Material Testing Equipment Controller

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***Abstract* — The Materials Testing Equipment Controller (MTEC) is a device intended to control a testing apparatus that simulates the forces exerted by the human foot while in motion. The purpose of this equipment is to test the material qualities of the orthopedic inserts used by military personnel. Eight actuators will be used to provide the desired loads in the material while eight load cells measure how the material reacts to these stresses. This project is sponsored by the University of Central Florida Department of Mechanical, Material, and Aerospace Engineering.**

***Index Terms* — Amplifiers, Data acquisition, DC motors, Microcontroller, Printed circuits.**

I. Introduction

The idea behind the "MTEC" was originated after a presentation given about material testing by Dr. Gordon. It has been shown that there is a lack of material testing equipment in universities, not the big equipments that cost Hundreds Thousands of dollars, but small ones that are considered table-tops which could be used by students in their own labs. The aim was to design a table-top mechanical device and a control box that manages that mechanical device. The table top mechanical device will be built by a group of mechanical engineers and the control box, the "MTEC", will be created by our group of electrical engineers.

The MTEC will be able to interact with a computer through which the equipment's instructions will be loaded. Throughout the test, the user must be capable of controlling the device through a user interface. Also, information relevant to the test and the status of the testing equipment must be made available to the user at all time during operation. All information acquired in the test will be temperately stored in the device. The user will be able to extract this data for later analysis through the use of a flash drive or through a computer connected to the device. In order to achieve the desired level of functionality, the MTEC design will require the integration of several key components. A microcontroller will be at the center of the device. All other subcomponents will be operated and coordinated through the MCU. Because the testing equipment will use eight actuators, the microcontroller will be capable of operating each one separately. Also, it will collect data from all eight load cells and use it as the feedback for the control system driving the actuators. Most importantly, however, it will store this data inside the memory of the device. A USB port will be incorporated to connect the flash drive through which data will be extracted. A display will be incorporated with the microcontroller to allow the user to see the status of the experiment and testing equipment at all time during operation. Some basic user interface will be made available to the user to control the basic operations of the MTEC. A graphical user interface (GUI) will be developed to facilitate the data input process through the computer. Finally, because the device will be operated in a laboratory environment in which damage may occur, all the previously mentioned components will be fit into a sturdy enclosure sustaining rigidity against accidental strikes.

II. Overview of the MTEC Functionality

Through the graphical user interface the user will be able to enter a desired force history file in terms of force in pounds and time in seconds. The GUI will then generate the instruction file for the MTEC according to what the user has entered. The MTEC will subsequently be connected to the mechanical device and starts to provide for motor control along with data acquisition for that mechanical device. While running the test on the material, all the information is being recorded on an SD card. The user can then take the SD card and perform data analysis for everything that was stored on it. He or she can create graphs, charts, regression analysis, and deduce how the material would react to stress and fatigue.

Fig.1 MTEC controller and orthotics

III. MTEC COMPONENTS

The design approach was simplified by the group in the following block diagram below (Fig.2). It shows all the components of the controller connected together by one microcontroller. Results are stored onto a USB or SD card as far as data output. The user will be able to input the force history file through the graphical user interface. Accordingly, motor control is provided to the actuators and the load cells attached to the actuators will provide reading for the force exerted.

