FINAL REPORT
SPECIAL PROBLEMS 2900
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OUTLINE

SENSORS

Mechanical Sensors
- Bimetalic thermometer
- Fluid expansion thermometer
- Gas expansion thermometer
- Change of state sensors

Voltage Output Sensors
- Thermocouple
- Thermistor
- Infrared

Light Sensors
- Pyranometer
- Quantum Sensor
- UV Meter

O_2 Sensors
- Absolute/Relative Gas Concentrations
- Effects of Temperature
- Effects of Barometric Pressure
- Effects of Humidity
- Calibrating O_2 Sensor

DATA LOGGERS

CR1000
- Power Requirements
- Diff/Single ended Channels
- Excitations
- Control Ports
- Switched 12 volts
- Ground

LoggerNet
- Setup
- Connecting Screen
- Edlog/CR Basic
- LoggerNet Plotting

Introduction

This guide is an effort to create a better understanding, or at least better access to information of electronic data acquisition systems and environmental sensors in the Crop Physiology Laboratory at Utah State University.

Taken from Hatfield and Baker:

> To begin our fundamental understanding of sensors and logging systems one must look at our history and how scientists used mechanisms to sense the environment. During the first half of the first century Hero of Alexandria and the second century B.C., Philo of Byzantium came up with the thermoscope by experimenting with pneumatics. The liquid-in-glass (LIG) thermometer came in ca. 1641. The earliest (LIG) thermometers used alcohol as the liquid. Later mercury was tested as early as 1657 but it wasn't as accurate as gas, even though it reacted faster to temperature change.
>
> LIG thermometers were the first to be used to form a network of temperature stations in 1654. These thermometers scale were only 50º with the freezing point at 13.5º. Before the standardization of the thermometer scale there was no way of comparing temperatures. Each thermometer maker used his own method of constructing thermometers, and without a standardized scale there was no calibration method. Thermometers made by different craftsman could not be compared. Although, the use of melting snow was used as the first fix point calibration, there was no second fixed point. From about 1724 and 1742 Fahrenheit and Celsius developed a temperature scale that used the freezing and boiling point of water. The Celsius scale originally had 0º as the boiling point and 100º as the freezing point, but is now accepted that Marten Stromer, Celsius' successor, changed the scale to what it is now.
>
> During the mid 1700s craftsman began making sensors using the principal of deformation. This was done with unlike metals fastened together at one end and connected to levers on the other. With different expansion coefficients and as the temperature changed the two metals strips would bend at different rates forcing the lever to indicate a temperature. This mechanism was called a Bimetalic thermometer.
>
> Hatfield and Baker (2005)

Voltage Output Sensors

Thermocouples
In the early 1800s, thermocouples were produced and began their great contribution to science. A thermocouple is made by joining two dissimilar metals at one end to form a loop. Changes in temperature at the junction induce a proportional change in electromotive force (EMF) at the other end. As the temperature rises, the EMF increases, though not always linearly (Omega, 2004). The EMF can be measured by a high quality digital multimeter (DMM), but it must be capable of resolving microvolts.

There are many kinds of thermocouples and each thermocouple is made with unique characteristics for unique applications. Here are the characteristics of the three most common and most used thermocouples in the Crop Physiology Laboratory. Click on the hyperlink in the chart below for millivolt/degree changes, more thermocouple types, and specifications. The *efunda* (Engineering Fundamentals) hyperlink also has additional information regarding thermocouples.

http://www.efunda.com/designstandards/sensors/thermocouples/thmcple_intro.cfm

Figure 1.

Material (+ and -)	**Temperature Range** °C (°F)	**Sensitivity@** 25°C (77°F) µV/°C (µV/°F)	**Error***	**App.****
Type E Chromel & Constantan (Ni-Cr & Cu-Ni)	-270~1000 (-450~1800)	60.9 (38.3)	LT:±1.67°C(±3°F) HT:±0.5%	I,O
Type T Copper & Constantan (Cu & Cu-Ni)	-270~400 (-450~750)	40.6 (22.6)	LT:±1~2% HT:±1.5% or ±0.42°C(±0.75°F)	I,O,R,V
Type K Chromel & Alumel (Ni-Cr & Ni-Al)	-270~1350 (-450~2500)	40.6 (22.6)	LT:±2.2~1.1°C(±4~2°F) HT:±0.375~0.75%	I,O

*: LT = Low temperature range, HT = High temperature range
**: I = Inert media, O = Oxidizing media, R = Reducing media, V = Vacuum
Constantan, Alumel, and Chromel are trade names of their respective owners.

