Incorporating a Software System for Robotics Control and Coordination in Mechatronics Curriculum and Research

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Abstract

The goal of this paper is twofold: to develop a software system using MATLAB to control and coordinate of tasks between mobile robot and robotic arm to solve sophisticated robotics tasks, and to use the software in teaching an undergraduate course in robotics in Mechatronics program at the university. This robotic system will help students to understand the basic and advanced concepts about robotics also will be used in research for graduate students in many application such surveillance applications. The software will be composed of ten modules. The developed software system allows a mobile robot attached with the robotics arm to navigate in an environment autonomously. The mobile robot accepts the commands from the human being (operator) using three different techniques. The mobile robot starts navigating to detect many objects based on color(s) and shapes, and also sends these information back to the operator throughout Graphical User Interface (GUI). With a camera attached to the mobile robot, the software will be able to classify the objects based on color (s) and shape(s), and to determine its/their position. The software will be implemented in MATLAB and in addition, the image and signal processing toolboxes available in MATLAB were used as functions in the software. The co-ordinate position of the object in the image and the actual distance of the object from the camera are to be determined. A camera calibration technique was developed to convert object pixels to real co-ordinations. Finally, the robotics arm attached to the mobile robot picks the object(s) of interest that is/are present in the vicinity. A set of robotics behaviors was developed to help the mobile robot navigate in a crowded environment to avoid detected obstacles. The mobile robot used in this project is Pioneer 3-DX which is a small but very durable and robust robot. Pioneer 3-DX comes with a SICK LMS200 Laser Range Finder installed on top and has a 360 degree sonar transceiver and bumpers array in the middle and bottom, respectively. The demonstrated characteristics of the developed software system indicate an improvement in picking certain objects located on hazard and unsafe environment where it would be too dangerous to send in a human subject.

This real world robotic setup would be an excellent teaching and demonstration tool for students in mechatronics and related programs. Specifically, the authors are planning to offer a new introductory course on robotics in which the software will be taught in the lab. This course includes 10 modules in which groups of students will use the developed software to control and navigate two different sets of robots: a mobile robot and a robotic arm. Furthermore, the authors are working on a new advanced course on robotics for graduate level, which will address more advanced topics in industrial robotics application.

Keywords

Teaching Robotics, Robotics Control, and Robotics in Mechatronics undergraduate curriculum, Coordination between mobile robot and robotics arm.
Background

A key driving force in the development of robotic systems is their potential for reducing the need of human presence in dangerous work environments. The nature of any of these challenging work environments require that such robotic systems be able to work fully and accurately in achieving human supplied goal [1, 2]. One approach to developing these systems is to develop a single robot that can accomplish particular goals in a given environment. However, the complexity of many environments or missions require a mix of robotic capabilities that are too extensive to design into a single robot [2]. Additionally, time constraints may require the use of two kinds of robotics systems working together in order to successfully accomplish an objective. Thus, coordination among heterogeneous robot must be considered. For example, mobile robot coordinating with a robotic arm can accomplish missions that no one robot type can accomplish alone. Since such coordination between mobile robot and a robotic arm will often be operating in dynamic and unpredictable environments, software control system must be developed.

Problem Statement

Because of operational limitations of mobile robots and robotic arms, the use of one single type of robot is not sufficient to perform complex tasks. Integrating a mobile robot and a robotic arm to work together in a coordinated manner may help accomplishing more sophisticated robotic tasks. This challenge needs to be addressed and solution(s) to it will provide advanced robotic systems and allow robots to handle more sophisticated tasks. One of these tasks is, a mobile robot with arm navigates the environment and automatically detects and collects objects of interest. Also, the robot and the user can mutually interact during this process. For example, once an object is detected and collected the robot may ask the user if its location should be recorded. In another scenario; the user can instruct the robot to return to any object location where the robot uses previous knowledge in planning its path back to that object. The research addresses these needs for coordinating mobile robot and robotic arm by developing software for both of them that allow heterogeneous robots to work together robustly and reliably to accomplish their mission.

Research Objectives and Functional Requirements

The goal and objectives of the software system for control and coordination of tasks among mobile robot and robotic arm are stated in this chapter. The functional and non-Functional system requirements, design specifications, and various approaches to complete the project are also presented. In addition, system models illustrating different stages of the proposed approach are provided.

A. Research Goal and Objectives

The goal of this research is to develop a series of robotic labs that use to help students to understand how to integrate and incorporate the software system based on Matlab for control mobile robot and robotic arm to accomplish specific tasks. The following is a summary of the project objectives:
1. Development of software for mobile robot control and robotic arm operation. Development of low-level mobile robot and robotic arm functions and behaviors, such as speech recognition, robot navigation, and arm control.
2. Development of image processing algorithms for object recognition using object colors and shapes.
4. Integration of the mobile robot software, robotic arm software, image processing and camera calibration algorithms to deliver an integrated and completely operational software system.

