

## **Robotic Motion Control**

### **Commercial Applications**

Robots are showing up in many aspects of human life, keeping people safe, exploring harsh environments, and automating many everyday tasks. One popular line of robot assistants is iRobot Corporation's Roomba™. At \$120 to \$400, customers can select one of these robots to automate vacuuming and sweeping around the house. Some come with scheduled cleaning features, and wireless command centers as well. iRobot also offer a programmable version of the Roomba called the Create™ at \$130, which is targeted at developers and robotics students. It is identical in most respects, except for its lack of cleaning apparatus. The Roomba and Create have 32 on-board sensors which keep them informed of obstacles, and allow them to communicate with a remote or charging base station. The Create also offers serial ports allowing a developer to easily extend its features. The Remotec ANDROS family of robots, by Northrop Gruman, finds wide usage with "first-response" teams such as law enforcement, and military. These robots are mostly tank-style rovers with versatile robotic arms. The arms provide tools such as grippers, work-light, camera for remote control, and environmental sensors. As a mission critical application where lives may be at stake, an ANDROS robot requires highly accurate control systems. What all of these machines have in common is that they are mobile, and goal oriented. The design of effective mobile robots involves intelligent, efficient, and accurate motion planning and execution systems.

### **Background**

A robotic motion control system is one example of a classic negative feedback system. It has at minimum four components [1]. 1) A digital controller handles decision making, and signals lower subsystems in order to meet higher level motion goals; 2) power switch and power drive circuits control the motor more directly, and are tailored to the type of motor they drive; 3) a motor uses an electromagnetic mechanism to create torque on an output shaft, which effects motion; and 4) a sensing mechanism closes the loop, feeding the measured motion back to the digital controller.

### **Control Systems & Components**

#### Servos

As the literature [2] suggests, servos incorporate all of these components into one device. A single board will host the controller, and the power circuits for the motor. A potentiometer communicates the actual angular position of the motor back to the controller. Servos are said to operate "proportionally",

in that the motor is driven with power proportional to the error in the angular position, until the motor shuts off. They are popular in robot applications because they are self-contained, inexpensive and power efficient. The interface is basic: they typically need a single external control line which sets the position to track. Complex applications, like robot manipulators or humanoid robots with their many moving parts, benefit especially. They are good local motion control units, but a more capable controller or processor is usually required to coordinate several servos, and other systems the robot may have.

### Intelligent Controllers

While for some applications a classic PID control approach may suffice, others demand robustness and fault tolerance that rigid algorithms can't always offer. Fuzzy logic controllers fill that gap. They allow one to address hard to model decision problems. A fuzzy controller takes in defined system parameters, and consults a rule-base that details appropriate responses. Multiple rules can be activated at once, and to varying degrees. This fuzziness makes the system very flexible and able to handle large grain disturbances. In [3], the researchers have applied a fuzzy theory to a navigation controller in a modular fashion. Separate layers handle different aspects of the decision making – i.e. obstacle avoidance, high level orientation, and low-level pathway navigation. The responses are then fused intelligently. When coupled with neural networks, intelligent controllers can even give robots the ability to learn behaviors. Neural nets can be thought of as mappers or associators; given a vector input, they produce a certain vector output. They are modeled after the brain: each neuron takes in inputs, weights them, and thresholds the response according to an activation function. With well chosen input-output patterns, and appropriate mathematical techniques, one can train a neural net to recall desired responses to some unanticipated inputs by incrementally adjusting the neuron weights. Studies like the work in [4] are looking into algorithms for tuning neural networks as they operate, which allows for highly advanced robotic autonomy in certain tasks.

### Optical Encoders

Regardless of how sophisticated the controller is, the system may still fail to meet its goals if decisions are made on faulty data. One device used to track rotational motion is the optical encoder. It can be found on many things from hobbyist robots and RC vehicles, to silicon fabrication machinery. The components of an optical encoder are as follows. A transmitter, such as an LED, is mounted opposite a receiver such as a photodiode or phototransistor that can translate light to an electrical signal. A metal disk is fabricated with slots, and mounted on the rotating element, so that it spins between the

transmitter-receiver pairs. As the rotor turns, the receiver periodically sees the light through the slots, generating a waveform which is directly related to the angular speed, and position. There are two types of encoders: absolute, and incremental. In an absolute encoder, each step on the disk is given a unique slot pattern. An incremental encoder has much simpler disk, with one slot per step. It also has a “home” slot to recognize full rotations. One optical pair tracks rotations through the home slot, and two optical pairs, conventionally “A” and “B”, measure through the same track of slots. They output periodic signals as a measure of angular speed, and are placed at different angular steps so that the phase shift between them indicates direction. In [1], the author notes that incremental encoders are more cost-effective, and likely to be found in common robots, like the Create robot. The resolution of an optical encoder is limited by the number of steps that can be encoded on the disk. One technique that improves resolution is quadrature decoding. The digitized forms of A and B signals are pulse trains, with a 90 degree phase shift between them. Quadrature decoding counts every edge, resulting in four times the resolution of the encoder itself. Interpolation techniques can improve on this even more [5]. The general approach is to count chosen intermediate values in the analog signals when digitizing. Most interpolation techniques involve comparing the analog signals to reference voltages, but in [5] Cheung introduces a technique which compares the A-B signals with each other. His approach multiplies the resolution, without much of the overhead and limitations referenced techniques suffer.

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