Weather Station Project

Feasibility Study

• Executive Summary

A weather station installed on or near Lisgar Collegiate Institute is feasible, and can provide a basis for enhanced curriculum for the gifted Grade 10 science class. The preliminary project parameters call for a solar/battery powered sensor unit communicating by low power FM radio to a laptop based data collecting/analyzing station in the classroom. Six meteorological instruments have been identified as suitable for construction by students using available tools and materials. A rough estimate of the major items indicates a likely cost of $750 or less. The primary concern is the attenuation of radio signals getting to the classroom. Of secondary concern is the ability to power the station from inexpensive commercial solar panels.

• Introduction

The Engineer in Residence (EIR) program of the Professional Engineers Ontario (PEO) matches a volunteer engineer with a school to help bridge the gap that can exist between the real world and classroom theory. By demonstrating practical applications of what they are taught, students are motivated to pursue education and careers in science, technology and math. Derrick Oswald has been assigned as the EIR for Lisgar Collegiate Institute with Dave McKay as the teacher liaison.

Preliminary discussions between Derrick and Dave identified the creation of a Lisgar weather station as a possible project to augment the Grade 10 science curriculum unit on weather. This present study is meant to satisfy four goals:

- determine if the project is possible given the many criteria to be satisfied
- ensure the project is within the scope of a Grade 10 class
- perform a preliminary cost estimate of the project
- identify possible alternatives for student built instrumentation

• Description

The initial concept is comprised of the elements identified in Illustration 1 Weather Station Block Diagram. An overview is provided below, but the reader is directed to more detailed sections that describe the various subsystems.

A commercial solar panel and battery provide the power necessary for the exterior portion of the weather station. This is described more fully in the Power Subsystem section, but fundamentally it is a 6 volt battery bank, charged by a solar cell which is capable of generating a minimum of one Watt (on average) when exposed to the light levels expected during the winter months in Ottawa.

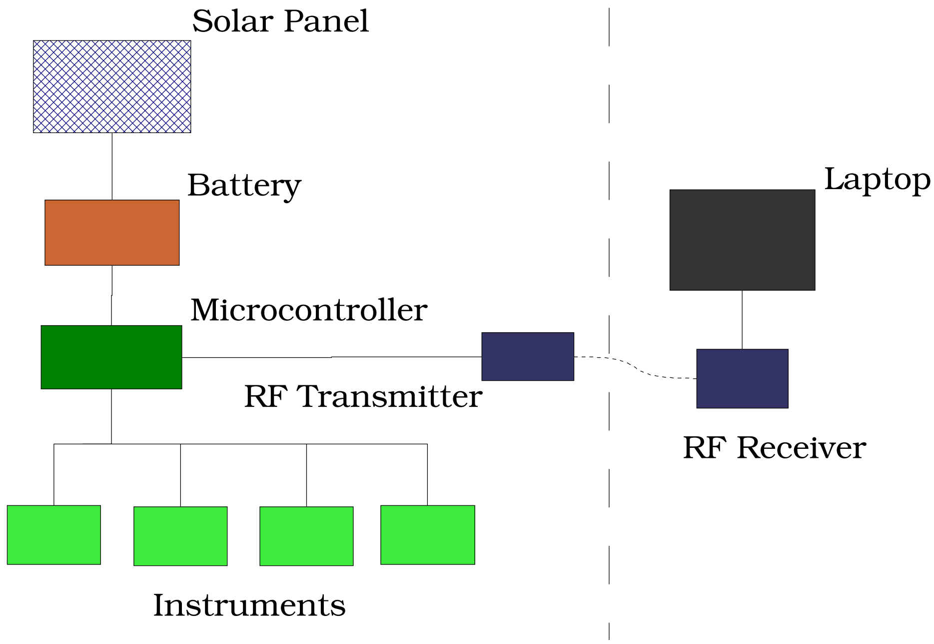

Illustration 1 Weather Station Block Diagram

A microcontroller, described in the Microcontroller section, is responsible for converting the analog values from the meteorological instruments and multiplexing them into a serial data stream which is passed on to the radio subsystem. It is a low power, low speed module which is programmed in the Basic language.

