AC 2007-1438: A GENERAL PURPOSE SENSOR BOARD FOR MECHATRONIC EXPERIMENTS

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Introduction

In the past decade most undergraduate engineering programs have adopted mechatronics in some form into their mechanical engineering curriculum. However, due to their multidisciplinary nature, mechatronics courses[1-3] across the programs vary significantly. Some courses focus on microprocessors and programming, some on sensors and others on controls. There are also mechatronics courses based on robotics. There are also mechatronics capstone design projects.

At Cal Poly Pomona, mechatronics is offered in all these flavors depending upon the course and the instructor. Experience indicates that students who are involved in mechatronics projects are the ones who had some prior exposure in this field and therefore are excited about this relatively new area of study. Efforts are underway to introduce mechatronics early on and as part of this initiative, a general purpose experimental set-up (mechatronics sensor board) has been designed and built.

To make the application of sensor board interesting the system is built around a stationery model car with a sensor array and two microcontrollers (a Javelin Stamp and Basic Stamp). The Javelin Stamp was chosen as the main controller board, with the Basic Stamp as its slave controller. These two controllers process the data and control lights, motors, and a servo. There are five input switches on the display panel as well as a two-line LCD display. The sensor array includes two distance sensors (infrared and ultrasonic), two temperature sensors, a light sensor and accelerometer.

The entire system is constructed on the lid of a plastic storage box for easy transportation. The storage box goes over the board and snaps shut, enclosing the entire model. The AC power adaptor is mounted on the side of the storage box, so the entire unit can be transported without any shifting parts. The system, by default, operates in a demo mode in which each sensor operation is demonstrated.

Demo mode is very useful for new users as they can step through various functionalities of the system. Once acquainted with the basic operations, users can design and develop their own experiments. The general layout of the board is shown in Fig 1. Fig 2 shows fully assembled mechatronics board.

