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Wireless Sensor Based Home Automation as an Educational Springboard

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***Abstract*—This paper details the design and development of a system that is intended to be used as a tool to educate and excite young school leaver to pursue engineering education, especially in the field of sensors and sensor applications. The system is essentially a home automation platform that allows users to interact with a network of sensors and actuators. The system consists of four hardware components; the computer/webserver that controls the network of sensors and actuators, the device the user will use to access the web server, the sensors/actuators of the system, and the microcontroller that bridges the web server and the sensor/actuator network. The end user of this system will be expected to assemble various components of the system together and in doing so, will gain an exposure to the engineering field. This exposure will increase the awareness of what engineering entails and hopes to prompt future students to take up engineering as a field of study. The system, while being a platform for exposing engineering, can also be a platform for future projects requiring remote access to an autonomous sensor network with the ability to change the environment around them, such as zoological research projects tracking the endangered birds. Finally, the system, capable of sensing temperature and light, controlling 230V 10A mains appliances and a keyless entry device, could be used simply as a home automation system in its own right by an interested hobbyist.**

Keywords- home automation, education, learning platform

I. INTRODUCTION

While the engineering and computer science fields are two of the fastest growing industries in the world, they are also suffering from under representation in new students starting tertiary education [1].

This project aims to provide a platform that can be added to the current collection of resources being used to raise awareness of engineering and computer science and instill interest and a feeling of capability in potential new engineers. There is a lack of understanding as to what engineering actually entails [2]. There is also a perception, particularly among younger people, that the profession “engineer” is synonymous with “tradesman”, “welder”, “machinist”, “fitter and turner”. Very clearly this is not true, however it is deeply damaging to the engineering field if people see engineering subjects as lacking glamour based upon this perception. There are many groups offering products to try and deal with this perception and inspire interest in the engineering and computer science fields; “The Funway into Electronics” kits once offered by Dick Smith Electronics were how many people first became introduced to electronics, these kits however have stopped being produced by DSE. Jaycar electronics are still selling their “Short circuits” series of DIY electronics kits, however both of these companies have moved towards consumer electronics. New companies like Adafruit electronics are providing a service whereby they manufacture and sell electronics and electronic accessories that can be used to encourage people into engineering and electronics, but interestingly, their products are also used by students in their own learning, experimentation and personal projects.

There are currently many mechatronic systems being used to help expose and familiarize potential future engineers to the field, however the predominant trend is to use self-contained robots that sense their environment and move IN their environment. Tools like BeeBot, Probot [3], and systems like LegoMindstorm are being used in kindergartens, primary schools, and high schools/universities respectively [4]. All of these systems move themselves around their environment; they do not create a change in their environment.

There are systems available that change the state of their environment; Ninja Blocks is a crowd sourced project that takes plug and play modules and lets the user program actions based upon the “if this, then that, else this” architecture. The issue is that once a user has set up the system, there is no room for a lay-person user to play or experiment; even though the project is open source, to dive into the code and modify the project to suit their means requires making the jump from layperson to fully qualified developer. This project seeks to remedy this by providing a platform that gets set up by the user right from the start. As it is the user that is doing the setup, the user will learn the code and the workings of the system to a level that they can then start to repurpose the modules for their own means, add features to, or remove features from the system according to their wishes.

This article is organized as follows: Section II reviews related work in educational engineering systems. Section III provides an overview of the system. The Hardware design and implementation is discussed in section IV. Section V outlines the wireless communication protocol implemented in the sensor-actuator network. Section VI illustrates the software design and user interface used in the project. The results of

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some experimental testing is detailed in section VII. The paper finishes with some discussions and conclusions in section VIII.

II. Related Work in Educational Tools

There are (and have been) may many electronics companies that have contributed to the library of tools and teaching aids. Here will be introduced the four most prominent historically and current companies.

Dick Smith Electronics is credited with being one of the great founders in the DIY electronic scene. They started offering their "Funway into Electronics" kits in 1979[5], these kits provided a means for enthusiastic people to be introduced to and become familiar with electronics. There were 2 volumes released with the first containing 20 projects. The first volume focused on the use of analogue electronics and the second on digital/IC based circuits. Sadly these kits started to become discontinued in 2008, when DSE started moving towards commercial electronics [5].