Thermocouples have a great advantage over other sensors because their wide range of measurement and their sensitivity. Thermocouples, when in contact with other metals, can change the electromotive force or can even pick up a stray current coming from the surface. For these reasons, when measuring a surface temperature one should consider using a shield such as these depicted in Figure 2.

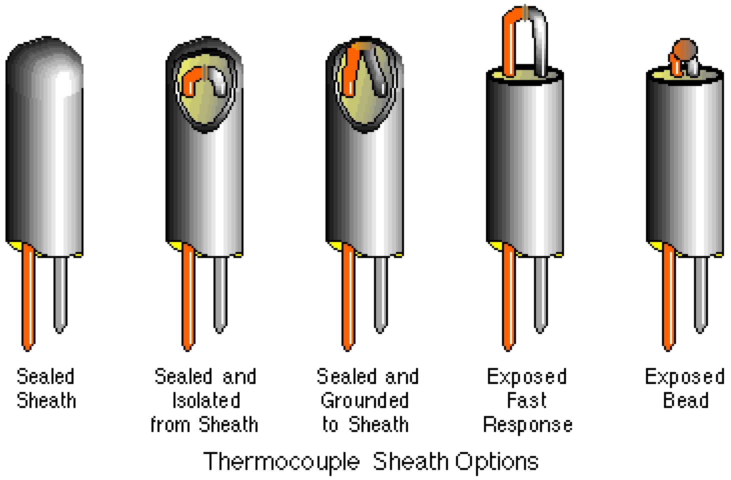


Figure 2. Capgo

Connecting the thermocouple to the data logger is quite easy. Because thermocouple colors vary, each color goes to an assigned input/output channel. On Type E thermocouple wire, the RED goes to Diff. channel (L) and the PURPLE goes to Diff. channel (H). Red is always negative (Low) in thermocouples.

Thermistor

A thermistor is another temperature-sensing element composed of sintered semiconductor materials which resistance changes proportional to change in temperature. Thermistors usually have negative temperature coefficients, which mean the resistance of the thermistor decreases as the temperature increases.
Thermistors have an accuracy of ± .1ºC to ± .2ºC depending which thermistor you use. They are one of the most stable of sensors and can be used effectively in very small spaces. These sensors use single ended channel technology.

109-L Temperature Probe

The 109-l temperature probe in Figure 3 is a general purpose sensor that can be used to accurately measure the temperature of a variety of media, most commonly air, water, and soil. The 109 temperature sensor consists of a thermistor encapsulated in epoxy filled aluminum housing. The probe measures temperature from -50° to +70°C. It is designed for durability and ease of installation and removal. Aspirated radiation shield is necessary when the temperature sensor is exposed to sunlight. More information can be found at http://www.campbellsci.com/documents/manuals/109.pdf (Campbell Sci., 2005)

Figure 3, Campbell Sci.

Infrared Temperature Sensor

To measure canopy or leaf temperature, an infrared thermometer will be the practical sensor. The infrared sensor monitors leaf-to-air temperature gradient by which one can determine the transpiration rate and stomatal conductance. Figure 4 is the model IRT-SP made by Apogee Instruments. For more information on infrared thermometers click the link below: http://www.apogee-inst.com/infrared_temperature_sensors.htm

Figure 4. Apogee Inst.

Quantum Sensor/Pyranometer/UV Sensors

In the greenhouses, it is important to have light for optimal growth and it is useful to know the light levels these plants receive during a 24 hour day. In each greenhouse and growth chamber, there is a quantum sensor (Figures 5,6) sensing the level of light in intervals set by the datalogger. A quantum sensor measures the Photosynthetic Active Radiation or PAR, which is the wave length between 400 and 700 nm. This radiation is measured as Photosynthetic Photon Flux (PPF) or watts m^{-2}. The PPF has a unit of quanta (photon) that is measured in μmol m^{-2} $^{s-1}$. (See Apogeeinstruments.com)

Figure 5. © 2005 LI-COR

All this is done with a small silicon solar cell. The silicon cell produces a small current that is proportional to the total irradiance being observed. For further specs, click on the links: http://www.licor.com/env/PDF_Files/190SA.pdf, http://www.apogee-inst.com/pdf_files/qso.pdf.

