

Designing Low-Cost Sensors

Compatible with LEGO® Mindstorms™ Robotics Invention System™

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Abstract

Within the past few years, many robot platforms have been introduced as powerful educational tools in schools at all levels. Among them, the Robotics Invention System™ (RIS) from LEGO® stands out as an excellent instrument for the quick and easy introduction of students to the exciting world of robots. We discuss here (1) how the sensor design represents an educational tool in itself and its educational benefits, (2) aspects of low-cost, RIS-compatible new sensor design and (3) provide an example of new sensor design.

Introduction

After the release in 1998 of the first RIS, two more versions were subsequently launched. While each of these later versions incorporated a considerable number of improvements in both software and hardware, the number of original LEGO® sensors available is limited to a set of four: touch, light, temperature, and rotation. It is inevitable that after mastering the basic features of the system, the users contemplate the expansion of its system capabilities. Although third party, RIS-compatible sensors are available – for a price – there is a more rewarding way to add new features to a RIS-based robot project. By designing new sensors that are directly compatible with the RIS software and hardware, several immediate benefits are reaped: low cost, posing attractive and exciting technical challenges for students, hands-on learning of interfacing concepts, and the clear understanding of the relationship between sensors and software.

Designing a new RIS-compatible Sensor

For the purpose of this paper, we will use the term SENSOR to refer to both actual sensors (i.e., parts that connect directly to the RIS sensor/input ports) and actuators (i.e., modules designed to connect to the motor/output ports of the RIS). Several examples for the

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first category are the magnetic sensor and the metal detector module. For the second category, we mention a LED-based motor direction display and/or monitor, an electromagnet module, and a night-vision IR projector. The number of possible sensors is infinite but in the real world this number is greatly reduced by restrictions placed by costs, precision, development time, and available technologies. For RIS users this number is made even smaller by additional requirements: the new sensors should be mechanically and electrically compatible with the existing RIS hardware and should not require modifications of the existing software. In other words, a newly designed RIS-compatible sensor must emulate one of the existing original LEGO® sensors. If we add reliability, simplicity, and esthetics to the list of requirements, the creation of new RIS-compatible sensors looks obviously difficult. On the bright side, there is at least one requirement that is not stringent for most of the educational robotics applications: demand for high precision measurements. With this assumption, we show below that the mission can be accomplished.

From our experience with elementary and middle school students during our Art Of Robotics summer camps and after-school classes, most new sensor ideas are born from immediate robot design needs (i.g., Magnetic Sensor described below). Other original ideas are generated by students contemplating the possibility of embedding certain exciting features of specific toys into robotics-related projects (i.g., Metal Detector sensing module - description available upon request).

From concept to the assembled sensor

There are several steps to be taken when considering the design of a new sensor. The first one is to specify its technical characteristics (i.e., parameters to be measured, range of values, required precision, etc). The second step consists of research to identify possible measurements techniques, available sensing elements and electronic components for signal processing. A comparative analysis of the results of this research is used to determine the simplest and least expensive solution. During this analysis,

small adjustments of the initial technical specifications may be required. If the sensor requires electric circuitry, a circuit diagram is created as a next step. Individual components of the sensing circuit must be able to withstand the standard RCX™ voltage of 9V DC.

Next, students are involved in creating a list of materials, parts, and tools necessary for prototype assembly and they identify online or catalog suppliers for each item. We have already created a comprehensive list of low-cost suppliers that is available upon request.

The most exciting phase of the design process is assembling and testing the prototype. The circuit diagram is used by students to assemble the sensing circuitry first on a prototype board and, after being tested, on a pre-printed circuit board. The assembled circuit is then housed in an enclosure constructed from standard LEGO® parts.

Meeting The Design Requirements

One of the general design constraints is the cost of the final product. In the case of RIS-compatible sensors, the cost can be kept extremely low (i.g., approximately \$1.85 for the Magnetic Sensor, \$9.40 for the Metal Detector sensing module) either by using inexpensive components or by using “ready-to-sense” modules removed from various off-shelf devices.

The mechanical compatibility requirements are easily met even for the most oddly shaped sensors by placing them in a housing structure made of standard LEGO® parts. Although the dimensions are not very important, keeping the sensor size comparable to that of the original LEGO® parts facilitates the easy integration in standard RIS projects.

Because the RIS software can not be easily modified to recognize new types of sensors, one of the most important issues in the sensor design process is the compatibility of the new sensing module with the existing software. This goal is achieved by emulating one of the four existing LEGO® sensors (temperature, touch, rotation, light). In order to avoid unexpected behavior caused by misinterpreted sensor output by the RIS software, a thorough analysis of the sensor behavior under diverse situations is conducted.

Among the original LEGO® sensing elements, the touch sensor is the best to emulate because in TOUCH mode, the RCX™ unit (the microcomputer at the core of the RIS) monitors only two states: Open/Closed. Both the Magnetic Sensor and the Metal Detector module take advantage of this feature.

Electrical compatibility is assured by using either a custom cable/connector assembly or an original LEGO® electrical cable to connect the new sensing modules to the sensor ports on the RCX™ unit. This solution leads to proper

electrical contacts and reliable mechanical coupling. In cases where the sensing circuitry needs a power supply, this cable plays the double role of carrying the sensor output signal to the RCX™ and supplying power to the sensor from the battery pack mounted inside the RCX™ unit.

Although during the design phase various solutions could be employed for the prototype circuit, soldering the final circuit on a printed circuit board is strongly recommended to increase the reliability of the sensor, especially when used in mobile robotics projects. However, soldering should be performed only after the prototype sensing circuit was thoroughly tested and adjusted for optimal performance.

Design and Assembly Tools and Materials

A wide variety of tools and materials are needed during the design and assembly process of a new sensor. However, many designs will require just a soldering iron and several common tools and materials. For example, in order to assemble our magnetic, vacuum/low pressure, and temperature sensor kits, only a soldering iron, cutter, sharp pointed tool, small pliers, instant glue, wire, and several standard LEGO® parts are required. For more complex sensors, a multi-meter may be useful, along with other test/measurement equipment.

Designing a RIS - compatible Magnetic Sensor

The idea of a magnetic sensor surfaced during an experiment where an RCX®-based mobile robot had to be kept confined to a pre-determined, but easily reconfigurable area. A quick solution would be to place a continuous wall around the perimeter and use a light sensor attached to the robot to detect it and trigger a stop-turn-go reaction. But to reconfigure the walled perimeter was a quite difficult task, especially when the whole set had to be moved to another room.

An interesting solution suggested by one of the campers was to use magnets as markers around the pre-determined perimeter and a magnetic sensor to detect them.

Our research led us to two possible sensing elements: one based on the Hall effect, the other based on a Reed switch. We chose the Reed switch solution because it emulates the original LEGO® touch sensor without any modification. The Reed switch is in fact a simple switch, closed in the presence of a magnetic field, open in its absence. As a result, by connecting the two external terminals of the Reed switch to the two wires of a cut Lego electrical cable, the new sensor can be directly attached to the RCX unit (to any of its input ports).

Using the RIS software, the input port is set to Touch Sensor status. As a result, any RIS program reading this

port will be able to “decide” whether there is a magnetic field present in the proximity of the magnetic sensor.