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Computer Interfacing to Real-world: Low-cost Approach

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Computer Interfacing to Real world: A Low-Cost Approach

Abstract

This paper is about how to interface the real world to a computer. Using a low-cost multifunctional Data Acquisition (DAQ) Box with analog in/out (AIO), digital in/out (DIO), and counter, various experiments are designed to introduce several important aspects of computer interface to sensors and actuators. Fifth semester students take EMET 230 as a required course during an eight-semester BS EMET degree program.

1. Introduction

Today, microcontrollers and computers have changed the way humans interact with the mechanized and automated world. Almost every common appliance such as cars, vending machines, washing machines, and dishwashers incorporate a computing system. Information is gathered by sensors and processed by computers or microcontrollers to enable a system response through actuators as shown in Figure 1. Many purely mechanical systems have been replaced by electromechanical systems. For example, encoders now replace the speedometer and odometer worm, wheel, and cable systems. Electric motors with gearboxes replace four bar mechanisms or geared mechanisms in car window openers. Batteries and electric motors replace the coiled spring for energy sources in wristwatches. The previous mechanical systems were simpler and more easily visible while some of the newer technology replacing them may not be as visible. There is a need for the engineering students to become aware of how the replacement technology works by interfacing and interacting with them.

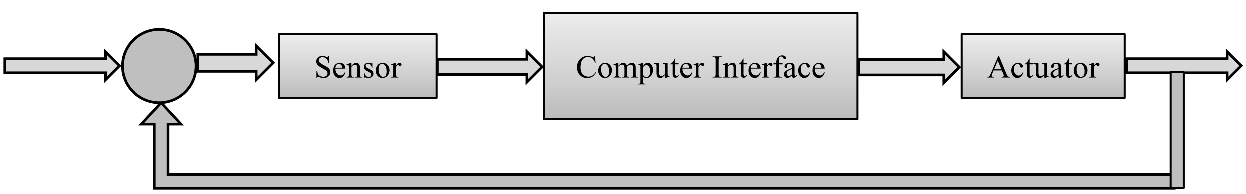

Figure 1: A simple sense, process, react loop.

Using sensors and sensor data in engineering classrooms has become increasingly beneficial for engineering education. As pointed out in a paper by Arsenault, et. al., hands on, sensors and sensor data motivates students to pursue science and engineering disciplines as well as associated career paths [1]. Lessons in the classroom quickly become more interesting [2] and engaging [3].

Current students are generally not tinkerers like many engineering students of the past and lack a deeper appreciation for these devices. In addition, the industry approach of replacing instead of repairing has only exacerbated the problem. While there is tremendous attention from both academia and industry in these devices and machines, there is a general time lag in bringing these technologies to the classroom. The high costs of laboratory equipment and the short life span of the equipment hold back many engineering and technology programs from offering courses in these areas. To overcome the cost and constant need for upgrades, the author designed a course titled "Computerized Input-Output." The course introduces students to the exciting world of interfacing sensors and devices to a computer and programming them to exhibit intelligence, while learning about sensors, measurements, programming, Graphical User Interfaces (GUI), and other important skills that are desirable in the modern industry. A Data Acquisition (DAQ) box is used to interface the world to a computer via sensors and actuators. A low cost DAQ, National Instruments NI USB-6001, is required equipment for each student, instead of an equally-priced textbook. Penn State University (PSU) license permits an install option for students to use LabVIEW™ (LV) on their own computers for educational purposes only. In addition, the DAQ is used in subsequent semesters for other classes, adding value to the student investment. Hopefully, the students will use this equipment to experiment and tinker outside the class, adding valuable hands-on experience that many students lack.

This paper presents the syllabus and topics selected. The paper will discuss the development of some of the exercises and projects used in the class. These activities develop student's interest in hands-on experience which may lead to experimentation outside the classroom. This approach also proved very helpful when all classes were held virtually online due to the COVID-19 pandemic. The author hopes that this information will help faculty and staff from other institutions take a similar approach to measurements, DAQ, and experimentation in order to help students learn about computer interface, programming, and GUI development.

2. Syllabus

This course is offered at several campuses in PSU as part of the BS in EMET degree program. A faculty curricular committee with two representatives from each of the four (now five) campuses meets once a month to discuss curricular changes, assessment, etc. as related to the BS in EMET program. The committee considered a major curriculum revision, and as part of this revision, the committee felt a need for a course that would introduce students to programming, flow charts, sensors, and interfacing with computers. The author of this paper took it upon himself to develop the course outline, which was approved by the committee. The developed syllabus is presented in Appendix A. The syllabus went through several iterations before it was finalized. The topics are listed below with some explanation for the choices.