Figure 6. Apogee Instruments

Pyranometers without their labels can look similar to UV Sensors and identical to Quantum Sensors. The only difference from the Pyranometer, Quantum sensor, and UV sensors is the range of spectrum being measured. Generally, this range is between 300-900 nm.

O_2 Sensors

Several things that must be considered for accurate measurements when using the O_2 sensor (See Figure 7).

Information taken from Apogee Inst., 2005:

- **Absolute/Relative Gas Concentrations**

Figure 7. Apogee Inst.

A common unit of measure for O_2 concentration is either a fraction or a percentage relative to other gases in the air. The concentration of O_2 is 20.95% and has remained the same for several hundred years. This means that 20.95% of the molecules in the air are O_2 molecules. This percentage (20.95%) is the same all over the world at any elevation. Absolute O_2 is measured by the concentration or the amount of O_2 molecules per unit volume. This difference of altitude in measuring absolute O_2 could be the difference of a runner winning or loosing a marathon. Maybe this runner is getting fewer molecule of O_2 per breath, leaving him breathing harder or gasping for air. This is caused due to higher elevation and fewer molecules of O_2 per unit volume.

- **Effects of Temperature**

According to the Ideal Gas Law, gas concentration decreases by .34% per 1º C increase in temperature and has an O_2 decrease of 0.07% per 1ºC (.34% * .2095) increase in temperature. Also there is an excitation that occurs in the sensor that causes the output to increase by about .10% O_2 per 1ºC per temperature increase. With this net effect, there is an increase of 0.03% output.

- **Effects of Barometric Pressure**

"The ideal gas law shows that absolute gas concentration increases by 0.99% (1kPa / 101.3 kPa) at sea level for every 1 kPa increase in pressure. Because air contains 20.95% O2, a 1 kPa pressure increase results in an increase of 0.21% O2 per kPa (0.99% * 0.2095) increase in barometric pressure at sea level. Due to lower barometric pressure at higher elevations, the percentage increase in absolute gas concentration per kPa increases with elevation."
(Bugbee and Blonquist, 2005, p. 1,2)

- **Effects of Humidity**

As humidity increases, water vapor molecules displace the O_2 molecules and decrease the output of the sensor. The effects of humidity are increased in warmer temperatures because of its ability to hold moisture.

- **Calibrating the Apogee O_2 Sensor**
    - Measure the output of the O_2 sensor in millivolts. Make sure this is done in a well ventilated area so that O_2 concentration is at 20.95%.
    - Divide 20.95 by the millivolt output to get the multiplier. This multiplier will be correct for current elevation, barometric pressure, temperature, and humidity at that time.
    - Change as needed when barometric pressure or humidity changes.

The links below provide more details regarding the use of Oxygen Sensors.
Oxygen Sensor Specifications
Oxygen and Air PDF
Apogee Instruments, 2005

Dataloggers

Figure 8. Campbell Scientific CR1000

Campbell Scientific CR1000

- **Power Requirements:** The CR1000 requires 12VDC. The logger will not operate properly above 16 volts and below 9 volts. Input voltages in excess of 18VDC will damage the logger. One can determine total operation time on a battery by dividing the battery capacity (Amp-hours) by the total current draw.
- **Diff/Single ended Channels:**
    - **Differential measurements** are present when the voltage is measured between two inputs. Both inputs must be within the common mode range of the datalogger. The sensor is wired to an H (high) and an L (low) channel. Differential measurements may eliminate errors due to a difference in ground potential between the datalogger and the sensor, such as when external signal conditioning circuitry is powered from the same source as the datalogger. Differential measurements have better noise rejection than single-ended measurements. (see LoggerNet Help)
    - A **Single-ended measurement** is when the voltage is measured with respect to ground. On the data logger, one differential channel is two single ended channels. Therefore, a datalogger has twice as many single ended channels than differential channels.

- **Excitation**
  Excitation ports give programmable control to resistive bridges and are only switched on during measurement. These are generally used for advancement of channels on a multiplexer, or an excitation of an O2 Sensor, RH probe, and many other sensors.

- **Control Ports**
  There are 8 digital I/O ports on the CR1000. As an input, they can be set Low (0 volts) High (5 Volts) using the port set or Write IO instruction. A digital output port is most used to energize a relay, because the port itself has a low current output capability (2.0 mA at 3.5 V).