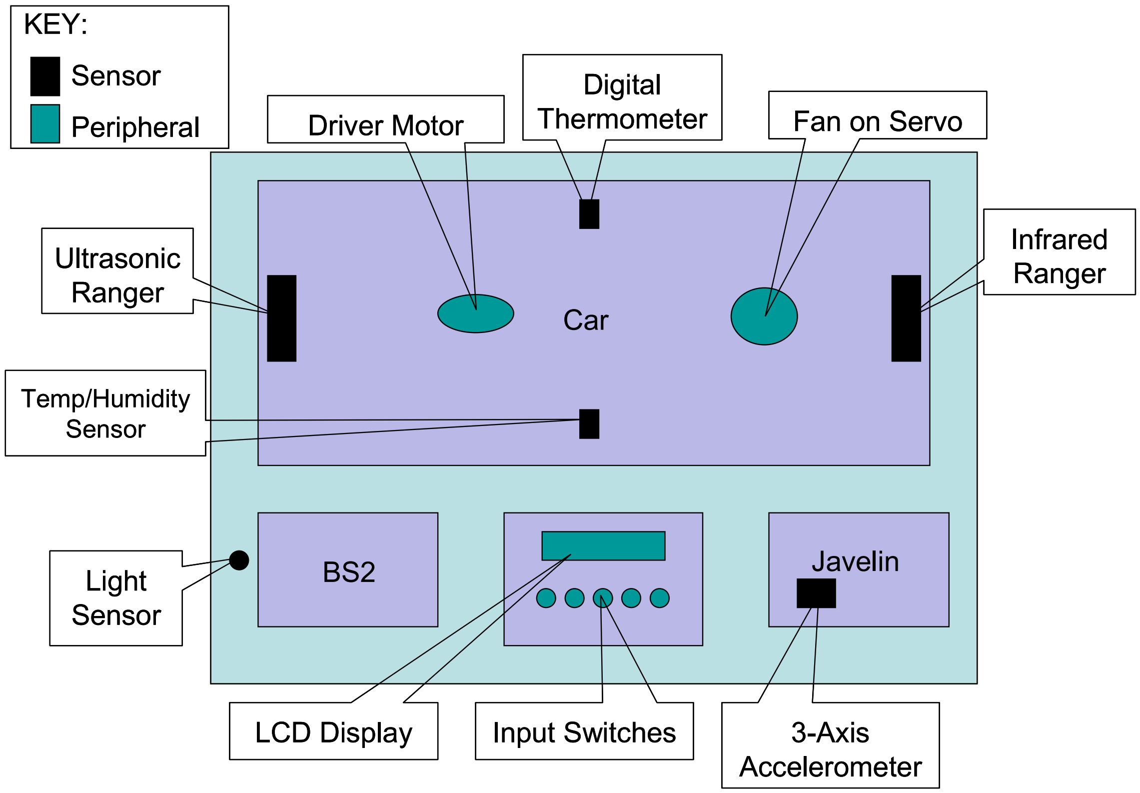


Fig. 1 – Mechatronics Experimental Setup Layout

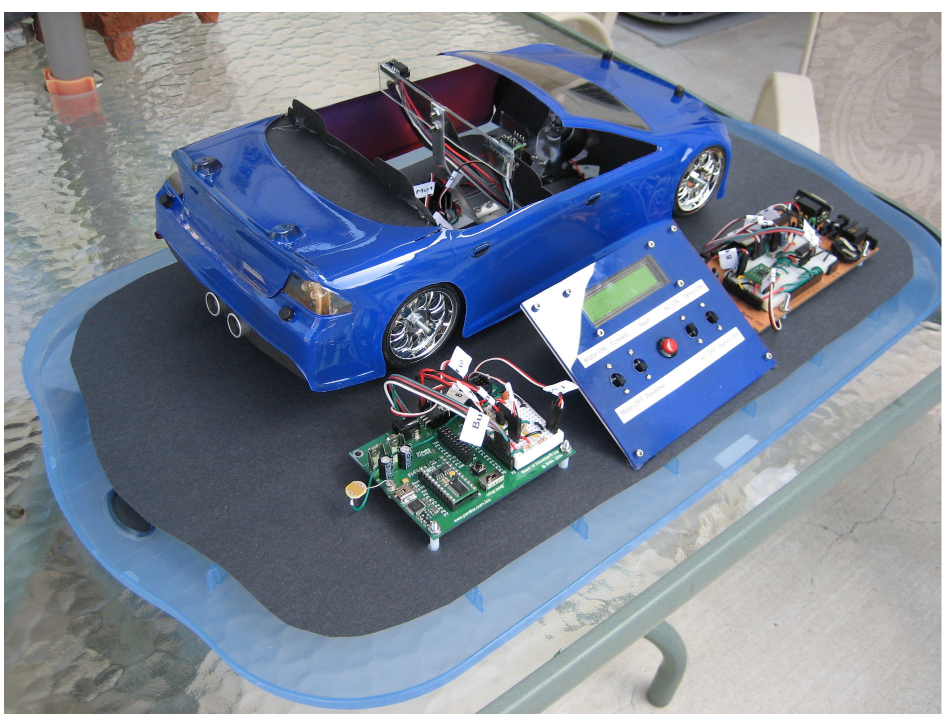
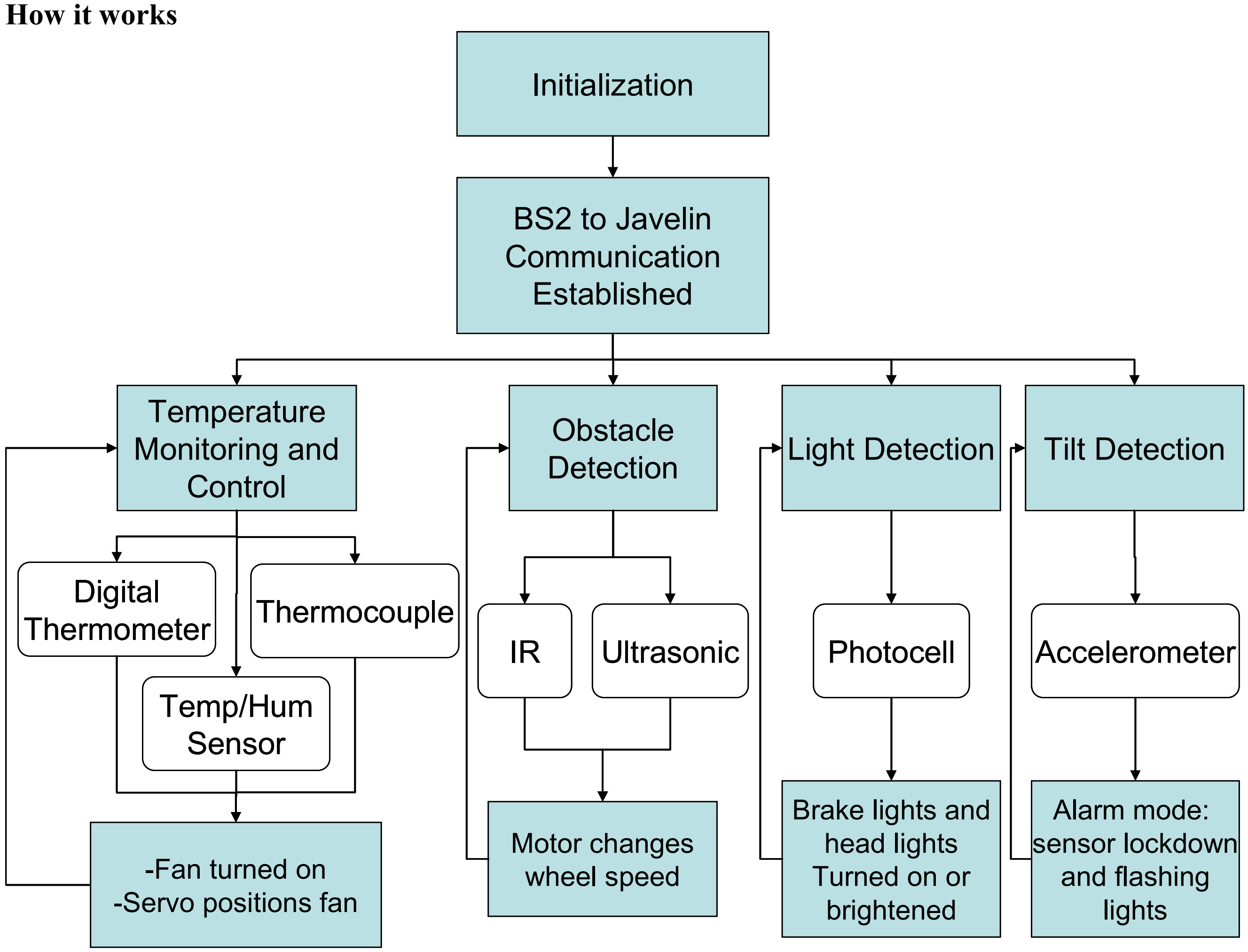