- Introduction to input/output (i/o) and computer interface at a block diagram level
    - User friendliness has really helped the plug & play interface mature to the point that most people (students included) never have to think about the inner workings. Therefore, students need to be educated about the basics of what else goes on behind the scenes in computer interfaces. This topic discusses the basics of how plug & play works and the modules, software, or firmware along with drivers that contribute to achieving exposing students to the inner workings. The instructor has freedom to pick any specific interface to discuss in the class.

- Properties of signals. Analog vs. digital. Types of linearity. Basic idea of digitization (frequency, sampling, windowing), significant figures, rounding, truncation, resolution, accuracy, precision, Error in measurement, Calibration etc. Basic statistics of data.
    - Any interface to a microcontroller or computer has to deal with signals. The topics involve properties of signals and analog vs. digital signals. Some of the important aspects of acquiring the signals like frequency, sampling, resolution, digitizing with

    - varying number of bits are also introduced. The importance of calibration is also introduced with examples.

- Components of a typical computerized i/o systems. Input vs output. Types of inputs and outputs along with their differences. Use of several commercial DAQ boards to discuss how inputs and outputs are handled.
    - Here the focus is on commercial DAQ boxes. Before designing this course, the faculty found that students struggled with selection of DAQs for their Capstone Design Projects, which the author co-taught for several years. We also found that students generally tended to avoid DAQ for their Capstone Design Projects. As mentioned, the students use NI USB 6001 (previously NI USB 6008) as the DAQ for this class. They are required to compare and report on pros and cons for up to four different DAQs from different manufacturers. After this introduction, the number of capstone design projects that used DAQ increased.

- Basic programming blocks and structures used in various computer i/o systems software. For example: sequential structure, for and while loops, decision structures (e.g., like if, if then else, switch, case) Boolean logic. Designing modules for common tasks. Demonstration of these techniques using commercial software LV.
    - These topics are the basics for any programming language. LV is used to teach programming in this course. DAQ along with sensors are also used at various stages along with actuators. Students are introduced to graphs for presenting data, and experiments for calibration are introduced.

- Steps in input/output setup, configuring, processing, and closing.
    - These topics start with extracting appropriate information from data sheet of the DAQ and understanding its significance. Next information from data sheets of sensors and actuators are extracted and discussed. The discussion helps students understand what to look for to be able to interface the DAQ, sensor and actuator to build a working system. The discussion also assists the setting parameters in the software that the students will have to develop.

    - These topics delve further into the details of what is required to be understood from a data sheet of the DAQ along with the sensor or actuator information. How to relate the information to enable the development of the hardware and associated software to get a working system.

- Graphics user interface principles in general.
    - Given that LV is a visual programming language, faculty found it necessary and important to talk about user interfaces in general and how to incorporate some of the basics of user interface in the programs that were developed in the class.

3. Learning outcomes

The learning outcomes of this course are listed below.

- Draw a block diagram of a computerized input-output system.
  - For technology (and engineering) students a very important skill would be the ability to draw a block diagram of any system they are working or learning about. The students are given several examples to practice.
- Differentiate between analog and digital signals.
  - With the advent of extensive use of computers (& microcontrollers) the differences in analog and digital signals have become very important. Understanding the difference helped the students pick appropriate tools to handle them.
- Describe digitization, sampling and their effects on signals acquired.
  - As the use of computers (& microcontrollers) has increased, so has the need for students to understand the importance of digitization, sampling, and its impact on signals. Students are given examples to understand the importance of these concepts in handling signals.
- Use LV to acquire a signal, process it, and present the data in a technical way using graph, equations, etc.
  - This outcome addresses one of the key aspects of this course: the use of LV to acquire, process, and present the data/signal for various audiences.
- Utilize several programming structures like for and while loops, case structures, basic logics etc. to build DAQ software.
  - Introduction of the basic elements of any modern programming language is addressed by this outcome, and LV is used to introduce the concepts. Students were required to draw flowcharts so the algorithm and logic behind the programs they developed are easily explained and documented.
- Be cognizant of Graphical User Interface (GUI)
  - A key concept of visual interfaces is the GUI. Students are made aware of basic GUI principles, and discussion is done with several examples during class, homework, and projects.
- Be able to integrate a sensor, an actuator, and an indicator using DAQ and LV.
  - One of the goals of this course is to bring together the integration of sensor, actuator, and indicator. Several of the experiments in the course highlight this aspect.

