The Use of Low-Cost RC Servos in a Robotics Curriculum

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Abstract

Small hobby servo motors designed for remote controlled (RC) model cars and airplanes are commonly used actuators by robotic hobbyists. They also serve as actuation for a number of commercially available robotic kits. These inexpensive RC servo motors can serve as a useful low-cost alternative actuation method for student projects and laboratory investigations. This paper discusses two laboratory assignments and two independent student research projects that have used this type of actuation.

Introduction

RC Servo motors are a common actuator utilized by robotic hobbyists and serve as actuation for a number of commercially available robotic kits. These small servos utilize pulse-proportional control and provide simple and accessible open-loop actuation. The servos come in a variety of sizes, and with costs on the order of $10US, they fit within any budget. Simple modifications can be made to convert the ~180° range of motion to continuous motion. The addition of a serial control board provides an effective means of managing a number of servos from a variety of platforms. An additional advantage of using these servos is that they are easily adapted for both direct (wired) and remote (wireless) control. The authors have found serial control of RC servos to be useful in a variety of laboratory exercises as well as independent student research. Within our robotics program, we have used the serial control of RC servos as part of commercial kits such as the Palm Pilot Robot Kit and the Robix RCS-6 construction kit. We also have used RC servos as part of student designed robotic vehicles. In the following sections, we

- provide curricular background for our undergraduate program,
- list some of the low-cost equipment that we utilize, and
- detail some of our laboratory equipment and student designs that utilize RC servo motors.

Background

Midshipmen in the Systems Engineering Major at the U. S. Naval Academy take an interdisciplinary curriculum with an emphasis on control systems and dynamics. We offer three robotics courses that satisfy senior-level technical elective requirements. The first course emphasizes manipulators and machine vision, including coordinate transformations, forward and inverse kinematics, Jacobians, and simple image processing. The second course covers camera-robot calibration, visual servoing, and pattern recognition. The laboratory for these two courses consists of ten robotic workstations outfitted with machine vision systems. We use both the SCORBOT ER-V and the ROBIX™ RCS-6 kits. The third course, on mobile robotics, covers the design and implementation of various locomotive methodologies, closed-loop control systems, sensor suites, novel actuators and path planning techniques for mobile robots using the Parallax Basic Stamp II™ and the RCX microcontroller from the LEGO® MINDSTORM™ robotics development kit. Programming environments for all classes include MATLAB™, Borland C/C++, PBASIC and NotQuiteC. A one semester programming course is a prerequisite for all of the robotics courses. The curriculum that we utilize focuses on open-ended problems with more than one plausible solution. The use of reconfigurable kits (ROBIX and LEGO) permits rapid prototyping of solutions to challenging problems in a reasonable time frame while still maintaining technical rigor and an appropriate level of intellectual challenge. With an excess of 100 robotics students and no teaching assistants, we seek equipment that is easy to integrate, suitable for use in multiple sections, and effectively reinforces classroom theory.

Equipment

RC servo motors, designed for remote control vehicles, come in a variety of sizes. Common brand names include Hitec and Futaba. Six RC servo motors and a variety of links and connectors come in a Robix RCS-6 kit (http://www.robix.com). These kits can be used to build small serial or parallel (Ebert-Uphoff 2003) manipulators. These kits provide students with a quick and easy way to prototype and investigate workspace design. The kits come with a parallel port interface with a set of velocity profile commands. We have found that direct access can be achieved with a separately purchased serial motor control board, such as Pontech's SV203 or a SSC-II controller. (The SV203 has five on-board analog-to-digital converters to read in data from analog sensors. The SSC-II features only serial servo control.) This type of interface permits students to develop functions and to utilize array variables in a programming environment such as MATLAB or C/C++.

Developed by Carnegie Mellon University, the Palm Pilot Robot Kit (http://www-2.cs.cmu.edu/~reshko/PILOT/) features servomotors modified for continuous rotation. The three equally spaced motors control omni directional wheels to provide holonomic motion. The kit includes the SV203 board to read in data from ranging sensors and send control commands to the three motors. The kit is designed to be controlled by an on-board Palm Pilot (purchased separately). Alternatively, the SV203 can be connected to a wireless serial modem and controlled remotely by a PC or microprocessor.