Jaycar started offering the Short Circuits range of DIY electronics kits around the same time as DSE and these are still being sold. There were only 3 volumes released with a total of little over 72 kits. Jaycar remains one of the select few retailers of electronics retail shops still in operation, and the only retailer of electronic components in many cities and towns in New Zealand. This is a great feat.

SparkFnun electronics is an online retailer of electronics and electronic components, as well as accessories such as breakout boards for components, this allows customers with only breadboard prototyping ability access to more advanced sensors and electronics. The other part of their business is networking their customer base together via their comments sections and forums. This allows customers wanting to learn, to be taught by the community of the internet.

Adafruit Industries, the final organization could be considered the current champion of the engineering and electronics education environment [6]; they have electronics kits, components of many kinds ranging from microcontrollers and sensors to the more mundane such as switches and PCB headers. They also sell children's toys; fluffy pillows in the shape of resistors and capacitors, these toys are targeted at children under 10 so that they can be exposed to the appearance of electrical components from a very young age. Adafruit industries also have a "learning system" whereby they distribute knowledge about their products, ideas for projects, explanations of various concepts like the MIDI protocol. Adafruit offer support to customers through the use of an online community forum. Adafruits founder Limor Fried is considered to be one of the founders of the open hardware movement [8]; creating products and kits that she sells and profits from, while also releasing all the design files and information for free. In this way, people can learn by looking at how each kit is built and look at the design methodology [7].

III. System Overview

The Home Automation System, shown in figure 2, is comprised of several blocks: the sensor/actuator network (S.A.N), the sensor modules gather information about the environment and the actuator modules act to create change in the environment; the web server, which stores and serves the webpage for the user interface and handles requests and commands sent from the end user; finally, the web interface, this is an interface that facilitates access to the data recorded by the system and allows the user to alter the state of the system outputs. The sensor-actuator network topology has been discussed in the wireless communication section.

The sensor modules have been implemented as shields for an Arduino UNO, whereas the mains actuator module and the keyless entry module have been designed with ATMEGA 328P as the on-board processor loaded with the Arduino boot-loader.

IV. Hardware Design and Implementation

A. Sensor Module

The sensor module consists of a microcontroller interfaced with a temperature sensor, a light sensor, and a wireless RF transceiver. These sensor boards, powered from the microcontrollers USB programming port, wait for a command to be sent to them and then reply with the appropriate data. To make the unit completely mobile and independent of wall power source, it can be powered by a battery.

The temperature sensor chosen was the Dallas DS18B20 1-Wire bus temperature sensor. This sensor has 12bit precision and very simple wiring. This sensor was chosen as it is very cheap, readily available from a wide variety of sources, there are also many tutorials on how to use this sensor with microcontrollers. These qualities mean that this sensor increases the effectiveness of the system in the context of exposing people to engineering and computer science; by being available, affordable, and supported by the community.

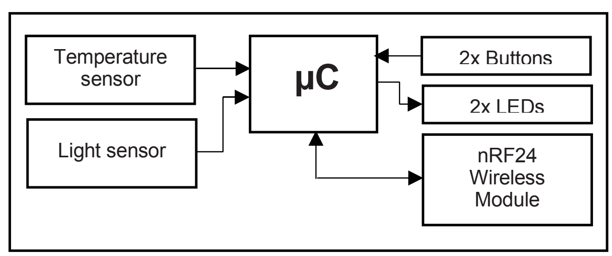

Figure 1. Sensor Node Block Diagram

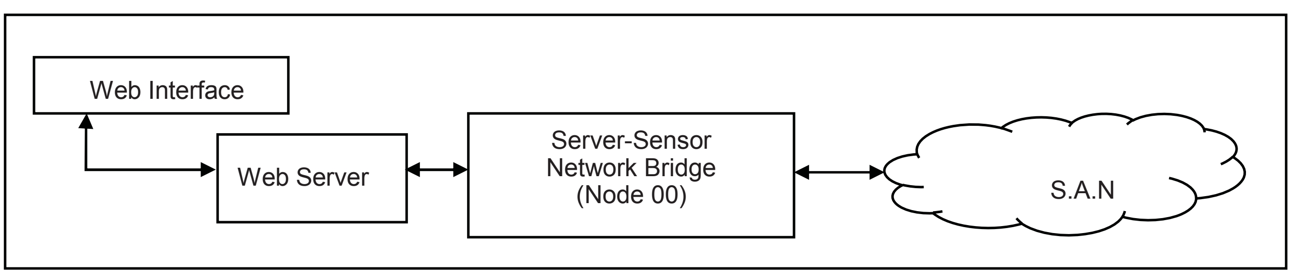

Figure 2. System Functional Block Diagram of the Home Automation System

The light sensor used on the sensor board is a photo transistor but essentially acts as a common place Light dependant, the only practical difference being the type of sensing element present in the sensor. On each of the first prototype of the sensor nodes are two buttons and two LEDs, these were put in place to assist in debugging during the prototyping/development phase, they can also be used later to input user commands or display information to the user.