These objectives will be documented as a modules for robotics course in Mechatronics program to help students to build the basic and advanced robotics concepts. There are 10 modules: – Introduction to robotics (Module 1), elements of robots (Module 2), kinematics of serial and parallel robots (Module 3 and Module 4), velocity and static analysis of robots (Module 5), dynamics of robots (Module 6), motion planning and control (Module 7), flexible manipulators (Module 8), wheeled mobile robots (Module 9) and advanced concepts & topics (Module 10).

B. System Functional Requirements

1. The functional requirements of the software system are explained in this section. Functional requirements are the technical criteria the software is expected to achieve. Integrated software system is expected to provide the following capabilities:
2. The mobile robot and robotic arm must be operated autonomously.
3. The mobile robot must be able to recognize objects by shapes and/or colors.
4. The software must allow the robot to retrieve objects of interest from the environment.
5. The software must be able to provide images from the environment to the user.
6. The user must be able to switch between platforms, i.e., mobile robot and robotic arm.
7. A user friendly graphical user interface (GUI) must be developed and integrated with the software. The GUI must allow users to interact with the robots using speech commands.

The above seven functional requirements are important characteristics of the developed software system. The system must satisfy all these requirements.

The robot's safety is considered by always allowing the robot to perform its action(s) in an obstacle free workspace. The software of this project should be scalable. Also robustness and reliability of the developed hardware and software must be considered in the design. Flexibility is also an important non-functional criterion of the system and good technical support will help users become familiar with the system and resolve any problem fast. A no reliable system will be source of problems to the users. The system uses communication tools to enable the mobile robot local communication functions. The system requires 128 Mbytes of hard disk space as minimum storage space.

Proposed Research Approach

There three different types of robotics control strategies, 1) reactive, 2) deliberative, and 3) hybrid. The hybrid control architecture is chosen over the reactive and deliberative control strategies for the following reasons. First, hybrid architecture tends to have a high degree for each targetability. The existence of deliberative components in the hybrid architecture provides it with the required flexibility and allows it to be used in applications where purely reactive systems are not sufficient. Second, hybrid architecture often explicitly attempt to ensure
robustness which is also one of the requirements of the developed system. Modules within the various deliberative either attempt to monitor the performance of the reactive behaviors. The main idea of having coordinated robotic system is to increase the robustness and reliability in achieving robotics tasks through coordination between mobile robot and robotic arm. This is an important requirement of mechanism for combining behaviors, including the proposed approach for combining behaviors, which is the subsumption architecture. Figure 1 represents a functional block diagram of the proposed approach. From block diagram it can be understood that the software of the integrated system starts when the user sends command to the robot through friendly graphical user interface (GUI). The mobile robot navigates the environment and automatically detects some potential objects of interest by using robot perceptual and fusion software. The mobile robot and the user mutually interact during this process because once an object is detected and classified the robot may ask the user if its location should be recorded. Once the Mobile robot finishes building a representation of the environment during the learning and navigation phase, then, the arm could start to pick up objects from the floor and retrieve these objects back to the user.

**Figure 1. Functional Block Diagram of Proposed Software System**

**Detailed Description of the Development Mobile Platform**

The Pioneer 3-DX mobile robot, shown in Figure 2, has two (2) independent wheels, one (1) castor wheel, three (3) batteries, two (2) motors with encoders, two (2) microcontrollers—one for robot itself and the other for arm, a power board, eight (8) sonar sensors in the front, eight (8) sonar sensors in the back and a canon PTZ camera. Communication with a PC can be done using wireless or wired connection to a laptop or desktop. The Pioneer 3-Dx has a 50x49x26 cm aluminum body with two (2) wheels and can move at speeds up to 1.6 meter per second. At slower speeds the robot can carry payload of up to 23 kg including additional batteries and accessories. Pioneer 3-DX's hinged battery door makes hot-swapping batteries simple through a
P3-DX base can run 18-24 hours on three fully charged batteries. With a high capacity charger, charging time is only 2.4 hours.

Sonar sensors: P3-DX supports both front and rear sonar arrays, each with eight transducers that provide object detection and range information for collision avoidance, localization and navigation. The sonar positions in all arrays are fixed one each side and six facing outward at 20-degree intervals as shown in Figure 3. Each sonar array comes with its own driver and electronics with sensitivity ranges from 15 centimeters (6 inches) to 8 meters. Ranging technology (sound navigation sonar) has been widely used in Time-Of-Flight (TOF) measurement systems since they are inexpensive and convenient to use. TOF is the time elapsed between transmission and a pulse.
One of the important limitations of these sensors is their low angular resolution. Acoustic Sensors widely are used as they are inexpensive and convenient to use. Sonar sensitivity adjustments controls are accessible to the user directly. Reducing the sonar-gain setting will increase the robots ability to see small objects.