The radio system has a low power transmitter on board the weather station and a receiver in the classroom. These modules are described in the Radio Subsystem section.

The meteorological instruments are student constructed and provide for basic measurement of ambient temperature, pressure, wind velocity and direction, humidity and precipitation. Some options for student constructed instruments are described in the Instrumentation section.

A laptop computer is responsible for demultiplexing the sensor readings, performing conversions to SI units and storing readings. Optionally it can be tasked with analysing the data and providing a live feed to a web server. The software needed on the laptop is described in the Software section.

• Power Subsystem

The requirements of the power subsystem are dictated by the components which have the following power characteristics.

- **Microcontroller - 120mW**

The BasicX-24 literature from Netmedia only specifies the microcontroller consumes 20mA but doesn't say at what voltage. Looking at the documentation it indicates the on-board regulator will produce 100mA at 5V, of which the microcontroller takes 17-25mA so we assume the specified 20mA is at 5V, so the power consumption is 100mW. If the microcontroller is run at 6V, the current would not increase, but there would be extra power dissipation probably equivalent to a series resistive load, or (P = VI = .02[6 – 5]) roughly 20mW. The sleep mode could reduce this to a negligible value (8mW).

- **RF Transmitter - 48mW**

The FM-RTFQ1-433 FM transmitter module again has an on-board regulator, so the specification only lists the operating current as (max) 8mA, which we assume is at 5V for a power of 40mW. For operation at 6V, an extra 8mW would be lost in regulation.

- **Instruments - 832mW**

The instruments would be provided with a power budget to be shared among them. An average power budget would be set by the remainder of the available power divided by the number of instruments. Some choices of instruments would not require much, for example a simple 10K potentiometer attached to the wind vane would consume $6^2/10000$ or 3.6mW, while other choices would require more. Given a solar panel/battery that can supply 1 Watt, the power budget for the instruments is 832mW, or approximately 140mW for each of the six instruments. This would be roughly 23mA at 6V. A limited amount of 5V power (67mW) would be available from the regulated supply on the microcontroller module. This would be about 13mA or about 2mA for each instrument, and would reduce the available 6V unregulated power.

- **Solar Panel/Battery + 1000mW**

A possible solar panel/battery combination is available as consumer landscape lighting. Canadian Tire sells two 'Pagoda solar lights' for $25 which could be scavenged for the solar cell and battery components. Presumably these lights are designed for Canadian winters which would mean the batteries, under normal operation can tolerate -25°C. It is unclear what the battery voltage is, but at minimum it should be greater than or equal to 1.5V. At that minimum voltage, four of them could be joined in series to achieve the 6V needed. Their nominal voltage may be 3 to 5% above this value, leading to an unregulated voltage closer to 6.6V. The battery voltage could also be 12V, in which case two of them in parallel could compensate for the extra power lost in the onboard regulators having to reduce the voltage to 5V, i.e. an extra 6V at 20mA and 8mA respectively would dissipate an extra 168mW.

At this point, without having purchased one to take apart, my guess is that they are 1.5V batteries internally, so that 4 of them will be required. This is arrangement is shown in Illustration 2 Power Subsystem.