- **Power Regulated 5,12VDC**
  The CR1000 has two continuous 12-Volt (12V) supply terminals--one switched 12-Volt (SW-12) supply terminal and one continuous 5-Volt (5V) supply terminal. Voltage on the SW-12, 5V terminals will change with the CR1000 power supply. The 5V terminal is regulated and will stay a constant 5-volts ±4% when CR1000's power supply stays above 9.6 volts.

- **Ground/Protection from lightning**
  All data loggers must have a good ground, and a direct earth ground is preferred. All system components should be earth grounded: Dataloggers, Input/Output multiplexers, sensors, power supplies, weather boxes, towers etc...

For the owners manual of the CR1000 click this link: CR1000 Owners Manual

LoggerNet

LoggerNet is a software interface that gives the user tools to setup, configure, and collect data from a single or network of loggers. The data can either be stored on the logger or can be downloaded in real time to a computer. Before establishing a communication link between the computer and the logger, you should connect power supply to logger (see Datalogger Power Requirements). Also, connect the Isolated Optical Interface, which creates an optical break and prevents a direct line of connection from the datalogger to the computer. Now you can install LoggerNet 3.1 or higher.

Setup

On the LoggerNet tool bar, setup is used to add dataloggers to the network, create communication channels between the logger and computer, and set data collection schedules.

Connect Screen

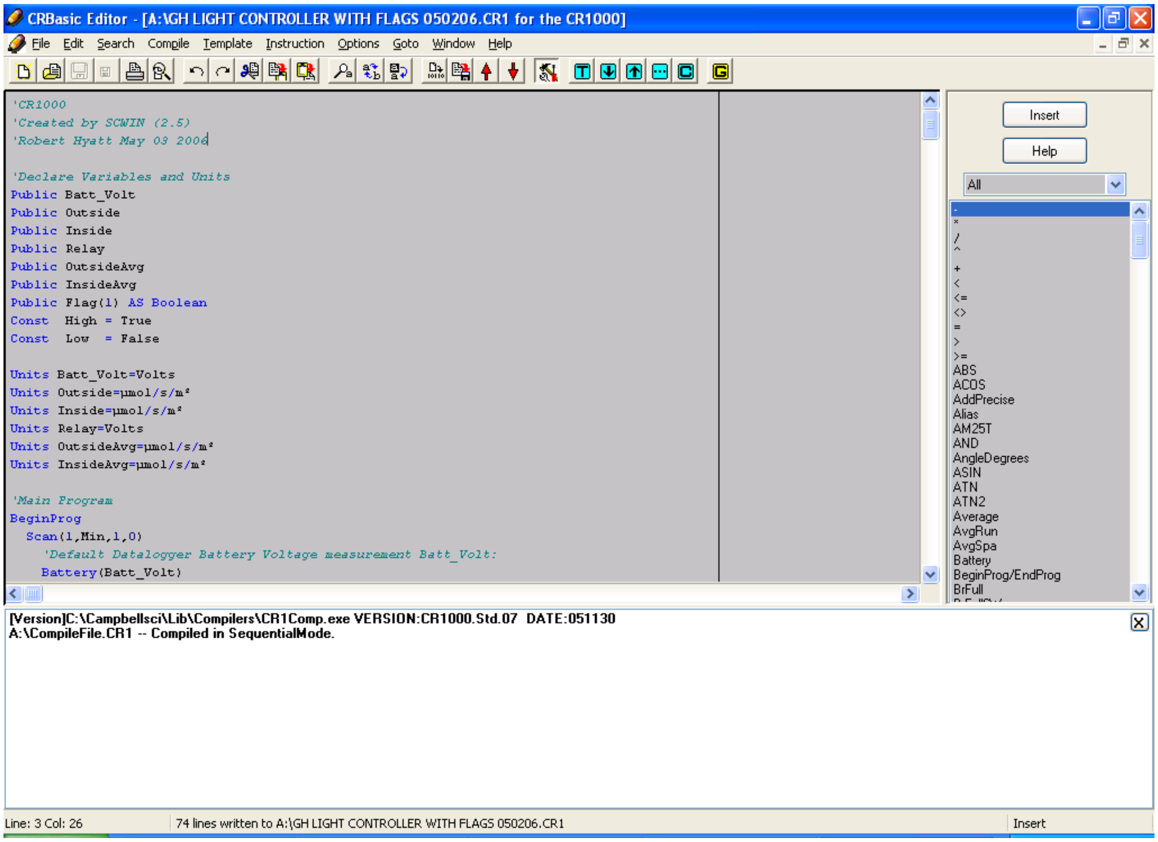
The Connect Screen is used primarily for starting/stopping or checking the operation of the datalogger. Data can also be collected manually by clicking the Collect Now button under the Data Collection area.