The first generation prototype of the sensor node is shown in figure 3

The sensor pictured is equipped with 4 temperature sensors, each using a different method of reporting data, two use an analogue output (one requires a trimming potentiometer), one uses a 1 wire interface, the final sensor, doubling as a temperature/barometric pressure sensor, used the I2C communications protocol. This was to provide a variety in the types of interfaces that students can play with

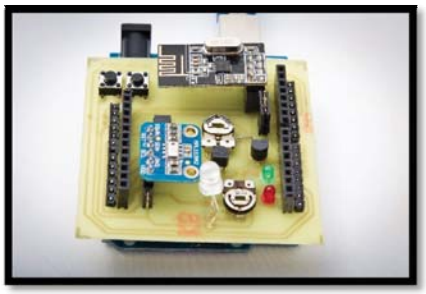

Figure 3. 1st Generation Prototype Sensor Node

B. *Mains Actuator Module*

The S-A networks second element are the actuators, these are a mains actuator module and a keyless entry module.

The mains control module is outfitted with a single temperature sensor, light sensor, two buttons, two LED's, a standard NZ mains outlet plate, and a 250V 12A relay as shown in figure 4. This is to switch domestic mains appliances up to 2400W (10A). This is the maximum rating of a standard NZ domestic mains outlet. The module is powered entirely from the mains by way of a small transformer. The modules mains hardware is over rated to 12A to avoid dangerous failure, the unit is also fused at the input of the transformer, the output of the mains switching hardware and thermally fused close to the relay in case the unit starts to overheat. The fully assembled module is shown in figure 5 and the circuit board with essential components are shown in figure 6. The mains actuator module is not intended to be opened and modified by the user; hence it is safe to be used even by young persons.

C. *Keyless Entry Module*

The keyless entry module is outfitted with the same sensors as the mains actuator module, plus an RFID reader board. It outputs to a servo motor. The servo is used to actuate a leaver that can be easily fastened to the handles of many deadbolts. This is easily upgraded to control a door strike. The RFID reader board used is a design from an Austraian company called Priority1Designs, this was selected as it supported the widest range of RFID tags, most notably the EM4100 series of

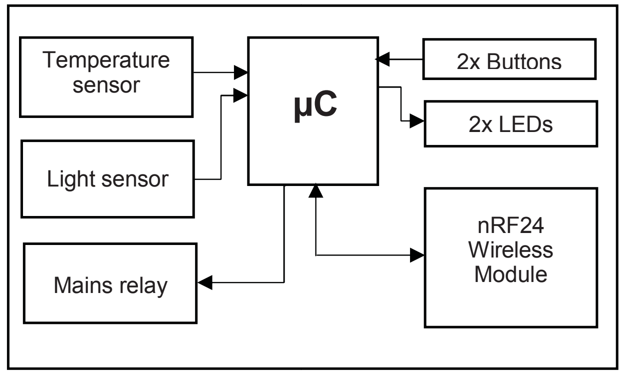

Figure 4. Mains Actuator Functional Block Diagram

Figure 5. Mains Actuator Module

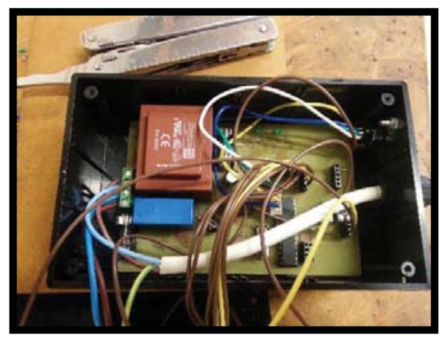

Figure 6. Inside the Mains Actuator Module

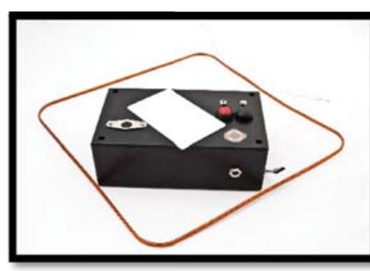

Figure 7. Keyless Entry Module

transponders. These are readily available in a wide variety of packaging options from online shopping sites like ebay.com.Figure 7 shows the keyless entry module fully assembled but without the servo/door strike actuator. The functional block diagram of the keyless entry system is shown in figure 8.