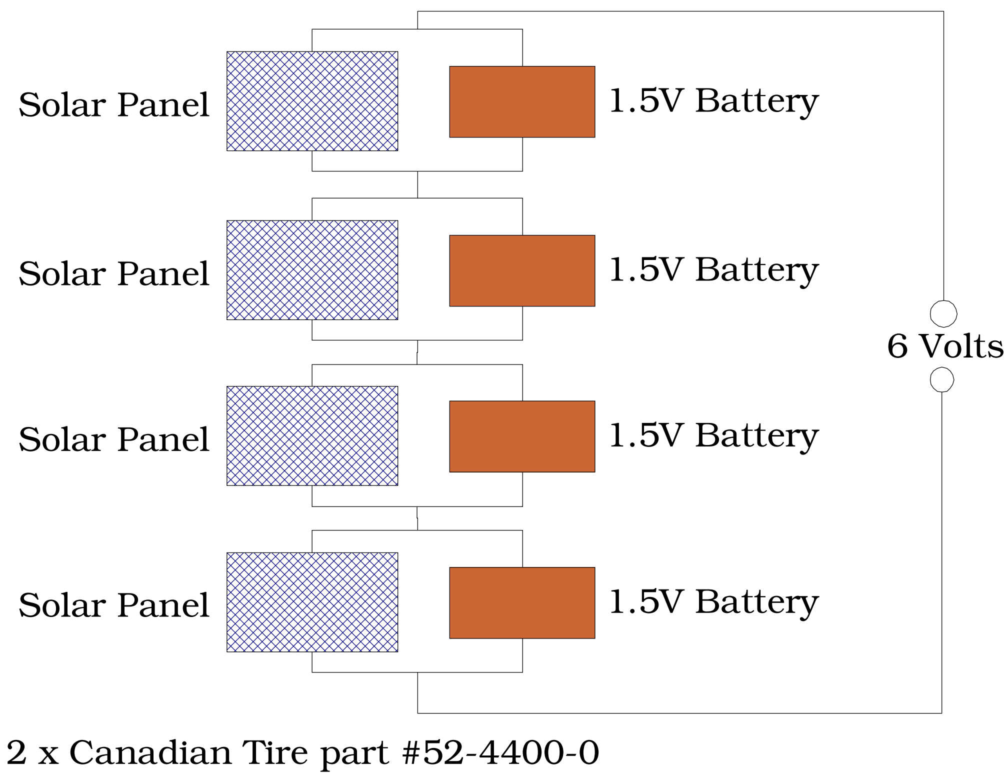

Illustration 2 Power Subsystem

It remains to be seen if the solar energy that can be obtained using these solar cells will be greater than the energy required. As a rough calculation, the solar energy in broad daylight at the equator is more than 1KW/m^2. Ottawa, at a latitude of about 45°, receives on average about cos(45°) of that or 700W; in the summer more, in the winter less. Let's say 600W in bright sunshine in winter. On an overcast day, it's probably cut to less than ½ of that, so call it 300 W/m^2. From the miniature picture in the catalogue, the solar panel on the Pagoda solar light is about 5cm by 10cm, or .005m^2. So the available solar energy from four cells is 6W. Silicon solar cells are about 15% efficient, so they will only convert 900mW. And unfortunately they have to gather enough energy over 8 hours to last 24, so average available power is 0.900 * 8 / 24 = 300mW, which doesn't appear to be enough unless the instruments are all fairly frugal. We should consider power conservation modes for the controller and instruments where possible, and a low duty cycle,especially in adverse conditions. The BX-24 is capable of entering several sleep modes, one of which is a power down mode. During this mode, current is reduced to approximately 1.5 mA, depending on the system configuration. The processor can stay in this mode indefinitely, or it can be caused to wake up due to a watchdog timeout or a level interrupt. By suitable choice of watchdog timer setting (say every minute or so) and by entering sleep mode, the power consumption can be matched to the bleakest of winters. One analog input can monitor battery voltage, and another digital input monitor ambient light level with some sort of photo cell. Using these inputs the microcontroller can determine if and when to enter low power/sleep mode. The radio frequency transmitter with on board voltage regulator has no exposed enable pin, and thus appears to need to be on at all times.

- ## Microcontroller

The problem of multiplexing the various signals (analog, counter and digital) from the various meteorological instruments onto the RF transmission data stream can be accomplished with a low power microcontroller. The first one that leaps out from a search of the internet is the Basic-X controller (http://www.basicx.com) by Netmedia (http://www.netmedia.com/) for CDN$69.99 from robotshop.ca (http://www.robotshop.ca/c214721p16434656.2.html). This is a knock-off of the Basic STAMP microcontroller (see Illustration 3 BasicX-24 Microcontroller).