Edlog/CR Basic

Edlog and CR Basic are editors for creating programs for the Campbell Scientific data loggers. Canned Instructions are included for sensor measurement, intermediate processing, program, peripheral control, and data storage. The built in precompiler will check for any known programming errors and warn of potential problems in the program.

CR Basic is the newest programming language designed for use with the newest dataloggers. Its structure is taken from the "C" computer language. As seen below, (Figure 9), the CR basic editor is made up of three sections: the program entry window, the instruction panel, and message area.

The program entry window is where the algorithm is created. This includes the declaring of variables, units, and any mathematical expressions. Using canned instructions from the instruction panel, the user may author a basic program to monitor sensors and control components. The message area appears when the program is compiled and checked for errors.



```
'CR1000
'Created by SCWIN (2.5)
'Robert Hyatt May 03 2006

'Declare Variables and Units
Public Batt_Volt
Public Outside
Public Inside
Public Relay
Public OutsideAvg
Public InsideAvg
Public Flag(1) AS Boolean
Const  High = True
Const  Low  = False

Units Batt_Volt=Volts
Units Outside=µmol/s/m²
Units Inside=µmol/s/m²
Units Relay=Volts
Units OutsideAvg=µmol/s/m²
Units InsideAvg=µmol/s/m²

'Main Program
BeginProg
  Scan(1,Min,1,0)
    'Default Datalogger Battery Voltage measurement Batt_Volt:
    Battery(Batt_Volt)
```

```
[Version]C:\Campbellsci\Lib\Compilers\CR1Comp.exe VERSION:CR1000.Std.07  DATE:051130
A:\CompileFile.CR1 -- Compiled in SequentialMode.
```

74 lines written to A:\GH LIGHT CONTROLLER WITH FLAGS 050206.CR1

Figure 9. CR Basic

For an updated manual of LoggerNet click the link. [LoggerNet Manual](#).
For CR Basic go to pages 190-196.