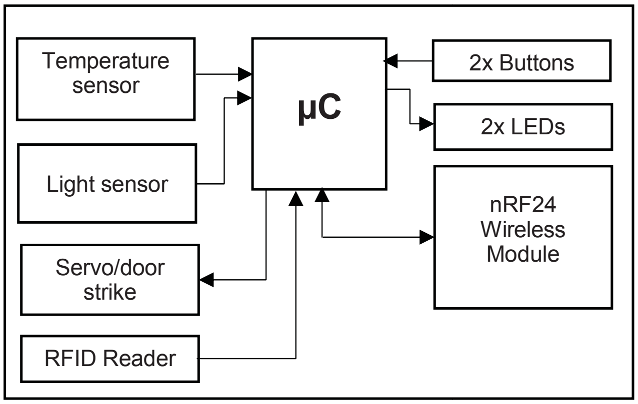

Figure 8. Keyless Entry Node Functional Block Diagram

D. *Microcontroller*

The microcontroller used was the Arduino UNO (ATmega328P), this microcontroller was selected for its availability of common online shopping websites, it's affordability, but most crucially, for its ease of programming and extensive support community. This makes it an obvious choice over other more technologically capable platforms like AVR, PIC, 8051, and ARM processors, when trying to introduce newcomers to engineering with little to no microcontroller experience.

The development board also comes equipped with a USB interface circuit, this simplifies programming, powering the sensor for operation, and communication to the web server.

E. *Wireless Communication Hardware*

The Sensors all talk to each other wirelessly by means of a Nordic Semiconductor wireless module, specifically the nRF24L01.

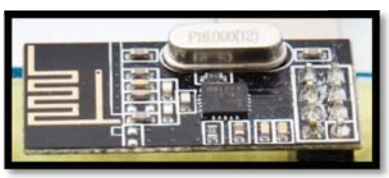
Figure 9. nRF24 2.4GHz, Wireless Radio Module

These 2.4GHz Wireless modules are similar to the ZigBee radio modules in many respects but with a few key advantages. Firstly, as with all other components, they are incredibly cheap; a single ZigBee module can cost as much as \$80NZD, the nRF24 radio modules can be purchased for as low as \$1.20, the most expensive higher power modules with an external, omnidirectional antenna giving several hundred meters range (or more with a directional antenna) can be purchased for as low as \$8.00NZD. This is an incredible price point, this along with their extensive availability from a vast number of suppliers, allows many radio modules to be purchased by a user not versed in sourcing electronic components from specialist suppliers. The nRF24 modules draw very little power (0.14mA in sleep mode, 13.6mA in transmit mode) and communicate with the micro controller using the SPI bus and have an over the air data rate of up to 2Mbps. The 256kbps option gives better range however as the frequency 'spillage' is less; as a result there is less interference to the signal being transmitted. The nRF24 wireless radios divide their transmit/receive hardware into several 'pipes', the nRF24 module has the facility to transmit data on one 'pipe' and synchronously listen to another 5 pipes, this allows for tree, star, and mesh network topologies. The one disadvantage to the nRF24 is that it does not have the same academic support community in terms of the availability in literature and code libraries; at the time of writing, the nRF25 does not have any libraries that support self-managing, address-less mesh networks for example. In this respect ZigBee is best for several thousand dollar budget academic research. There are however very good libraries and code examples available for the maker community, one of which is a library that manages communication in a 5-ary tree network up to 5 layers deep

F. *Server computer*

The credit card sized, single board computer Raspberry Pi model B, was selected as the computer for the server and host controller due to its low price (\$40USD), its low power consumption (>5W), its small size (87x56x20mm), its wide spread availability, and, most crucially; the extensive support that the community using the Raspberry Pi offers. For a newcomer to the world of computer science, setting up a standalone, always-on system, the Raspberry Pi satisfies all these requirements.