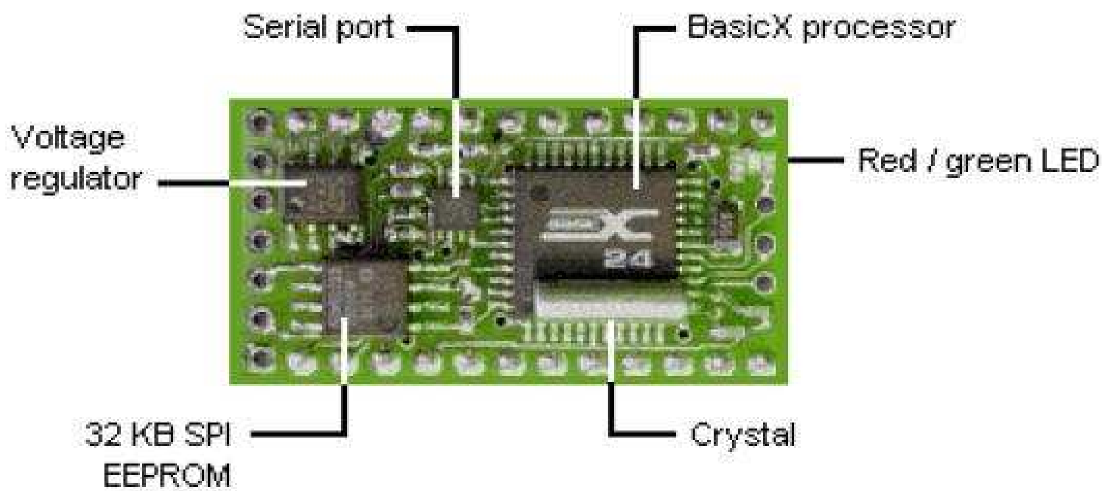

Illustration 3 BasicX-24 Microcontroller

The development system, which comes with one BasicX-24 chip included, is CDN$185.89. Although there's not much to it, you need one of these kits to get the Basic compiler and to be able to program the EEPROM. The circuitry is described in the documentation, but I believe it is advantageous to just buy this off the shelf. The cost can be amortised over a few projects.

This controller can be configured for 8 analog inputs (10bit), 11 digital inputs/outputs and 2 serial I/O pins. This means two analog inputs can be furnished for some instruments that need to measure two things at once. The microcontroller is shown in Illustration 4 Microcontroller Connections.

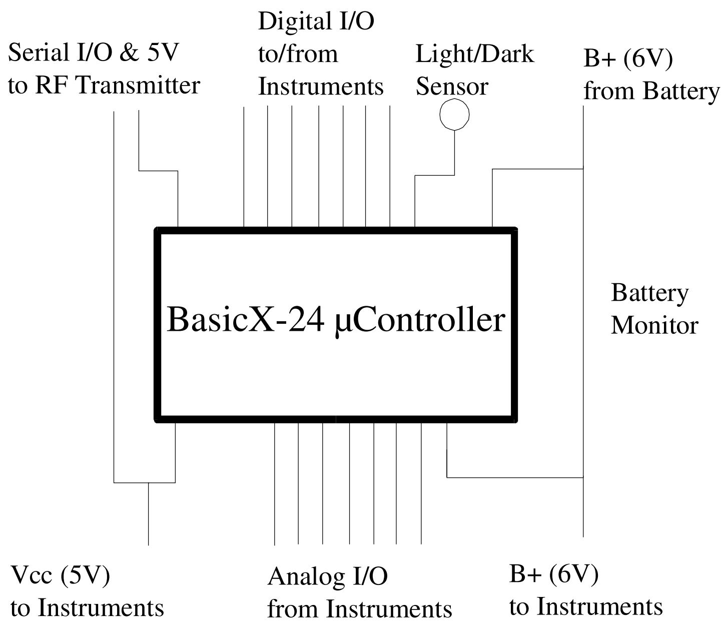

Illustration 4 Microcontroller Connections

Although I dislike Basic for it's codification of a lax programming style, it is quite accessible to novice programmers once a few fundamentals are explained to them. It would be possible for one or two of the keener students to program the telemetry on both ends of the FM transmission. By the way, this level of work would be suitable for a first year university co-op student report.