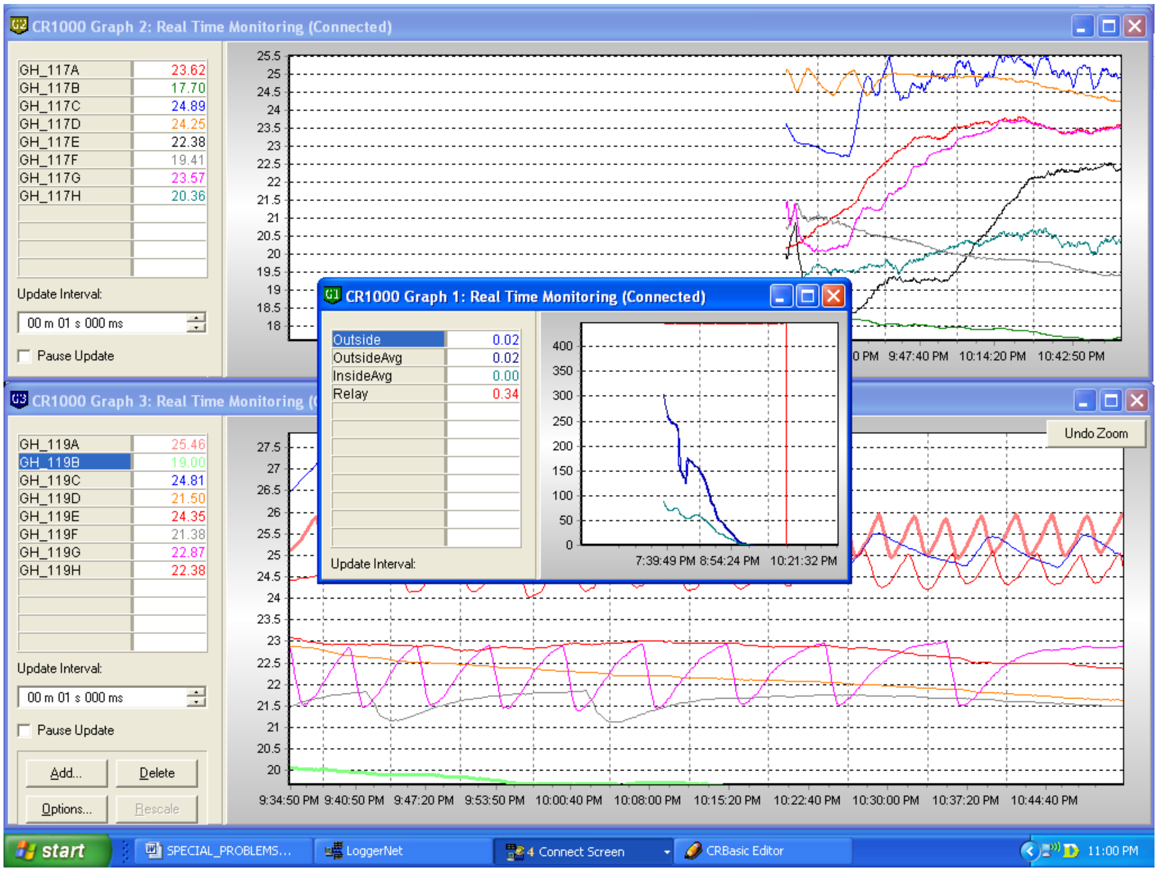
Below is the code written for the Research Greenhouse at Utah State University. This program is written specifically to monitor the photon flux outside and control the PPF inside and outside the green house. It has a 16 hour photo period between 6am and 10 pm.

```
'CR1000
'Created by Robert Hyatt May 3 2006

'Declare Variables and Units
Public Batt_Volt
Public Outside
Public Inside
Public Relay
Public OutsideAvg
Public InsideAvg
Public Flag(1) AS Boolean
Const  High = True
Const  Low  = False

Units Batt_Volt=Volts
Units Outside=µmol/s/m²
Units Inside=µmol/s/m²
Units Relay=Volts
Units OutsideAvg=µmol/s/m²
Units InsideAvg=µmol/s/m²

'Main Program
BeginProg
        Scan(1,Min,1,0)
                'Default Datalogger Battery Voltage measurement Batt_Volt:
                Battery(Batt_Volt)
                'LI190SB Quantum Sensor measurements PAR_Tot and PAR_Den:
                VoltDiff(Outside,1,AutoRange,1,True,0,_60Hz,9.04,0)
                If Outside<0 Then Outside=0

                '15 minute average of Outside PPF
                AvgRun (OutsideAvg,1,Outside,15)

                'LI190SB Quantum Sensor measurements PAR_Tot_2 and PAR_Den_2:
                VoltDiff(Inside,1,AutoRange,2,True,0,_60Hz,10.57,0)
                If Inside<0 Then Inside=0

                '15 minute average of Inside PPf
                AvgRun (InsideAvg,1,Inside,15)

                'Relay Voltage monitor
```

```
        Voltdiff (Relay,1,mV5000,3,True ,0,250,.09984,0)
        If Relay<0 Then Relay=0

        If TimeIntoInterval (6,24,Hr) then Flag(1)=High
        If TimeIntoInterval (7,24,Hr) then Flag(1)=High
        If TimeIntoInterval (8,24,Hr) then Flag(1)=High
        If TimeIntoInterval (9,24,Hr) then Flag(1)=High
        If TimeIntoInterval (10,24,Hr) then Flag(1)=High
        If TimeIntoInterval (11,24,Hr) then Flag(1)=High
        If TimeIntoInterval (12,24,Hr) then Flag(1)=High
        If TimeIntoInterval (13,24,Hr) then Flag(1)=High
        If TimeIntoInterval (14,24,Hr) then Flag(1)=High
        If TimeIntoInterval (15,24,Hr) then Flag(1)=High
        If TimeIntoInterval (16,24,Hr) then Flag(1)=High
        If TimeIntoInterval (17,24,Hr) then Flag(1)=High
        If TimeIntoInterval (18,24,Hr) then Flag(1)=High
        If TimeIntoInterval (19,24,Hr) then Flag(1)=High
        If TimeIntoInterval (20,24,Hr) then Flag(1)=High
        If TimeIntoInterval (21,24,Hr) then Flag(1)=High
        if TimeintoInterval (22,24,Hr) then    Flag(1)=Low

        If flag(1)= True then if OutsideAvg <= 1000 then     (PortSet (1 ,1))
        endif
        If Flag(1)= True then If OutsideAvg >= 1100 then    (PortSet (1 ,0))
        Endif
        If Flag(1)= False then (PortSet (1,0))




    Nextscan
EndProg
```

LoggerNet Plotting

LoggerNet's plotting feature is great way to get a better understanding of the behavior of the environment being monitored.. As a graphical interface, it can receive real-time data from the datalogger and display it as lines, dots, dashes and various colors on the screen. (see Figure 10).



