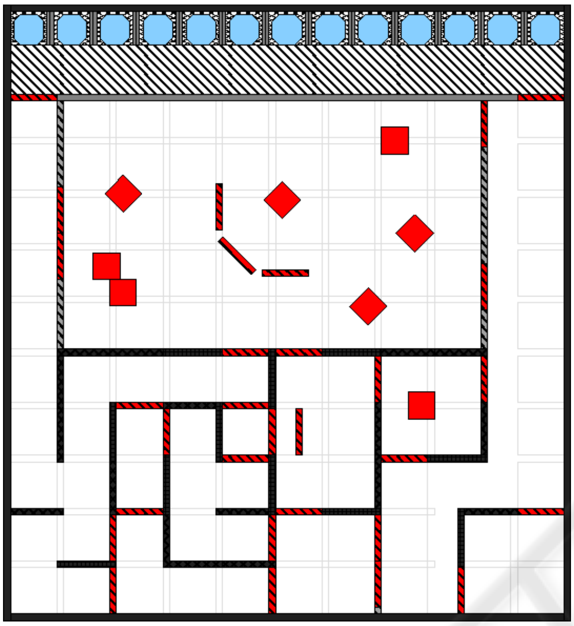

Figure 3: Design of the Arena. Movable (pop-up) obstacles are highlighted with a red color. Docking boxes are placed on the top (hatched area).

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.

6 ASSIGNMENTS

The system allows to solve and test a broad spectrum of tasks. The important part of the system is therefore a collection of assignments that users (students) can solve with it. The assignments are sectioned into several categories (courses) according to their difficulty, domain, and dependencies to other assignments.

Students should be introduced to the system first, so they go thru several simple demonstrations and exercises to become familiar with basic functionality and features of the system. These exercises encompass loading and running user's code on the robot, gathering sensor data, working with logging system, etc.

Four introductory courses have been arranged in order to afford students knowledge of fundamental algorithms in key robotic domains. These are focused on:

- Simple robot control (reactive, behavioural, teleoperation, dead reckoning, etc.)
- ”classical” robot control (follow the carrot, pure pursuit, vector pursuit, PID, motion models, etc.)
- Sensor processing and environment modelling (continuous localization, Monte Carlo localization, Kalman filters. occupancy grids, sensor models, etc.)
- Path and motion planning (wall following, combinatorial planning, sampling-based planning, potential fields, etc.)
- Communication, coordination, cooperation

Advanced courses are based on complex *Top Assignments (TA)* that comprise from several fundamental problems mentioned above. These courses are organized so that students learn all necessary fundamental algorithms (by solving corresponding assignments) needed to solve *TA* of the course. *TAs* can be divided into two groups: basic and advanced. Basic Top Assignments are typical problems in robotics and artificial intelligence, where solutions are well known and described. To this class of problems belong for example:

- Simultaneous Localization and Mapping
- Inspection, exploration, and coverage
- Pick & delivery

Each of these assignments can be solved with a single robot or with a team of robots.

Advanced Top Assignments are problems whose optimal or polynomial solution is not known. It is therefore expected, that the student will either study the literature to find some approximate solution or it will creatively develop its own approach. Typical examples of Advanced TAs are e.g. the following games:

- Treasure hunt
- Pursuit-evasion
- Capture the flag

These problems are typically designed as multi-robot, where cooperation and coordination of robots plays an important role (although treasure hunt can be performed by one robot).

Robot's goal in *Treasure Hunt* is to locate a place, where the treasure is and to navigate to this place. Access to this place can be granted under specific conditions that the robot must fulfill (e.g. finding a key, opening door, etc.).

Pursuit-evasion game is family of problems where multiple robots (pursuers) collectively determine the location of one or more other robots (evaders) and try to catch them.

Capture the flag generalizes the previous problem. The aim of each of two groups playing the game is to find and capture the flag defended by the opponent group. In other words, each group pursuits and evades simultaneously.

Each of the aforementioned assignments can be considered in different levels of difficulty determined by the environment (e.g. static x dynamic, orthogonal, grid-like or general), whether the environment is known, and abilities and equipment of opponents. These specifications lead in most cases to totally different solutions which increase variability of possible assignments.

SyRoTek system is designated to work also in open mode for trusted users. This mode grants full access to all features of the system and it is intended especially for researches and phd students for development and verifications of their algorithms.

7 CONCLUSIONS

While this paper is written the research is still in progress. Due to this fact, the paper presents only first results concerning system architecture, main ideas and first results.

An exhausting study of current state of the art in robotic e-learning was originated during previous period. 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 functionality. Moreover, SyRoTek robots were designed and their functional prototype was built.

Activities for the next time concern mainly to final design and production of 12 mobile robots, design and implementation of fundamental software functionality 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.

ACKNOWLEDGEMENTS

The presented work has been supported by the Ministry of Education of the Czech Republic under program "National research program II" by the project 2C06005. The support of the Ministry of Education of the Czech Republic, under the Project No. 1M0567 to Jan Chudoba is also gratefully acknowledged.

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