• Program

No attempt has been made to foresee all requirements, but the following are expected components of the microcontroller program

- port I/O setup – setting up registers in the chip to handle analog inputs and digital output on the I/O pins
- serial port setup – baud rate and stop bit settings to match expected PC settings, note that the RF power up is 8msec, so this code must wait that amount of time before entering the poll/send loop
- low power preparation – entering low power mode assumes the watchdog timer is set up to wake it back up
- poll/send loop – each sampling period, the microcontroller measures the instrumentation, assembles the data into an encoded serial byte stream and sends it out on the serial port, waits for the data to be transmitted (low power mode is not compatible with sending serial data, so the processor must ensure any data has been completely sent prior to entering sleep mode), kicks the watchdog timer and goes back

to sleep (with only 400 bytes of onboard RAM, there isn't much possibility of storing multiple measurement sets for ganged transmission later)

- **Duty Cycle**

If the six instruments have 10 bytes each to communicate to the base station, that's 60 bytes. The battery voltage monitor and ambient light level measurements can be considered another two instruments. With a 10% overhead for leading and trailing bytes, the packet is 88 bytes or so. With one start bit, one stop bit and a parity bit, each byte takes 11 bits. The maximum data rate on the FM radio is 9,600Hz (bits per second), which should probably be backed off to a safer data rate 4800 baud. So for 968 bits, transmission takes about two seconds (kind of a burst mode). For a measurement every minute, the duty cycle would thus be 2:60 or 1:30, with a corresponding reduction in power requirement. If the instruments need time to perform their measurements, this would obviously increase the duty cycle.

Radio Subsystem

We require a one way telemetry system with the following characteristics:

- low power (less than 50mW)
- low data rate (~100 bytes per minute)
- simple (student constructible)

The ABACOM Technologies company (http://abacom-tech.com/products.htm) sells AM and FM modules manufactured by RF Solutions (http://www.rfsolutions.co.uk) that would be suitable. These cost about CDN$80 for a transmitter (US$17, see Illustration 5 RF Transmitter Module) and receiver (US$37.50) pair with shipping (US$7.00). Note that these are cheaper directly from RF Solutions (£3.50 and £6.00 respectively, shipping £20.00, total ~CDN$60).

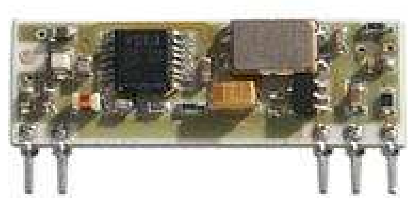

Illustration 5 RF Transmitter Module

- **Transmitter**

For power, the transmitter can use the regulated 5V available from pin 21 of the microcontroller. The documentation says 75mA is available, and the radio transmitter needs only 8mA. Extra decoupling capacitors would not be required since the 6V input is derived from batteries which have no ripple voltage. The remainder of the 67mA could

supply regulated power to the instruments.
The operating temperature range of the RF module is -25°C to +80°C, which is close to the nominal range of temperatures experienced in Ottawa, so no special environment conditioning will need to be employed and the RF module can be attached directly at the base of the external antenna, with a three wire connection (Vcc, Gnd and Data), see Illustration 6 FM Module Connection.

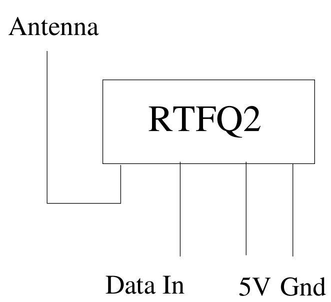

Illustration 6 FM Module Connection

- **Receiver**

Interfacing the receiver to a PC at the receiving end (base station) is accomplished with fairly simple circuitry. A regulator circuit, with necessary decoupling capacitors, supplies 5V to the RF receiver module from an external 6V direct current wall transformer. If an alternating current adapter is used, a diode bridge will also be required. A female DB-9 connector is exposed to connect to the PC serial port. Optional circuitry includes:

- switched-capacitor voltage converter (i.e. Maxim MAX1044 or Intersil ICL766D http://rocky.digikey.com/WebLib/Maxim/Web%20Data/ICL7660,MAX1044.pdf) and level shifting circuitry to translate the 0.8-4.0V data output to +/-5V, to satisfy the EIA/RS-232 standard which specifies positive and negative signal voltages, but in practice with short cables directly connecting the FM module output to the PC will probably work
- a signal strength meter derived from the 1.2-2.75V RSSI (Received Signal Strength Indicator) output to select the best antenna position and orientation
- audio output plug connected directly to the RF module to be able to listen to the data transmission just for curiosity
- a data indicator LED derived from the RS-232 output, with a suitable hold circuit and time constant to catch the relatively short bursts, for display of transmission detection in the absence of audio output

It is expected that this circuit will operate in a shirtsleeve environment and hence won't need low temperature capable components.
Some laptops don't have a serial port and one may need to be added with a suitable PCMCIA card.

- **Antennas**

The data sheet (http://www.rfsolutions.co.uk/datasheets/DS069-7.pdf) indicates this pair can transmit 75m within a building or 250m over open ground. However...
The 433MHz (ISM Industrial, Scientific and Medical UHF) band has a wavelength of 0.693m[†]. In this band, walls have a moderate attenuation, but concrete floors have a high attenuation, and metal is virtually impermeable. If we assume the weather station is immediately above the classroom, the RF path is about 10m (4m ceiling height?) and passes through two (presumably) concrete floors on the fourth and third story, and probably a corrugated metal roof covered with gravel and tar. This doesn't look good, but can probably be overcome.
Options to ameliorate the situation include:

- directional antennas on both ends to provide gain, i.e. Yagi antenna (see http://www.tfs.net/~petek/rockets/RDF/70ant.html for a description on the construction of a home-made 433.92MHz Yagi antenna as an example), but this wouldn't avoid the metal roof
- using a signal bounced off the armoury next door; brick, like concrete reflects UHF
- arranging for multipath additive interference by combining the direct (vertical) path with one bounced off the armoury, by moving the receiving antenna plus or minus half a wavelength (34.6cm) toward or away from the window
- placing the antenna on the third or fourth floor to eliminate passage through one or more concrete floor obstructions, which would entail running an RS-232 cable and making the receiver EIA/RS-232 circuit modifications mentioned, and perhaps also running a power cord if placement is on the fourth floor, but this wouldn't avoid the metal roof
- placing the weather station on the 'Gymnasium' roof, where a direct line of site may be achieved to a south facing classroom (it needs to be on the roof to achieve a 90m minimum distance to obstructions recommended by Environment Canada)

- **Software**

The software on the base station PC may be written in any language that can access the serial port. I would suggest Java. There may be some tweaking required to handle the lack of RTS/CTS handshaking on the serial port, but at 4800 baud it is unlikely that any data will be lost, given the speed of even the most ancient of laptops.

The software will primarily be responsible for demultiplexing the data stream, which will need to be coordinated with the multiplexing that was performed by the weather station microcontroller. The measurements will need to be logged to disk every so often, or perhaps even after every reception.
Optional tasks that can be performed by the base station:

- analyzing
- graphing
- uploading to or acting as a web server

[†]This is why the suggested quarter wavelength antenna is 17.3cm long.

- alerts on low battery power or instrument failures

Of course the more activity on the base station machine the more care will need to be taken that the incoming data isn't lost because of slow task switching.

Instrumentation

Protocol

The microcontroller will need to provide various methods of measurement, but in general each instrument would be provided with:

- up to 20mA unregulated 6V power
- up to 2mA regulated 5V power
- up to 140mW (between the two power sources)
- 1 (possibly 2) analog input
- 1 (possibly 2) digital input (for yes/no) or output (for trigger or reset)
- 1000 lines of Basic code to perform the sensing operation
- 500 msec in which to perform the sensing operation

There is a good discussion of home-brew weather stations at the West Carleton Amateur Radio site http://www.slvrc.org/weather/sensors.htm which covers real basic stuff. An emphasis should be placed on maximizing mean time between failures, due to the relative inaccessibility of the roof to students.