Fig. 2 – Fully Assembled Mechatronics Demonstration Board

How to use it

This model car features 6 sensors which relay information to two microcontrollers, which process the data and control lights, motors, and a servo. In addition to the 6 sensors, there are 5 input switches on the display panel as well as a 2 line LCD display. Two distance sensors are incorporated on the front and back of the car. To activate these sensors, the user switches the car into drive mode, chooses the direction (either forward or reverse), and places an obstruction in front or behind the car. The car's rear drive wheels will adjust their speed appropriately to the distance the object is from the car. If an object is rapidly approaching, the car's rear brake lights will brighten. In addition, the model also includes two temperatures sensors placed atop the car. There is a provision for thermocouple but it is not used in the current setup. Once a 2 degree Celsius difference is created between the two sensors with a hair dryer or other heating device, the car's simulated air conditioning system (a fan) will turn on and direct air towards the warmer section of the car. The light sensor is also incorporated on the display to activate the car's headlights should the room darken or the sensor be covered. Finally, the display has a tilt sensor, which functions as an alarm system. If the model is tilted or jolted, all functions will cease to run and the lights will flash continuously until reset. Fig. 3 shows functionality flow diagram.

How it works



Controller Boards

The Javelin Stamp (Fig. 4) was chosen as the main controller board, with the Basic Stamp 2 (BS2) as its slave controller (Fig. 5). Parallax microcontrollers were chosen because of their known ability to interface with various different sensors, as well as their popularity.

The Javelin Stamp is programmed using the Java language, but it doesn't run off of Sun Microsystems' standard Java. It was chosen over the BS2 as the primary controller because of its object-oriented programming style, allowing for each sensor to have its own class (program). This allows for a clearer, easy to understand main program as well as more versatility for others to reuse the code to modify the project or start one of their own. In addition, the Javelin Stamp offers the ability to run six "Virtual Peripherals," or tasks that execute in the background independent of the main program, a feature which allowed for faster run time and automatic updating of several sensors.

The Basic Stamp 2 was added to the project as a slave microcontroller to the Javelin Stamp after the number of I/O pins required for all of the sensors nearly exceeded the Javelin's 16 I/O pins. The BS2 receives input from the five switches under the display and sends the data via asynchronous serial communication to the Javelin Stamp, which processes the user input as well as the input from the sensors and sends back to the BS2 commands to turn on the lights or the motors.

