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Control System of a Semi-Autonomous Mobile Robot ⋆

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Abstract: In this paper, a control system, which has been designed for a semi-autonomous mobile robot, is presented. The robot has been developed as a part of a teaching aid. The teaching aid is aimed at practice of a path-planning theory. The main purpose of the robot within the teaching aid is physical execution of a path-plan scheduled by a high-level control system. The execution of path-plans is required to be accomplished by the robot autonomously, hence the 'semi-autonomous' appellation. The robot is based on an Arduino UNO microcontroller board. The robot acquires information about his workspace via reflectance sensors, encoders, and a magnetometer sensor. Since all these sensors provide only very limited information about the workspace, all the acquired data has to be used with utmost effectiveness. Thus, processing of the sensor data and multi-sensor integration is also considered in this paper.

Keywords: autonomous mobile robots, computer control system design, multisensor integration, path planning, data processing.

1. INTRODUCTION

Mobile robots are popular teaching aids within the education system. Many different types of mobile robots suitable for education have been introduced. They have been employed in different environments where diverse activities are required to be performed, e.g. line following (see Pakdaman and Sanaatiyan (2009)), collecting stuff, obstacle avoidance, or solving a maze (see Alves et al. (2011)).

Development of a teaching aid aimed at use of a mobile robot is a complex process. The process can be considerably simplified once a commercial solution is used, e.g. Cuéllar and Pegalajar (2014) used LEGO Mindstorms kit, or Harlan et al. (2001) and Rubenstein et al. (2014) employed products from a Swiss company called K-Team Corporation. Although many different commercial products are available on the market, it is difficult to find an inexpensive solution which perfectly fits a specific teaching purpose. Of course, as Mariška and Doležel (2014) showed, it is possible to use a virtual environment; nevertheless, students then lose the connection with reality.

A good experience with mobile robots while teaching path-planning techniques, presented by Alves et al. (2011), motivated us to enrich our courses on artificial intelligence with a practical exercise based on this experience. The lack of inexpensive solutions suitable for this purpose led us to develop a new teaching aid tailored to our requirements.

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This teaching aid consists of a maze, a camera system, a high-level control system, and a mobile robot. The goal of intended exercises, which will be realized by the teaching aid, is practicing of path-planning theory treated in a course 'Introduction to Artificial Intelligence 1'. The path-planning is supposed to be performed by the high-level control system while its execution is objective of the mobile robot. In this conception, autonomous execution of a path-plan is required by the mobile robot; hence the appellation 'semi-autonomous'. An autonomous execution of a path-plan is really not a simple task. Many different tasks have to be carried out by a control system of an autonomous or a semi-autonomous mobile robot. In this paper, description of a control system, which has been developed for the aforementioned mobile robot, is presented.

The rest of the paper is organized in following way. In section 2, the teaching aid is introduced and its components are detailed. In the same section, the intended use of the teaching aid is discussed in context of the path-plan execution. Physical execution of path-plans is conditional on sufficiently accurate knowledge of the environment by the robot. The robot gathers information about the environment via sensors. Considering this, the sensors of the mobile robot are explored in depth in section 3. Analysis of the control problem is considered in section 4. On the basis of the analysis, the control system has been divided into two levels. The higher level is presented in section 5 while the lower one is considered in section 6. The whole work is then summarized in section 7 where also advantages and disadvantages of the presented solution are discussed.

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2. TEACHING AID

In this paper, a control system of the mobile robot, which has been developed as a part of the teaching aid, is presented. Since the design of the control system has been significantly influenced by an overall idea behind the teaching aid, the purpose of the teaching aid is explained in subsection 2.1. As has been already mentioned, the teaching aid consists of four physical parts: the *maze*, the *camera system*, the *mobile robot*, and the *high-level control system*. Except for the high-level control system, all physical parts of the teaching aid had to be considered within the development process.