Figure 10. Raspberry Pi Model B Single Board Computer

The Raspberry Pi is a new product in the market and is attempting to introduce more people to the world of computer science and engineering, it has amassed a vast following in the 'maker' community. It has a 700MHz ARM core processor with a dedicated Graphics Processor, two USB ports and 100Mbps Ethernet, has hardware I/O with digital GPIO, SPI, I2C, USART, is capable of being programmed to generate PWM, and can interrupt off hardware input.

Running distributions of Linux, the Raspberry Pi is an incredibly flexible platform for experimentation.

V. WIRELESS COMMUNICATIONS PROTOCOL

The sensor-actuator network (SAN) uses a library developed by a 3rd party known as "maniac bug" [11] [12]. The library is known as "RF24Network" and provides a way to create a 5-ary tree network with up to 6000 addressable nodes. Messages can be sent from one node to any other node in the network by giving only its address.

The protocol is as follows, every node can have up to 5 children and there can be a maximum of 5 layers in the network nodes may only communicate with either their child or their parent, nodes may not communicate with their 'siblings' (nodes on the same level of the tree that share a common parent). For nodes to talk to their siblings, the message is first relayed to the parent and the parent forwards the message to the desired child.

The first node (the top of the tree) is addressed as node 0, the first child of this node is addressed as 01, the second 02, etc. The children of node 02 are addressed as 021, 022, 023, and so on.

Figure 11. is a graphic taken from maniacbug's blog, it illustrates a sample network of 14 nodes and shows how each layer in the tree is addressed, and reminds us that you can have nodes relaying data to other nodes down the tree, there by extending the range that we can communicate over.

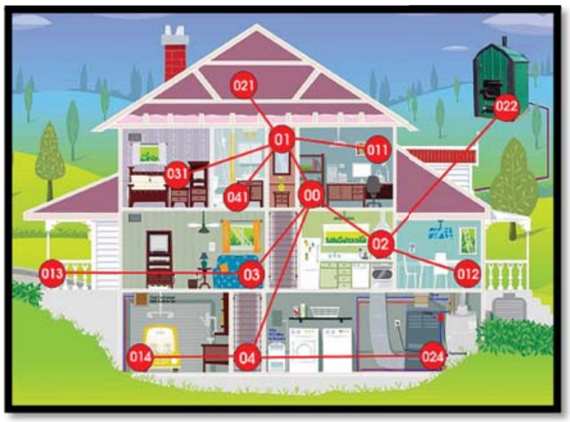

Figure 11. Diagram from ManiacBug showing the addressing of the RF24Network nodes

VI. SOFTWARE DESIGN & USER INTERFACE

A. Server software

The server is loaded with a web server application called Nginx, this serves up the static content of the webpage. The dynamic content (commands and responses) is handled by JavaScript code run by the Node.js runtime environment, this package allows the user to interact with the hardware through the internet and for the system to report back to the user.

Node.js is a cross platform software package, it can run on Windows, Mac, Linux, even webOS; an operating system developed by the PDA manufacturer Palm and now acquired by HP for use in many Smart TV's. With such a vast cross platform capability, the end use is free to decide if they would like to use the Raspberry Pi as detailed in this project, or if they would like to use the desktop/laptop they already own. Such flexibility can also help promote experimentation; there are examples of people taking android tablets and installing the Linux distribution Debian onto it, then installing and running Node.js. This now allows this project to be repurposed to create a totally independent sensor node operating off a battery and a cellular network internet connection, or, if the experimenter is so inclined, a satellite internet connection. As satellite modems are only \$100-\$200USD and subscriptions only a few tens of dollars a month, it is entirely feasible that this project could be used in such a situation.

The coding of the API and client-side is all done in JavaScript and takes full advantage of the packages that are available to Node.JS; serialPort, and SQLite are both used here. The server is programmed to be 'smart'; it does all of the processing. No data is sent from the sensor-actuator network to the server without being requested.

The whole system is very flexible as at any time a user can add a new node/actuator with only minor additions to the code in the server-side API, the client-side API, and the HTML file hosted on the server. All that need be added are HTML elements to display (or push) data from (or to) the system, functions to the client side API to tell the user interface device what to do with the data from/to the HTML document, and functions to handle the flow of data around the server-side API JavaScript (JS) file.