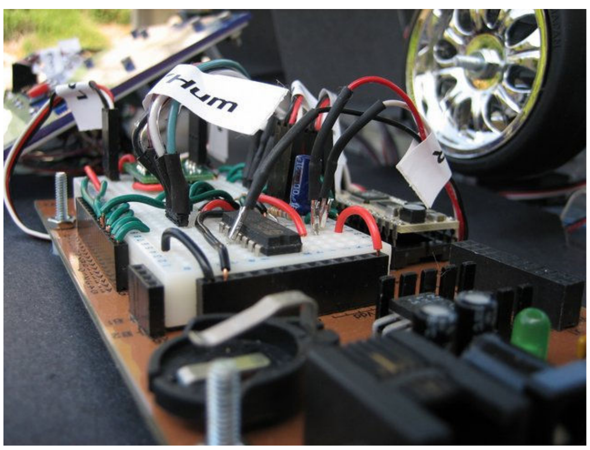


Fig. 4 - Javelin Stamp Controller Board

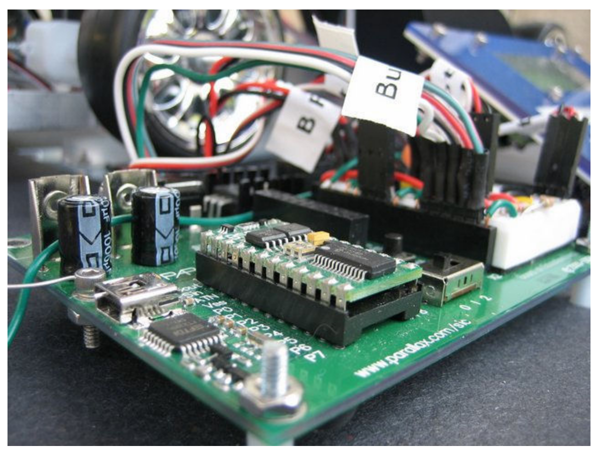


Fig. 5 - Basic Stamp 2 Controller Board

Programming Structure

The primary language used to program this model is Java, an object oriented programming language. To take full advantage of the features offered by this language, each sensor has its own class, or simply, a program that runs all of the features of the sensor, and when given the command, will return a simple output, either a distance, temperature, or other reading. For example, to obtain the distance reading from the ultrasonic distance sensor, only one line of code is needed:

```
ultrasonicSensor.getCm();
```

This line of code returns the distance in centimeters. All of the actual interaction with the hardware, shifting, and calculating is done in the sensor's class. This simplified the programming task tremendously, and allows others who read the program to understand it with less confusion. This example also demonstrates object oriented programming; the ultrasonic sensor is the object, and it's method "getCm()" is invoked to get the data from the object.

As with most microcontroller based projects, the main program is a single infinite loop. Unlike in standard Java, the Javelin stamp does not allow for multiple threads, so it too is confined to a single loop. The algorithm for the Javelin Stamp's main loop is as follows: get data from sensors, manipulate the lights and motors, and then send a command to the BS2. The algorithm for the BS2 is similar: get data from the display panel switches, send that to the Javelin, and switch on the motors or servo as needed. The serial communication protocol between the BS2 and Javelin is simple; the BS2 transmits a single data byte, the first 5 bits containing the states of the input switches on the display panel, and the Javelin Stamp responds with a command byte that tells the BS2 to turn on the fan or motor. Although there are some exceptions, the main programs of each are based around this algorithm.

Input and Output Devices

A button interface panel provides (Fig. 6) various options for user input. Fig. 7 shows the LCD display unit used in the setup. Fig. 8 shows the DC motor fan control and Fig. 9 shows the DC motors that drives the rear wheels through the a gearbox. Fig 10 and Fig 11 show a view of the headlight and brake light options.