4. Class format

The course EMET-230 is a 3-credit course that meets twice a week. Each meeting time is two hours long for a total of 4 hours/week. This longer time permits for the integration of experiments with lectures in the classroom. The class is held in a computer room with a maximum seating of 30 seats. LV™, NiMAX (measurement and automation explorer), and DAQmx™ are installed on all computers in the classroom and there is table space for working with hardware. The author worked with National Instruments (NI) to acquire the DAQ hardware at a discounted price. The department bought the necessary number of DAQ boxes before classes commence in the fall semester. Each student is required to buy the hardware for the class with substantial discounts provided by the University. The sensors, actuators, and other required hardware is provided by the University for each student in class as required. In Fall 2020, during the pandemic, a local vendor was used to create a kit that was also bought by the students and was subsequently used in Spring 2021. Appendix B lists the items that were included in this kit.

Each class is broken down into two one-hour blocks. Depending on the topic most classes begin with an introduction to a new topic in the first hour, followed by implementing LV and is generally then followed by a hands-on experiment in the second hour. Some experiments run for two or three class periods and are broken into manageable parts. Students are always required to submit a report for each experiment and upload their LV to cloud storage. The instructor runs every LV submission by connecting it to their own hardware setup, which is very similar to what the student used.

Weekly quizzes (approximately 4 – 6 minutes) are given at the beginning of the first class in the week to assesses programming knowledge and concepts that were introduced in the previous week. These quizzes are administered using Canvas (Learning Management System) and have a mix of multiple choice and descriptive answers.

5. List of Experiments

The experiments are described below with an explanation of what was involved in each of them.

a. DAQ hardware introduction.
    - This experiment introduces the students to the hardware. They assemble the hardware and interface to NiMAX to test the hardware. This experiment introduces them to the basic features of the DAQ box. It also provides the opportunity to talk about how the hardware, driver etc. work with the computer and its operating system, which is Windows 10 for this class.

b. LED using Digital I/O.
    - In this experiment a LED is lit using a digital i/o pin. It requires the students to set up the digital pin as an output pin. They need to calculate the required resistance for the TTL signal and think about limiting the current. Discussion about TTL, CMOS etc. is also introduced in this class.

c. Calibration curve using a standard voltage source.
    - Before this class, the students are introduced to Analog Input and the notion of calibration. Using a standard power supply along with a calibrated and certified multimeter, the students verify the voltage read by their DAQ box analog input. They use several data points and develop a calibration curve (linear as expected) for their specific DAQ boxes. This gives them the opportunity to discuss calibration, various types of calibration curves (linear – nonlinear etc.), certification of calibration, requirements for recalibration and certification, etc.

d. LED using Analog Out.
    - Using the Analog Out of the DAQ box, the student develop a program to turn a LED on and off based on other logic conditions in the program. There is a current limit from the DAQ Box and students are required to first read and understand this upper limit of the hardware from its specification. They are then required to compute necessary current limiting resistors to protect the hardware. This provides an

opportunity to introduce students to the power limitation for devices that interface to computers and how external power is required for higher power devices like motors.