Vision system:
The camera available on the robot is the Active Media Robotics’ Cannon VC-C4 Pan-Tilt- Zoom (PTZ) color camera [6]. It can be easily integrated with Active Media mobile robots. This camera can be configured for use with any of custom vision routines, or with ACTS color tracking application. The PTZ camera system shown in Figure 4 includes the Cannon VC-C4 with Pan—Tilt—Zoom mount and power cables.

There are several software available that can perform image capturing by this camera. Matlab and VC++ are the mostly widely used software. Matlab image processing
Toolbox can be used with this camera and it provides the user with an extensive suite of robust digital image processing and analysis functions. The basic data structure in Matlab is the array, an ordered set of real or complex elements.

**Development of Graphical User Interface**

Graphical User Interface is an important step toward satisfying the last functional requirement of this work which is integration of the mobile robot software, robotic arm software, and image processing and camera calibration algorithms to deliver an integrated and complete operational software system. The various programming language options for developing Graphical User Interface (GUI) are C, C++, Visual Basic (VB), and Java. Among these alternatives Visual Basic 6.0 is used as the programming language because it is very flexible particularly in developing executable code leading to a user friendly interface, as shown in Figure 5.

![Graphical User Interface (GUI)](image)

*Figure 5. Graphical User Interface (GUI)*
The robot components integrate well with VB environment. The requirements for the integration of the hardware and software subsystems are bi-directional communication and real-time feedback. The components of the hardware subsystem were integrated by properly setting up the server computer and connecting the robot accessories via USB, AUX, and COM ports. Once the robot and computer were connected, the robot server and camera server were started. Confirmation that the system was properly started was obtained from the command prompt window which indicated that the robot and camera were successfully connected. After this confirmation, the hardware subsystem was prepared for testing with the software subsystem. The graphical user interface shown in Figure 37 performs many functions. The user connects to the robot by clicking on the 'Start' command button. The user can end the connection with the robot by clicking on the 'Shut' command button. Driving functions consist of command buttons 'Go', 'Back', 'Stop', 'Left', and 'Right'. The user can control the mobile robot and the robotic arm through selection of robot behaviors. When the 'Start detection' button is clicked the detection algorithms are invoked and the mobile robot runs its detection system. The image screen can display images and figures important to the user. The user can interact with the robot by several ways like 'click' buttons or 'type' text or by 'voice' commands.

The framework that control the robot was added to VB code in the form of ACTIVEX DLL called PioneerClient 1.0 Type Library. Likewise Microsoft Speech SDK was also added as an ACTIVEX DLL called Microsoft Speech Object Library. Matlab's Image Acquisition and Image Processing Toolboxes were used in conjunction with the robot camera for object detection, object classification, and object identification in the environment. The output data from Matlab programs was stored in the context space. Information is sent in the form a binary text file.

**Testing the Software**

Several experiments were conducted with different tasks to test and evaluate the software control system. The proposed design of intelligent control strategy for the mobile robot and robotic arm and the subsumption architecture for combing behaviors were used in these experiments. The results of the testing were documented with photos and movie clips. Followings are descriptions of one of the test scenarios.

**Test**

In this scenario the object classification based on shape is tested. After the mobile robot navigated in the environment and detect some objects with the same color but different shapes. The user asked the robot through GUI to classify these object based on their shapes. The GUI provides the user with the following information regarding to these objects: 1) life image of the object, 2) name of the object after the classification process is done, and 3) the classified figures through list of figures under command button "see figure". Figure 6 shows the mobile robot has classified triangular, after the user used command button "classify object". Finally, the user may request the robot to pick up the object of interest. Then, the robot arm moves to accomplish this task through certain planned movement sequence. This sequence include: 1) robotic arm at home position, 2) robotic arm is fully extended and aligned with the object, 3) the robotic arm picks—up the object from the ground, and 4) the robotic retuned back carrying the object and putting it back on the robot, After that the robotic arm returned to the home position. Picking up object sequence is shown in Figure 7.carrying the object and putting it back on the robot, after that the robotic arm returned to the home position. Picking up object sequence is shown in Figure 46.
Figure 6. Select Object of Interest from a Class of Objects

Figure 7. Robot Arm Picking up Object Sequence.
Conclusions
The main goal of this research was to develop a software system for a mobile robot and robotic arm that would enable users to use the capability of both to coordinate their activities to accomplish a given robotic task with high reliability and high degree of performance. Using subsumption architecture for combining behaviors and hybrid paradigm for intelligent control strategy. Both of the proposed approach have been implemented and tested successfully through conducting many different scenarios. The testing results demonstrated the success of the designed software and the successful integration of the software with the experimental hardware. The results of this research will be converted to ten modules as mentioned before to support robotics course in Mechatronics and related programs. Also, this work will be initial work for future research for graduate students special in area of robotic human interaction.

References