The following are some possibilities for home-made instrumentation.

Anemometer

Nothing speaks weather station like a rotating anemometer. Although a few means are available for measuring wind velocity: rotational (wind cups), pressure tube, hot wire and deflection (vane), the most accessible home made anemometers are rotational. Numerous germane web links exist displaying varying levels of sophistication.

Wind direction can be measured with a simple weather vane attached to a rotational sensor such as a potentiometer or magnetic encoder. The challenge will be to provide time averages or damping of some sort.

Thermometer

Of the various choices for electronic sensing of temperature (thermocouple, thermistor, resistance and transistor), it is likely that the thermistor will yield the easiest target. An accurate current measurement will be needed, as will some compensation for supply voltage and likely some form of linearization (which could be done at the base station).

- **Barometer**

Many mechanisms exist for measuring pressure, most of them relative. An accessible design is a resistive strain gauge on a thin metal diaphragm sealing a cavity. This will need to be calibrated for temperature and linearized. It is standard meteorological practice to report pressure as sea-level pressure rather than surface pressure, so a constant offset will need to be added.

- **Precipitation Gauge**

UW has a station http://weather.uwaterloo.ca/ that looks somewhat home-built. The Belfort and Geonor precipitation gauges collect precipitation in a bucket that is connected to a weigh scale. As more precipitation falls the bucket gets heavier. The bucket is filled with a combination of oil and antifreeze to melt snow. The millimeters of precipitation during a given time period can be computed from the difference in scale readings. To convert between Snow Water Equivalent and amount of snow, the common way is to assume an approximation of 10 times the amount of snow as Snow Water Equivalent. Presumably evaporation in non-rainy times empties the bucket and re-establishes a base-line.

- **Hygrometer**

A simple psychrometer (wet/dry bulb hygrometer) is possible for students to build, but requires maintenance to replace the water and may not be very accurate when temperatures are a more than a few degrees below zero. A single chip from Sensirion (http://www.sensirion.com/) can measure humidity, as can the HIH 3610 humidity sensor from Honeywell (http://content.honeywell.com/sensing/prodinfo/humiditymoisture/). These operate on the principle that a dielectric, who's permitivity varies according to the water content, can alter a capacitance that can be measured (see http://www.jlcinternational.com/articles/humidity_sensor_elements_info.htm). This may be difficult for Grade 10 students to achieve, but if accuracy is sacrificed, this just may be possible. Calibration would be very difficult. This is probably one instance when buy versus make wins out.

- **Light Meter**

A Selenium photocell could be easily attached to one analog input, but it may be useful enough to make a simple circuit with a binary (light/dark) output to detect when overcast skys are present or darkness falls, so the controller can go into sleep mode (if it's not running permanently in sleep mode).

- ## Physical Plant

The weather station is probable best constructed as an open frame, on which are hung the controller and instruments. Care should be taken to minimize signal lead length and also to mount the RF antenna away from large areas of metal, which apparently act as a ground plane and attenuate transmitted power.

Depending on the construction method used, it is expected that materials and hardware to build the actual weather station structure would not amount to more than a hundred dollars or so.

- ## Budget

From the above discussion, the following monetary budget is derived:

Item	Cost
solar cell/battery	$50.00
FM receiver and transmitter	$100.00
Microcontroller development system	$200.00
laptop (on loan)	$0.00
mechanical structure/assembly	$100.00
six instruments[†]	$300.00
Total	$750.00

- ## Notes:

The weather underground http://www.wunderground.com has many links to 'personal weather stations', which are apparently for sale as commercial off-the-shelf packages. For example, a list of manufacturers is available at http://www.ambientweather.com/manufacturers.html . The nearest local 'personal weather station' is in Kanata and is visible on the internet at http://kanataweather.webhop.net. It runs commercial software to display the measured weather information and can be used as a model for student efforts.

[†]An average materials budget of $50 for each instrument may be achievable depending on the ingenuity of the students.