e. Daisy Chain using Digital I/O.
    - Students interface two or more DAQs to communicate using the digital input and outputs. This simulates a process where one station (simulated by a student's DAQ Box) communicated with the next station (simulated by another student's DAQ Box) in a process or manufacturing operation. LEDs from previous experiments are used to provide visual indications in addition to on screen indicators. The students need to discuss the protocol, handshake, when to abort, and other relevant issues to establish the communication and show a demonstration. This clearly opens the opportunity to discuss automated processes in a manufacturing setup, process control etc.
f. Generating the Diode characteristic curve.
    - Using a small signal diode along with analog output and analog input, students generate the diode characteristic curve. They then use curve fitting blocks provided by LV to fit various curves. In this experiment, they are required to understand the idea of where they have to measure the voltage drop using the analog input. They are also required to generate an analog output that is stepped from zero volts to a fixed maximum. This demonstrates the power of using a multifunction DAQ Box as a power source, a signal generator, and a multimeter.
g. Diode Rectification.
    - This experiment introduces how to generate a varying amplitude sinusoidal voltage to be supplied to a diode to study basic rectification. This also demonstrates the capability of using a multifunction DAQ Box as a signal generator. Analog input is used to measure the rectified output and graph it. Varying the frequency of the sinusoid are also introduced in this experiment. This provides an opportunity to talk about bandwidth and associated limitations of hardware. The classroom instruction also refers to the data sheet to pull out pertinent information that is needed to be understood to make the interface work.
h. NTC Thermistor.
    - In this experiment, a NTC (negative temperature coefficient) sensor is used. The data sheet is used to first discuss the specifications, which provides another opportunity to introduce reading data sheets to the students. A general discussion about the pros and cons of linear and non-linear sensors is used in the classroom and is exemplified with the NTC sensor. The need to understand the underlying mathematical model of the sensor during calibration are also discussed as part of the lecture. The students wire the circuit and write the LV program. Data is collected in a file and the concept of file input/output was introduced. The experiment uses beakers with distilled water heated to different temperatures along with a digital thermometer to act as the calibration standard. A second LV file is used to read in the data file and perform a calibration curve which was based on the underlying model.
i. Linear IC based temperature sensor.

- In this experiment, an IC based linear temperature sensor such as LM35Z is used. The students are once more taught how to read data sheets and pull-out necessary information to interface them with the DAQ box. The pros and cons of the linear temperature sensor is discussed. A calibration is then carried out with a set of beakers with water at different temperatures. A digital thermometer is used as the reference standard. The nominal calibration value from the data sheet is compared to what was obtained by the student, and a discussion about the reason for this is done in class and in the report.

j. Potentiometer as a sensor.
   - A potentiometer with a shaft and rotating contact is used for this experiment. Calibration of angular displacement to the voltage drop is carried out so students learn how to use a potentiometer as an angular sensor.

k. Motor control with external power and additional sensors.
   - In this experiment, a DC motor is speed controlled. The need for an "interface circuit" to make the low-powered DAQ box control the high-powered motor is discussed. Discussion about amplification circuits is carried out, in addition to discussion of freewheeling diodes to handle inductive loads. PWM (pulse width modulation) is also introduced to help with the control of the motor.
   - As a final project students have to control the speed of the motor based on a set temperature. One of the two temperature sensors can be used for this. They also have to indicate with LED's if the temperature is above or below the set point.

Optionally, students could be offered an option to come up with their own final project that will use two analog outputs, at least one analog input, and one digital input. Given this option, students have done various projects like a simple swinging pendulum that was balanced at different angles with the use of a motor with a propellor and a paper rolling machine to roll single-sheet, yearly calendars.

6. Pandemic Instruction

When the class was taught face-to-face (F2F), it was easy to use the two projectors in class to show the lecture and give guidance on how to build the virtual instrument (VI), setup hardware, and run the experiment. During the pandemic, students acquired their own DAQ box and component kit (Appendix B) for $185. The lecture continued in the same way as F2F and was broken down into two segments of one hour each. Videos were made to offer step-by-step instructions on the hardware setup and had to be done before class. In the first hour, the lecture content was delivered via Zoom and the hardware setup video was once more shown and discussed in case students had trouble. In the second hour, students were required to finish their hardware and develop the LV program. Zoom features like Screen Sharing, Remote Control, and traditional phone calling were extensively used to guide the students to help debug hardware and software on a one-on-one basis as would have been done in the F2F class. See some of the student comments for the pandemic fall semester in the next section.

7. Summary

Students in general like the course and the open-ended problems in the experiments. When compared to many other labs, the instructions were not necessarily following steps, take data, and go, but rather involved more thinking, discussion, and details that they did not get in other hands-on classes. Below is some feedback from students on this class: (comments are edited for spelling, otherwise just copied)

- Hands-on training is *positive*.
- Having Labview at home was nice and having no book.
- Other students took a lot longer to understand concepts, so I got bored.
- [I liked] Hands on work, ability to work at our own pace, the practicality of the course, motivation from the professor.
- purchasing the NI USB-6008 was a *huge improvement* in this class. I was not only able to learn labview but how to implement it in machines.
- *the demonstrations and handouts were good*, the extensive lecture and working through worksheet collaboratively as a group was slow and unbeneficial.
- The hands-on portion was positive.
- Dr. Professor appeared to work with the students independent of class time to help them successfully progress through the course material. Dr. Professor definitely provided a positive learning experience.
- There seemed to be unnecessary background information that was not used, more time could have been spent on the device terminology. The positive aspects of the class were the instructor interaction during the labs.
- How to implement the DAQ into an actual machine.
- How to use the DAQ to output sounds, how to chain together multiple DAQ systems to work together, and simply how to program with LabView.
- how to make a temperature sensor work, and calibration.
- DEFINITELY the professor’s attitude toward this class and his style of teaching helped my learning in this class.