CR1000 Graph 2: Real Time Monitoring (Connected)

GH_117A	23.62
GH_117B	17.70
GH_117C	24.89
GH_117D	24.25
GH_117E	22.38
GH_117F	19.41
GH_117G	23.57
GH_117H	20.36

Update Interval: 00 m 01 s 000 ms

☐ Pause Update

CR1000 Graph 1: Real Time Monitoring (Connected)

Outside	0.02
OutsideAvg	0.02
InsideAvg	0.00
Relay	0.34

Update Interval:

CR1000 Graph 3: Real Time Monitoring (

GH_119A	25.46
GH_119B	19.00
GH_119C	24.81
GH_119D	21.50
GH_119E	24.35
GH_119F	21.38
GH_119G	22.87
GH_119H	22.38

Update Interval: 00 m 01 s 000 ms

☐ Pause Update

Figure 10. 3 Greenhouse Temperature Monitoring

This example, Figure 10, is from the Greenhouse Lights monitoring/control system, all the greenhouse temperatures from 119A to 119H and 117A to 117H. The code used for the lights monitoring system is located on pages 11-12.

Class summery

Throughout my study of sensors, I have discovered that my favorite sensors are thermocouples. Mainly, this is because of their simplicity and ease in both instruction and maintenance. To me, it is pretty amazing that a combination of two metals with a reference junction can measure a voltage and get a temperature reading. Thermocouples are used throughout the Crop Physiology Laboratory. We use them for their sensitive and low cost readings.

I began with goals to learn EdLog programming and become familiar with its language and understand its syntax and structure. It was difficult at first because it was unlike any other programming that I have previously studied. The variables that you set for the program aren't declared, so to speak, in a type of group at the beginning of the program. Instead, they are declared as needed or first used. This made it difficult to keep track of where you were in the program and the area where you had first declared a particular variable. It has taken study and concentration to remember variables and to use EdLog. This language also does not have a user friendly format. It was limited to language capabilities already determined by the program. This presented a problem in combining canned programs one with another to establish logical instructions. While EdLog programming is still not the easiest of loggernet programming, I am better able to troubleshoot and complete programming needs for the Crop Physiology Lab and its partners.

CRBasic is the second programming language that I studied. CRBasic is software comparable to EdLog and is also used to customize standard programs and/or create advanced programs. With CRBasic, one can create a specialized program to utilize individual instruments to meet a need. In beginning, we can divide CRBasic programming into three parts. First, there is a declaration section where you can choose your variable names or unit of measure. Here, we declare our tables and their names. This creates a virtual storage area for all data that is collected and stored. Second, is a main program that uses the declared variables to form a set of instructions. This section also contains mathematical equations such as averaging, statistical analysis, and any counting that must be conducted. Canned instructions also belong in this section of programming. Finally, all data tables must be called and that data sent to the data tables to complete the end of program.

Having a background in C programming language, I found CRBasic to be more user friendly. There are special canned instructions unique for each measuring instrument that are very similar to EdLog. With each canned instruction, there are accompanying dialog boxes that provide options for setting up an instrument. This was invaluable because of the amount of time it saved in learning how to set up appropriate instruction for the program. CRBasic was also visually easier to read. At a quick glance, I could see what instruction went to what part of the program. Its use of brackets and parenthesis helped distinguish instruction one from another. There were also helpful color aids to indicate correct instructions.

It was necessary to learn both the EdLog and CRBasic programming. Overall, I thoroughly enjoyed the time I spend studying CRBasic. Its architecture is based on the C language, which is a language that many scientists can relate to. There are many more possibilities using this language, from taking temperature to measuring the growth rate of plants, it provides its user with a means of sharing data collection in a more common programming language. I hope to continue using the CRBasic programming language as well as Campbell Scientific loggers.

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