RC servo motors also can be utilized in student built robots. Links and mechanisms can be designed and built in a machine shop, or devised from LEGO components. Several online resources outline how to modify the servos to create a continuous rotation gear motor[1,2,3].

Reconfigurable Manipulators: ROBIX RCS-6

In order to facilitate the investigation of various manipulator configurations, we equip lab stations for two or three students with a PC, a Robix RCS-6 kit, an SV203 board, and a power supply. Software is written in the MATLAB environment, but any programming language with serial communication will work. A sequence of laboratory exercises reinforces topics covered in the classroom. A "spot-welding" exercise helps students experiment with manipulator design and issues such as throughput, accuracy, and repeatability. Spot-welding consists of affixing a star washer to various magnets located on a small toy vehicle. Other laboratory assignments include forward and inverse kinematics exercises to reinforce classroom theory in a visual manner. Students develop experience in writing computer functions as they develop their software.

Figure 1 A partially assembled Robix RCS-6 manipulator for "spot welding" laboratory exercise.

Student Designed Mobile Robot Platforms

Robotics courses that focus on design face a variety of challenges for the instructor. Primary among these is that the students must be provided with sufficient time to develop a novel solution to a design challenge. The amount of time required for a given challenge will depend not only on the objectives of the exercise, but also on the set of available materials. Much more can be accomplished in a semester if appropriate rapid prototyping tools are available. This has been the prime motivator behind the use of LEGO Technics and Mindstorms systems in secondary education.

What limits the effectiveness of LEGO systems for advanced designs is that the connectors and elements have a great deal of flexibility. This problem is compounded by the fact that complex gear trains require many connections and substantial physical space, and are in the end extremely mechanically inefficient. In our mobile robot design course, we use RC servomotors coupled to LEGO parts to rapidly prototype walking robots. This approach allows us to place high torque, low weight actuators on complex appendages without a great number of extra linkages. Students are then able to investigate walking robot designs and novel locomotion

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1 http://www.acroname.com/robotics/info/ideas/continuous/continuous.html
2 http://www.mekatronix.com/manuals/misc/servohack.pdf
3 http://www.seattlerobotics.org/guide/servohack.html

methods over the course of just a few class periods. Examples of completed systems are seen in Figure 2.

While the use of servomotors substantially decreases the mechanical complexity of most LEGO legged locomotion designs, the motors must be coupled to the LEGO pieces. This turns out to be relatively straightforward using the screws and mounting horns provided with most commercial RC servomotors, as well as LEGO frames, zip ties, wires and even rubber bands. This component of the exercise also provides the students with some insight into issues regarding motor mounts and systemic stress.

The real difficulty with using RC servomotors with LEGO systems is that the LEGO RCX is not configured to drive the servos. As such it is generally necessary for the instructor to support at least one additional computing or control platform (if the RCX is used at all), or to design a separate interface, as described online at (http://www.inchlab.net/2servo_interface.htm). The Parallax Basic Stamp II has straightforward servo control commands and is both relatively cheap and easily embedded in a fully mobile design. Another method is to use a separate control board (such as the Pontech SV203) with any processor capable of serial communication.

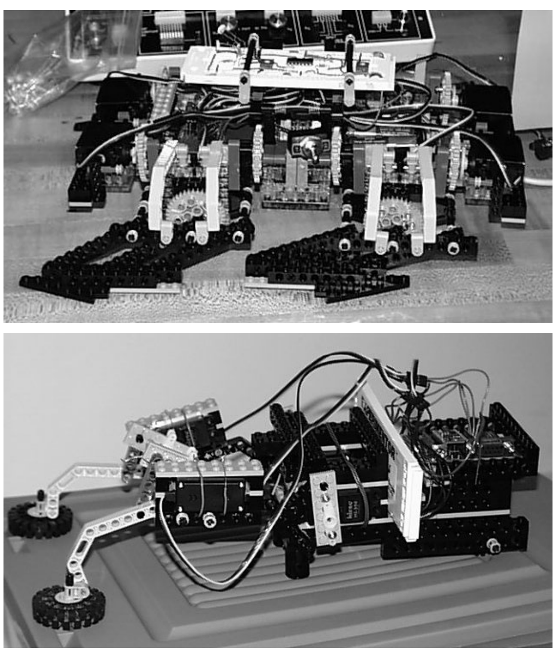

Figure 2 Lego walking robot prototypes.