Pandemic Fall 2020 Feedback

- What aspects of this course made you learn?
    - Professor absolutely cares about creating a positive learning experience and was willing to help and go the extra mile.
    - Working through the projects on my own time.
    - The walkthrough given and peers.
    - Teacher is very helpful and will work out any problem with you by making you learn and solve it instead of just helping with the answer.
    - The in-depth perception of knowledge. Very intelligent professor.
    - The professor’s understanding of the topics. The professor’s ability and willingness to help. The professor’s eagerness to learn and help others.
    - I really enjoyed taking Dr. Professors class. He is a really nice professor and seems to genuinely care about his student’s success. His handouts were extremely helpful in explaining things.
    - Very engaging and willing to help where he can. Nicely written lab instructions.

- I enjoyed what I was learning and saw how it could be useful after I graduate.
    - The PowerPoints.
    - The practice exercises completed in class.
    - The professor utilized guided discussion and practice quite well. He answered questions as he guided us through the exercises.
    - The videos that were posted helped.
    - The Professors usage of PowerPoint slides, as well as videos, was very helpful. While at times the learning experience was hindered by circumstances, the professor was very accommodating and understanding, regularly accepting work even after the due date had passed. I also appreciate his generosity, and willingness to help.
    - Students work through problems they might have. The Professor's attitude towards the class was very positive, and he seemed very happy to be teaching. The environment in general was very enjoyable and helped me get into specific topics being taught each week. I do not care what anyone says, I enjoyed his jokes too.
- What changes to this course could improve your learning?
    - Course is slightly difficult because if it being online.
    - Distance learning is not really my thing but that is not the professor's fault and is all I would change.
    - Navigating the canvas page for this class was not great.
    - The projects need to be clearer. There was a lack of direction and the professor basically said to figure it out even though this is an introduction course to the software.
    - This course would be much better to teach in person but other than that the course was very well done considering it is online.
    - Better instruction
    - How things are submitted
    - In class rather than online.

8. Conclusion

This class structure and format provided a rich learning environment for students to understand how to interface the world to computers. The experiments offer ample opportunity for students to learn through open-ended examples. Student comments reflect some of the positive aspects and what could be improved. The setup is well suited for the pandemic when all classes had to be held remotely. There is work planned to gather more extensive feedback from students to further study the learning impact of this course.

The author of this paper will be very glad to share the resources (PowerPoint slide deck, worksheets, experiment writeup, quizzes, projects, instructions videos etc.) developed with any faculty that wants to adopt the course on their university. (Please contact rungun.nathan@yahoo.com).

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Appendix A

EMET 230 – Computerized Input-Output Systems

Catalog Description:	**EMET 230<u>: Computerized I/O Systems (3)</u>** *Introduction to concepts of structured programming, data acquisition, computerized interfaces, and graphical user interfaces.* Course Co-requisite: EET 212W
Goals of the Course:	**<u>Computerized I/O Systems</u>** This course will provide the students with the knowledge of steps and issues to be addressed when deciding on computerized input-output systems. Understanding the basic property and types of signals, significant figures, rounding off etc. Steps in choosing hardware and understanding some of the principles used in the software design to develop user friendly and intuitive interfaces.
Relationship to EMET Program Outcomes:	EMET 230 contributes to the following EMET program outcomes: ▪ Students should be able to identify, analyze, and solve technical problems related to integration of electrical, mechanical, instrumentation, computers, and control components to perform industrial and manufacturing functions. (Outcome 1) ▪ Be able to plan and conduct experimental measurements, use modern test and data acquisition equipment, and be able to analyze and interpret the results. (Outcome 3) ▪ Be able to apply electrical, electronic, and mechanical devices; computers; and instrumentation systems, as appropriate, to the development, operation, troubleshooting, and maintenance of electromechanical systems. (Outcome 4) ▪ Demonstrate basic knowledge of control systems, including appropriate computer technologies and programming skills, as appropriate, for the applied as applied to the design, operation, troubleshooting, and maintenance of electromechanical systems. (Outcome 6)
Course Outcomes:	The specific course outcomes supporting the program outcomes are: ▪ <u>Outcome 1:</u> Apply electrical, electronic, and mechanical devices; computers; and instrumentation systems to the development, operation, troubleshooting, and maintenance of electromechanical systems. ▪ <u>Outcome 3:</u> Develop fundamental skills about signals, data acquisition hardware, interface etc. ▪ <u>Outcome 4:</u> Choose appropriate technology to solve computerized input-output problems. ▪ <u>Outcome 6:</u> Understand appropriate technologies, interfaces, operations, and maintenance of computerized interface systems.
Suggested Texts:	The following are suitable texts and/or references for this course: ▪ Learning with LabVIEW - Bishop ISBN-13: 9780134022123Publisher: Prentice Hall ▪ Measurement and Data Analysis for Engineering and Science, by Patrick Dunn, Publisher CRC Press, ISBN: ISBN 9781439825686
Prerequisites by Topic:	Students are expected to have the following topical knowledge upon entering this course: ▪ Knowledge of electrical systems. ▪ Digital electronics ▪ Electrical Circuits ▪ Basic statistics
Course Topics:	▪ Introduction to input/output and computer interface at a block diagram level.