Fig. 6 - Input switches and LCD on main display panel

Fig. 7 - 2x16 Backlit LCD display

Fig. 8 - DC motor fan controlled by servo

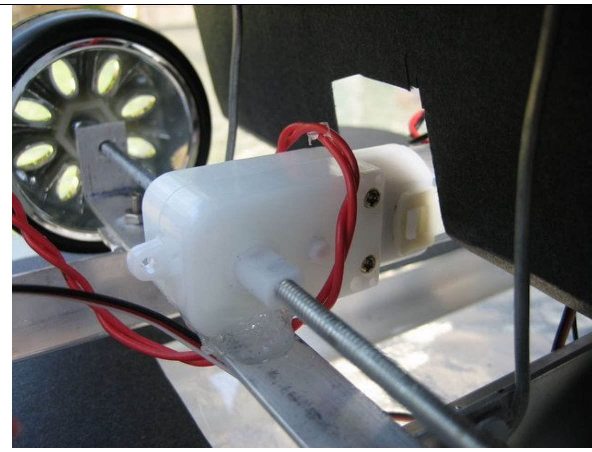


Fig. 9 - DC motor drives rear wheels through gearbox

Fig. 10 - Headlights, two LED's each

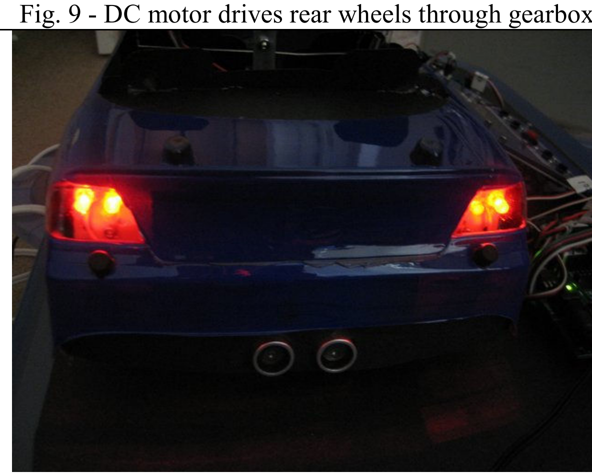


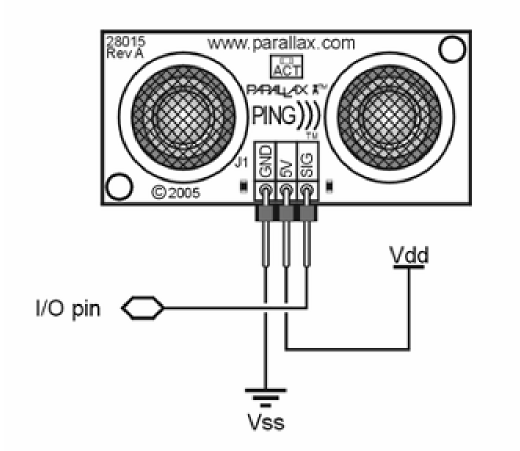
Fig. 11 - Brake lights, two LED's each

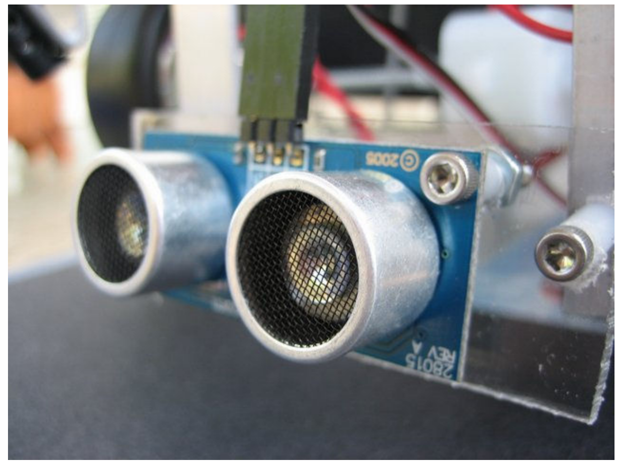
Sensors

In order to make the use of this board easy for all students, instructional sheets containing information about each sensor is developed and attached to the board for easy reference. Each instructional sheet deals with a sensor describing the physical principle behind the operation of the sensor, how it is used in real world, salient features and other relevant specifications along with a writing diagram and a picture. Instructional sheet for each sensor (Fig. 12 though Fig.) is shown below.

Fig. 12 – Ultrasonic Sensor

Sensor: Ultrasonic Ranger[6]
Diagram:

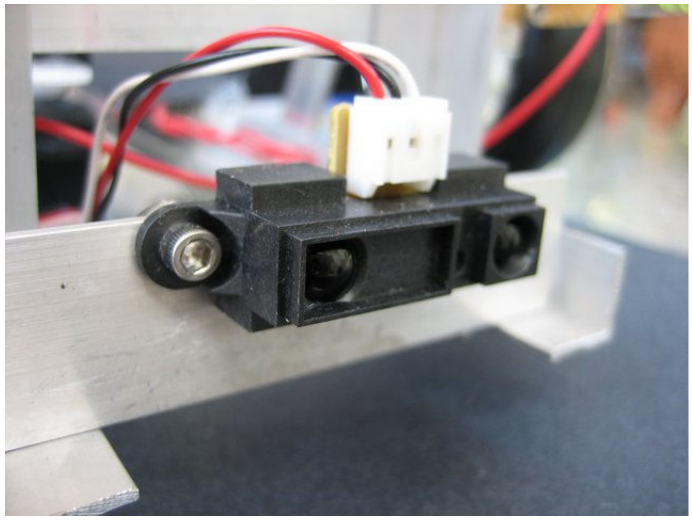




Principles of Operation: An ultrasonic burst of sound is emitted and reflects off the nearest solid object. The time it takes for the wave to return is directly proportional to the distance of the object.
Specifications: Range: 2 – 300 cm
Features: Ultrasonic range sensors offer a relatively wide detection beam and high degree of sensitivity.
How it's Used: The microcontroller sends out a trigger pulse, which causes the sensor to emit an ultrasonic burst. The microcontroller then measures the length of the returning echo, and based off of that, linear conversions can be used to estimate the distance within 1 or 2 cm of error.
Real World Applications: Ultrasonic sensors can be used in situations where depth measurement is required but direct contact unwanted. They can be used on cars for back up assist and object detection, or at drive through places (usually carwashes) to detect vehicles over the height limit.

Fig. 13 – Infrared Ranger

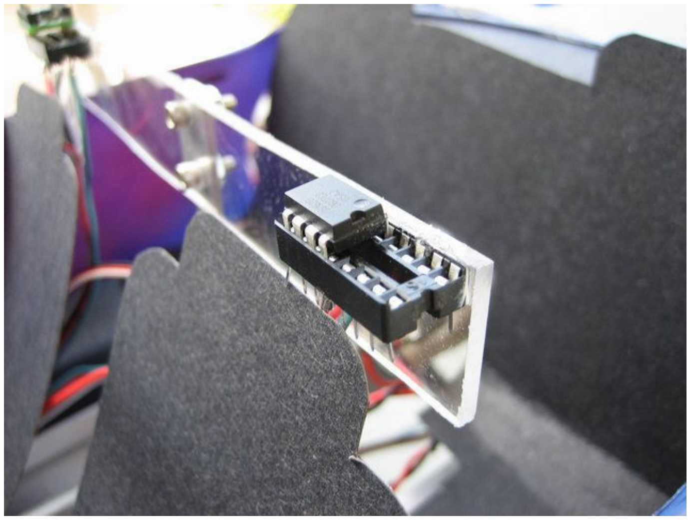
Sensor: GP2D12 Infrared Ranger[7]
Diagram:



Principles of Operation: The sensor emits an infrared LED beam, which bounces off the nearest object. The sensor takes in the return angle of the beam and outputs an analog voltage corresponding with that distance.
Specifications: Range: 10 – 80cm
Features: Because this IR sensor works based on the angle of the returning beam, it is less prone to interference from ambient light or the type of reflecting surface used. However, the voltage output is nonlinear, and requires conversion tables for accurate distance measurement.
How it's Used: The analog voltage output range from roughly .4v (80 cm) to 2.5v(4cm). Note that any measurement closer than 10cm will cause the analog voltage to drop, giving a false reading. In this application, the voltage was converted using an ADC circuit into usable data for the microcontroller. Finally, a linearization table or similar function is needed to calculate the actual distances.

Fig. 14 – Digital Thermometer

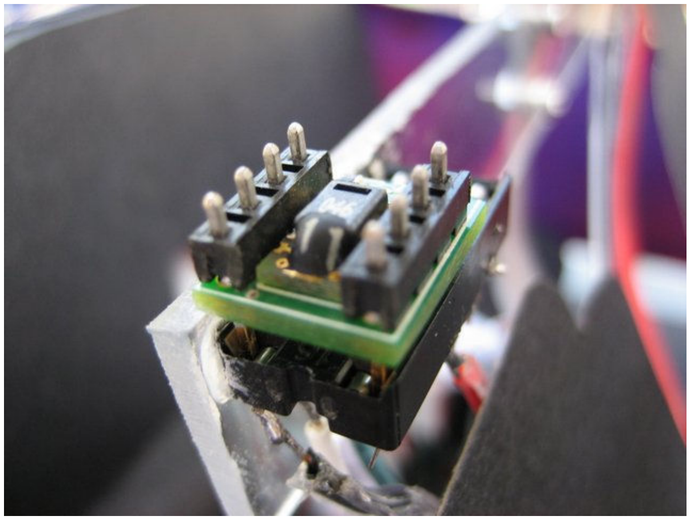
Sensor: DS1620 Digital Thermometer[4,5]
Diagram:



Principles of Operation: The DS1620 is a bandgap-based temperature sensor, which measures the difference between two voltages, one of them from a temperature-dependent silicon diode. As the temperature changes, the current flow through the diode changes, and the resulting voltage difference is converted to a digital signal through a built in ADC, resulting in a linear output.
Specifications: Temperature Range: -55°C to 125°C in .5°C increments
Features: The DS1620 is inexpensive and provides consistent measurements, however, temperature is only sampled once per second and the sensor requires 3 I/O pins for communication.
How it's Used: Data from the DS1620 is obtained through standard serial communication. A command byte is sent out to read the temperature, and another byte is received, indicating the temperature in two's complement.
Real World Applications: The DS1620 can also function as an independent thermostat, if coupled with a transistor. More advanced climate control systems in houses or cars may also take advantage of this low-cost sensor to improve cooling or heating efficiency. As demonstrated by this model, air flow can be directed to hot or cool spots to maximize the effect and efficiency of climate control.

Fig. 15 – Temperature and party

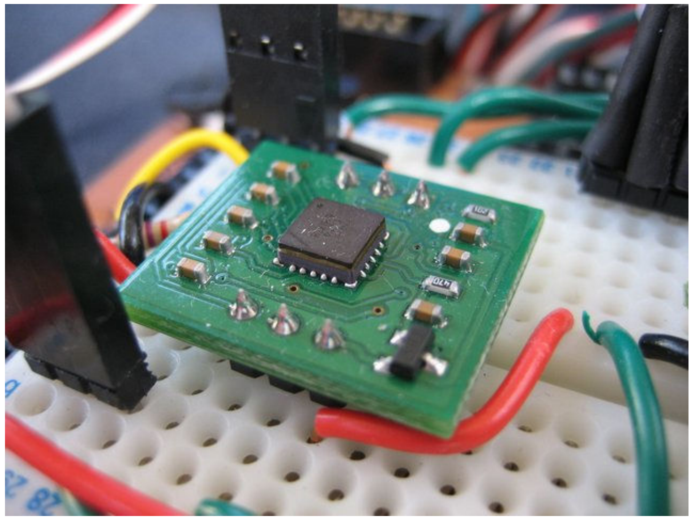
Sensor: Sensirion SHT11 Temperature/Humidity[9]
Diagram:



Principles of Operation: The SHT11 integrates two sensors, a humidity and temperature sensor into one package with a built in ADC and calibration constants to provide an easy to use, yet accurate sensor. The temperature sensing component functions the same as on the DS1620, using a bandgap-based setup. The data from both the temperature and humidity sensor are sent through a 2-wire serial interface.
Specifications: Temperature Range: -40°C to 250°C in 0.1°C increments
Humidity Range: 0 – 100 % in 0.1% increments
Features: While considerably more costly than the DS1620, the SHT11 does offer humidity readings, better resolution, and faster response times. This sensor is highly responsive to any slight changes in temperature and humidity, great for monitoring a rapidly changing environment.
How it's Used: Data from the SHT11 is received through a 2-wire serial interface. Conversion factors are used to achieve the desired units of either temperature or humidity.
Real World Applications: The SHT11 may function as a temperature and humidity sensor for more advanced climate control systems requiring more accuracy. In addition, it may be used for data logging for weather related applications. The SHT11 also has uses in the medical industry, as it can provide data to control humidity and temperature through humidifiers and air conditioners.

Fig. 16 - Accelerometer

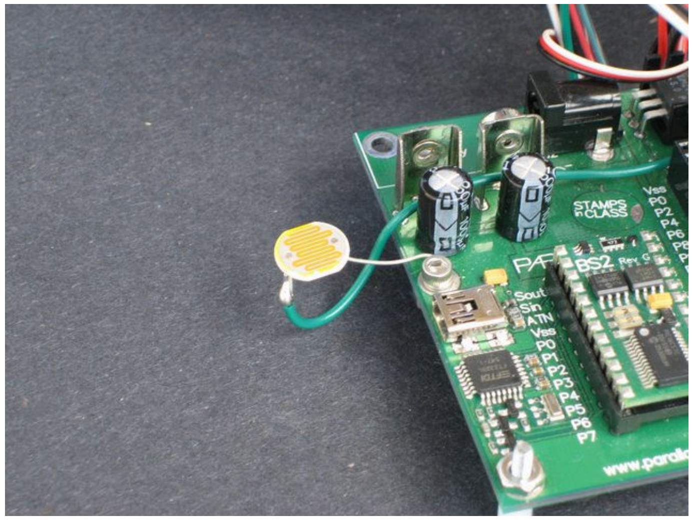
Sensor: Hitachi H48C 3-Axis Accelerometer[8]
Diagram:



Principles of Operation: The sensor integrates the 3 separate acceleration sensors with an ADC to provide data for each axis simultaneously.
Specifications: Range: -3g to 3g, in 0.01g increments
Features: This sensor may be used as an accelerometer or simply as a tilt sensor. As the latter, the earth's gravitational force causes one axis to read close to 1g and the other two near 0g, and any slight deviation reflects tilt occurring. As an accelerometer, the H48C is equally capable. Despite its 3g limit, the H48C can provide high resolution data and allows data sampling 200 times a second.
How it's Used: The H48C's clock and data lines may be shared with multiple sensors thanks to its chip select line. At any rate, data is obtained through synchronous serial communication, and conversion factors are used to obtain readings in g's.
Real World Applications: Accelerometers have many uses ranging from very simple to complex, involving lots of hardware and processing. In this model, it was simply used as a car alarm to detect slight tilt movements. Even further, accelerometers can be used to detect the motion of the car, and trigger actions during collisions or rollovers. Although the airbags for impact collisions need to be deployed quicker than accelerometers can provide a force reading, accelerometers can function as tilt or rollover sensors for cars and trucks, which could deploy side curtain airbags if a rollover is sensed. Even better, accelerometers may even monitor the car's cornering forces, and along with other sensors, determine if the car is on the verge of a rollover and take evasive action to prevent it. Accelerometers also provide crucial data for mobile robots, which are better suited to processing the force readings due to their slower pace. The weight distribution of a robot can be shifted to prevent the robot from tipping over on steep inclines or large obstacles. Finally, accelerometers play an important role in active suspension setups now used in some larger vehicles. A sensor is placed on the free moving part of the suspension mechanism on each wheel, and the conventional springs are replaced by inflatable airbags. As soon as a small force is detected (a bump or pothole), the airbag for that wheel either inflates or deflates, pushing that wheel down or up over the obstacle in the road. Although highly complex and difficult to implement seamlessly, this system would provide superior riding stability as well as safety for the occupants or cargo aboard.

Fig. 17 – Infrared Ranger

Sensor: Photoresistor
Diagram:



Principles of Operation: The resistance of the photoresistor decreases as more light photons are absorbed.
Specifications: Resistance Range: a few hundred ohms (bright) to 25 kilo-ohms (dark)
Features: This simple sensor is widely used and inexpensive. Although response time is slow (it takes about a half second to change from end to end), this sensor does provide variable data about the amount of ambient light.
How it's Used: The resistance generated by the photoresistor and consequent voltage is measured using a capacitor and ADC circuit. For the BS2, this is achieved with the RCTIME command and on the Javelin stamp, the ADC virtual peripheral (background process) is used.
Real World Applications: Photoresistors are widely used today. As shown in this demo, many automobiles utilize photoresistors in the dashboard to automatically turn on the headlights at night, eliminating the need for the driver to switch them on. This also prevents the headlights from being accidentally left on, since they are controlled by the car's onboard computer. Other applications include hand held devices such as cell phones, which often have keypads that light up in the dark.

Enclosed System

The entire demonstration board is constructed on the lid of a plastic storage box for easy transportation. The storage box goes over the board and snaps shut, enclosing the entire model. The AC power adaptor is mounted on the side of the storage box, so the entire unit can be transported without any shifting parts. The total cost of the project was roughly $500, half of that for the microcontrollers, a quarter for the sensors, and the rest for materials, hardware, and the other output devices.

Fig. 15

Conclusion

This experimental setup can be used in a variety of classes. It provides a structured and systematic way to introduce students to sensors, motors, microprocessors, controls and programming. The demo mode provides has been proven to be very useful in introducing the board to new students as it allows the users to step through various functionalities of the system. Once acquainted with the basic operations, users can design and develop their own experiments. The design, construction and testing of the board has been completed. The system was tested successfully with limited number of students to test its feasibility in a classroom.

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