By adding servomotors to a robot design course, it is possible to substantially increase the functionality of the parts kit with very little additional investment in time or resources. The internal gearing and control allow precise positioning without a great deal of additional hardware, and the motor itself is an excellent example for discussions on feedback control, gear ratios and gear train design.

Palm Pilot Robot for Autonomous Rendezvous and Capture Studies

There has been growing interest within the United States space community to develop autonomous rendezvous and capture (ARC) capability on unmanned space vehicles. There is, however, an inherent high cost associated with the research, development, and testing of autonomous rendezvous and capture in a space environment. Consequently, a robotic platform that is capable of accurately simulating spacecraft dynamic motion will enable students to study the problem in a low cost environment.

An inexpensive test facility that uses mobile robotic platforms to simulate relative planar motion for evaluating ARC control system logic and sensing strategies has been developed using a desk-top simulation computer, two mobile robot platforms, and a vision system (Ho et al. 2003). The simulation computer computes the dynamic behavior of the space vehicles in the space environment. The robot platforms representing the space vehicles will move in accordance to the simulated space vehicle behavior. The mobile robotic platforms used in the simulator are based on the Palm Pilot Robot Kit (PPRK) that was designed by the Carnegie Mellon Robotics Institute. The robotic platforms use three omni directional wheels in a triangular arrangement that can drive the platform in any direction with independent control of rotation, meaning it moves holonomically in the plane.

The main chassis of the PPRK was kept intact. The main feature of the PPRK is its ability to perform holonomic maneuvers and consequently it is able to simulate the orbital maneuvers of a satellite. The robot is intended to be controlled by a Palm Pilot Personal Digital Assistant (PDA), but for this project, a wireless modem was replaced the Palm Pilot to allow the transfer of command inputs from the controlling desk-top computer to the robot. Robot locomotion is provided by three hobby servo motors placed 120^o apart, as shown in Figure 3. The motors are controlled by a Pontech SV203 controller board. The servo motors are attached to omni-wheels, shown in Figure 4, which have rollers to allow the wheel to slide sideway.

Figure 3 Bottom view of a PPRK robot developed by Carnegie Mellon.

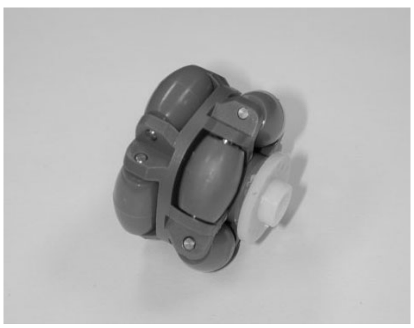

Figure 4 Omni-directional wheel.

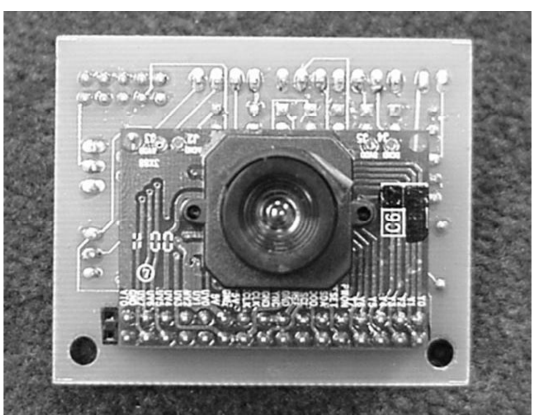

Figure 5 CMUcam developed by Carnegie Mellon

A CMUcam vision system (http://www-2.cs.cmu.edu/~cmucam/), as shown in Figure 5, is used to provide continuous positional feedback of the robotic manipulator. The CMUcam plays a role similar to the Global Positioning System (GPS) in determining the position of satellites. The CMUcam is capable of tracking color at 16.7 frames per second at a baud rate of 115200 and has a maximum resolution of 80 x 143 pixels. The resolution is limited, but it is sufficient for determining the centroid of the robotic manipulator.

The system is controlled within the MATLAB programming environment, which is able to communicate to the wireless modem and the CMUcam via the serial ports. The code simulates the relative dynamic motion of the spacecraft (mobile robots) in accordance with the Clohessy-Wiltshire linearized orbital equations of motion (Clohessy and Wiltshire 1960) (Wie 1998).