	▪ Properties of signals. Analog VS digital. Types of linearity. Basic idea of digitization, frequency, sampling, significant figures, rounding, truncation, resolution, accuracy, precision, Error in measurement, Calibration etc. Basic statistics of data. ▪ Components of a typical computerized i/o systems. Input VS output. Types of inputs and outputs, their differences. Use several commercial DAQ boards to discuss how inputs and outputs are handled. ▪ Basic programming blocks and structures used in various computer i/o systems software. For example, sequential structure, loops using for, while, decision structures like if, if then else, switch, case etc. Boolean logic. Designing modules for common tasks. Demonstration of these techniques will be done using commercial software LabVIEW. ▪ Steps in input/output setup, configuring, processing, and closing. ▪ Graphics user interface principles in general.
Computer Use:	The course will use computers to let students create interfaces, software components and build some computerized input-output systems.
Required Equipments:	Data acquisition hardware, and software. (For example, NI 6001, compact DAQ with suitable plugin modules like analog in, analog out, digital i/o, thermocouples modules etc. and LabVIEW). Miscellaneous components for interface like sensors, actuators, cables, terminal blocks etc.
Course Grading:	Course grading policies are left to the discretion of the individual instructor.
Library Usage:	The instructor may ask students to study various other vendor product manuals for students to get a better appreciation of the several complex issues involved in computerized input-output systems. Recent technical publications can be used to study current methods in computerized i/o systems.
Course Assessment	The following may be useful methods for assessing the success of this course in achieving the intended outcomes listed above: ▪ In-class quiz, tests, and examinations. ▪ Projects: Can be used to test student understanding issues for interface and how they design graphical user interfaces ▪ Homework problems

Appendix B

EMET 230 Equipment (per kit)

#	Item	Specification	Lab # (see section 5)	Quantity
1	NI USB-6001 Data Acquisition Card		All	1
2	LED	Red and Green	b,d,e, & k	2
3	Diode (also for rectifier)	1N914	f & g	1
4	Resistors (1/2 w 5%)	10W, 220 W, 1KW,	All	1 each
5	Thermistor	NTC-102-R	h & k	1
6	Temperature Sensor	LM35Z or similar	i & k	1
7	Breadboard (2.2 in X 3.4in)		all	1
	A small dc	motor (RF370CA - 12VDC motor) OR PC-130SF-09480-R	k	1
	Power transistor	TIP31c	k	1
	Diode	1N4004	k	1
	Resistor	100, 220, 500, 1000 ohm	k	1 each
	Capacitor	Ceramic 10 nF	k	1
	Linear temperature sensor	LM 35Z or similar	k	
	9V Battery Terminal	G/S(A-102)-R	k	1
8	Jumper Wires (Male - Male)	ST-254-MM-30	all	1
9	Jumper Wires (Male – Female)	ST-254-MF-30	all	1
10	Thermistor wires		h & i	~3.5ft
11	Potentiometers (0-350, 1K, one turn)		j	1
12	Alligator Clips		all	4
13	Screwdriver (127271) to fit USB-6001		all	1
14	All above items in a small carry box			1