In order to clarify the presented solution, all relevant parts of the teaching aid are detailed in this section. Specifically, the maze is presented in subsection 2.2; the camera system in subsection 2.3; and finally, construction of the mobile robot is described in subsection 2.4. Nonetheless, not only the physical parts of the teaching aid have affected the development process. The path-planning, which is analyzed in subsection 2.5, was equally important in the design of the control system.

2.1 Purpose of the Teaching Aid

As has been mentioned in the introduction, the teaching aid is aimed for practicing the path-planning theory. Within the exercises, students are supposed to make a *path-planning routine* according to a given assignment. The routine may find the shortest path between an actual position of the robot and a designated point in the maze. The target position is determined by a user.

In the presented teaching aid, the high-level control system collects all information which is necessary for the path-planning. Information about the current state of the robot, as well as about structure of the maze, is gathered via the camera system. The high-level control system also provides a user friendly environment where a user can simply determine a target position. However, no path-planning routine is integrated in this system. For the path-planning, routines developed by students are used. The high-level control system provides the acquired information in a suitable form to a currently employed path-planning routine. A *path-plan* provided by the routine is then physically executed by the robot.

2.2 Maze

The maze is a workspace of the robot. In order to offer a flexible solution allowing creation of different environments, a maze building kit has been developed. This kit has been designed as a modular system which consists of partitions of a fixed size, floor blocks, and posts. The dimensions of the partitions are $170 \times 170 \times 100$ mm and dimensions of the posts are $12 \times 12 \times 100$ mm. Here and further, dimensions of any object are written as length $\times$ width $\times$ height.

To each post, up to four partitions can be inserted into preformed tracks. The tracks are parallel to the longest edges of the posts and just one track is on each side of the post. Thus, the kit allows creation of different environments of rectangular layout where the partitions and the posts are obstacles from the perspective of the robot. Nonetheless, within the exercises, structures of mazes are limited by two requirements: the outer shape of a maze has to be rectangular, and a maze has to be a closed system (isolated from a surrounding world). For more information, see Škrabánek (2015).

In the context of this paper, surface coatings of partitions and posts are also very important, therefore they are detailed in this subsection, too. The partitions have been painted by a white color. A shade of the white is identical for all the partitions. Further, there are no significant irregularities on surfaces of the partitions. The posts are made from aluminum without any finishing. The posts can be also considered to be flat.

2.3 Camera System

The camera system is the only source of data about the real world, which is available to the high-level control system. The camera system consists of a stand arm and a camera. The camera is fixed on the stand arm and the whole camera system is placed such that the camera is above the maze. A procedure, which was presented by Škrabánek (2015), extracts information about the maze structure from captured images. The procedure provides this information in a form of a graph. However, as Škrabánek and Doležel (2014) showed, the camera system can be also used for an acquisition of information about a current state of the robot.

2.4 Mobile Robot

In the discussed teaching aid, a differential wheeled mobile robot is used. The robot has been developed at the University of Pardubice, Faculty of Electrical Engineering and Informatics, Department of Process Control. The robot is based on a microcontroller board named Arduino UNO, rev. 2. Communication with other electronic devices is possible either via USB cable or via Bluetooth module HC-05. Naturally, the Bluetooth module is used for communication with the high-level control system when the robot operates in the maze. The final version of the robot is shown in Fig. 1. As is obvious, the shape of the robot body is approximately a block of dimensions $110 \times 94 \times 83$ mm (without the Bluetooth module). A coordinate system relative to the robot body is depicted in the left down corner of the figure.

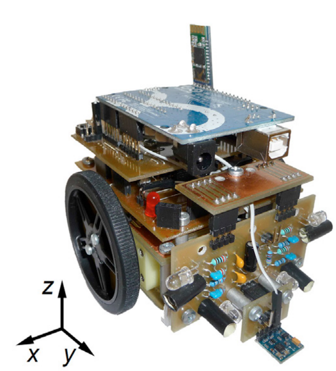

Fig. 1. Final version of the robot from the front view