Adding autonomous tasks is also very simple; in the server-side API JS file is a timer that ticks every n seconds. Into this timer one can add logic that governs when to switch on and off specific actuators based on sensor input. Obviously this could be coded to be configurable on-the-fly using only the web based user interface by someone wishing to create a very easy to use, dynamic system on the fly

B. Microcontroller software

The microcontrollers are programmed using C, these are programmed to be 'dumb' units that only transmit data when queried. This limits superfluous radio traffic and allows users to change what data is being recorded, where, and how frequently by only accessing the Raspberry Pi. This permits edits to the system to be made remotely via an SSH connection.

The Dallas temperature sensor (DS18b20) uses a library taken from an example page of the Arduino support website. The software library used to control the nRF24 wireless radio module is taken from a developer who goes by "maniacbug" on GitHub and WordPress. Both of these libraries are very easy to acquire and use and they have very good documentation behind them.

As the libraries for this project are all coded in C they can be used with a variety of microcontroller architectures; ARM, PIC, 8051, AVR, all with little to no editing of the original library. This makes the whole microcontroller system very accommodating.

The most interesting point about Node.JS is that it is runnable on many operating systems, this means that a user need not be constrained to use the Raspberry Pi if they already have their own computer.

VII. EXPERIMENTS AND RESULTS

The system and project is of no value if it cannot actually function to a satisfactory standard. A test of the autonomous control was conducted where a temperature sensor was placed in a room at head height and a heater was attached to the mains control module, the server software was then instructed to maintain the sensor at a certain temperature, in this case 24°C.

Figure12 shows the temperature of the room being maintained to 24±1.5°C with the use of an 1800W heater. This control margin is quite adequate for an educational project and would even be suitable for a standalone temperature control system.

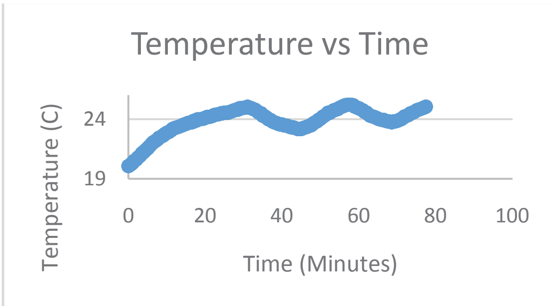

Figure 12. Recording of room temperature under autonomous control

Most importantly, this demonstrated autonomous control over a process variable. Even for a 3rd year engineering student this can be incredibly rewarding and exciting, for a person unexperienced in the field of engineering. Dabbling in the area of control theory can be incredibly enthralling.

VIII. Discussions and Conclusions

The system developed in this paper will serve as another tool in the current collection to demonstrate the things that engineering can lead to, or a tool to help educate potential students through use of a practical project. The system can also be used as a building block for future work by engineering students/maker communities. The current system could very well be used as the basis of another 4th year engineering project or maker project that requires a remote monitor/control system.

Research suggests that simply by exposing someone to something, they will, over time, develop a preference for the thing to which they are being exposed. This is the underpinning theory of advertising campaigns. Similarly if we expose potential new engineering students to interesting and rewarding engineering projects then they can be given the chance to engage with the subject and take up an education in the subject [9] [10].

This system needs supplementary work before it becomes a fully usable system that is presentable to the public; the system need to be comprehensively documented, tidied and packaged such that a user that is uninformed about the project can take the system package and extract information in an easy to understand order that will help them set up the system.

In summary, in going through the process of using this system, users will be exposed to many different facets of the engineering field, electronics, sensors, micro controllers, power supplies, wireless radio communication, wireless network topologies, computer science, programming, setting up servers, web development, interacting with a computer system using a command line interface, computer networking (when accessing the server from a device outside of the local network of a user's house).

The aim of this system is to provide users with a platform that can expose them to a realistic view of what engineering can lead to aside from the common misconception amongst many New Zealanders that the profession "engineer" is synonymous with "tradesman", "welder", "machinist", "fitter and turner".

As an actual example of a possible system, consider a reptile enclosure. Reptiles need a warm space created by a light/heater and a cold space to regulate body temperature. A system, using the described modules, can be put together to monitor and control temperature while broadcasting the temperature readings to a webserver. The system may also be used to control the food dispensation autonomously and remotely employing the mains actuator module and the wireless communication features. Putting such a system together and programming it will be an immense learning exercise. Sensors, actuators, wireless communication, web application development etc. all come together in this exercise giving the learner a rich experience.

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