Urban Search and Rescue Prototype

Urban Search and Rescue (USAR) is a challenging domain for robotic systems. The severe conditions present in most urban disaster sites require that platforms be small, powerful and flexible. These design requirements indicate that the actuators selected must have a small profile and low weight while still delivering sufficient torque to move the vehicle. Servomotors, with their high built-in gear ratio, make them an excellent, low-cost solution for these vehicles. Used in both positioning and locomotion, these devices are an excellent choice for prototyping USAR vehicles.

As part of a Trident Scholar project, a one year senior research program, Bryan Hudock designed and built a prototype for a USAR robot (Figure 6). The primary goal of this project was to develop a physical structure that would be sufficiently agile and flexible for this challenging terrain. The resulting vehicle is a segmented, tracked system with 'selective compliance.' All actuation uses off-the-shelf servomotors with brass gearing and high torque-to-weight ratios. The motors that drive the tracks have been modified for continuous rotation, while those that orient the segments have been left in their original condition. The system uses six servomotors per segment: four for tracks (two each top and bottom) and two for pitch and yaw control of the segments. The system is extremely agile, and can 'tunnel' through loose material by pushing simultaneously with the top and bottom treads in the same direction (as opposed to a single-tread system, where the top of the tread impedes progress if it makes contact with the environment). The selective compliance technique uses tensioning springs attached to the pitch controlling servomotors so that the natural equilibrium point of the system can be modified. The actual pitch of the vehicle is determined by the combination of spring tension and ground support, enabling motion over extremely uneven terrain without active control while simultaneously permitting controlled pitch motions for advanced locomotion.

This design relies heavily on the availability of compact, sturdy, geared electric motors. The use of

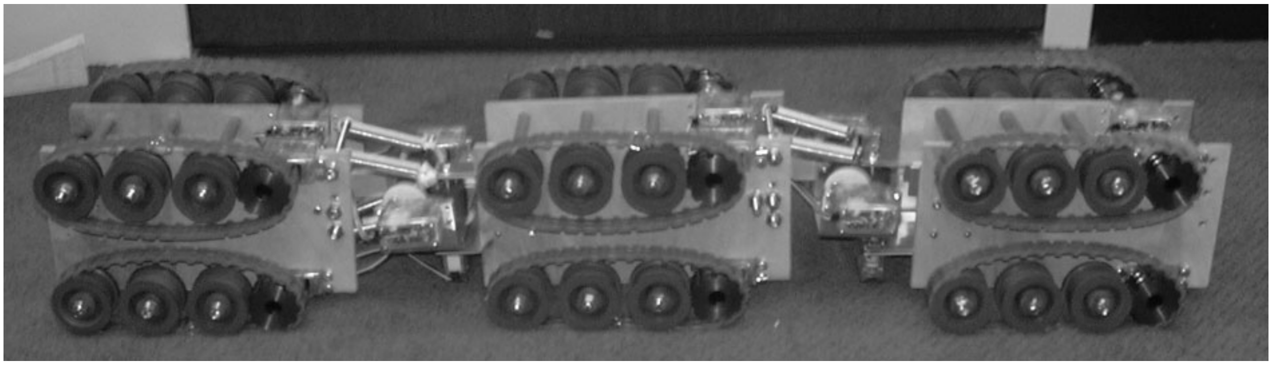

Figure 6 Urban search and rescue robot prototype featuring dual treads and selective compliance joints between identical segments.

standard RC servomotors enabled the student to focus much more on the novel robot morphology than on the intricacies of actuation system design. The student research project also looked at genetic algorithms to study gaits.

Observations

The use of small inexpensive robots in a robotics curriculum has a number of advantages. Manipulator and mobile robots created with servo motors permit students to quickly build and test robot designs. The addition of a RS-232 serial controller provides a simple interface between software and hardware. Limitations include limited accuracy, and slight variations in resolution, dead-zone, and accuracy between motors of the same type. These limitations, however, do serve to force the student to be aware of such practical issues. Student investigations can range from a simple Denavit-Hartenberg forward kinematics assignment, to a genetic algorithm study of gaits for a modular robot design. We hope these examples will serve as useful ideas in developing robotics laboratory exercises and projects.

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