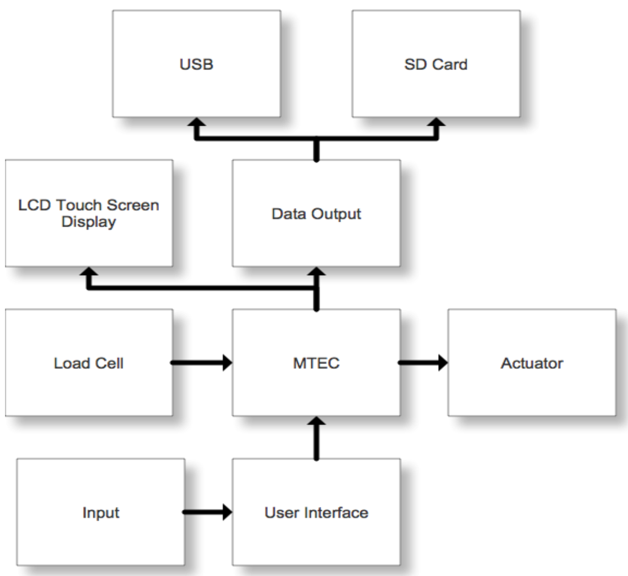

Fig.2 MTEC block diagram

A. Control Interface

The user will be able to input the commands start, pause, and stop at all times through this interface. By pressing the start button, the user will be able to begin the test. Whether the test has been stopped, paused, or it is starting from the beginning, this command will direct the MTEC to start or resume the operation of the testing equipment. The pause button must temporarily discontinue the operation of the testing equipment. However, when in the pause status, the user will be able to resume data acquisition by pressing the start button. Finally, the stop button must be able to command the MTEC to discontinue all operations of the testing equipment. Most importantly, this command must finalize the test and allow the user to collect the data acquired throughout the experiment. There is also a possibility that led lights could be used as indicators for the functionality of the different parts.

In addition to the previously mentioned commands, there are several notifications that may appear which will require the user's confirmation or acknowledgement. Once a test has a concluded, the user can choose to reuse to previous instruction set or performed a new test with a new instruction set. Either case requires the MTEC to format the preview test's data in order to allocate space for the new test. Therefore, the user will be made aware of this condition through a notification. In order to proceed or abort a new test, the user will be required to acknowledge this fact by pressing "OK" or "CANCEL". Also, if at the time of pressing the "PRINT" button there is not flash drive plugged into the MTEC a notification will appear. As that point, the user ran plug in a flash drive an press "RETRY" to collect the test data, or it can press "CANCEL" to continue with normal operations.

B. Load Cell

The MTEC’s original idea was to utilize the load cell to measure the force of an object being stretched. A tensile force will be measured as the MTEC’s machinery is clamped to the material and trying to stretch it in opposite directions. The load cell’s purpose is to read in the force of the pressure when applied to the material and then have the data recorded for the user. The load cell will constantly send information on the force of the material as it deforms over time due to a constant pressure that is applied to it. The load cell reads out the force by reading in the pressure that is applied on to it (in the case of the MTEC: between the linear actuator and the footpad) and also the applied excitation voltage. The strain gauge of the load cell is what converts the strain, or force that is being applied onto the load cell, into an electrical signal that can be read and translated into the data in pounds and/or Newton force that the user needs to read. Before actually reading the signal from the load cell, an instrumental amplifier is needed to filter out any noise and make the signal usable as the load cell gives its data in milli-volts.

The chosen load cell is the LCM200 that is capable of measuring both tension and compression. A positive output indicates a tensile pressure while a negative output signifies a compressive pressure. As the linear actuator is pushing the load cell into the material, a negative output will be read and translated from the sensor. The LCM200 has a capacity of 250 lb. which we will assume to be enough assuming the average human weight to be applied will be less. The following table (table 1) illustrates all the specifications for the cell used in the project.

Rated Output	1mV/V nom (250 lb); 2mV/V nom.
Safe Overload	150% of R.O.
Zero Balance	+/- 3% of R.O.
Excitation (VDC or VAC)	15 MAX
Bridge Resistance	350 Ω nom.
Nonlinearity	+/- 0.5% of R.O.
Hysteresis	+/- 0.5% of R.O.
No repeatability	+/- 0.1% of R.O.
Temp. Shift Zero	+/- 0.1% of R.O. / °F [0.018% of R.O./ °C]
Temp. Shift Span	+/- 0.2% of LOAD / °F [0.036% of R.O./ °C]
Compensated Temp.	60 to 250°F [15 to 121°C]
Operating Temp.	-60 to 285°F [-50 to 140°C]
Weight	0.6 oz [17 g]
Material	17-4PH S.S.**
Deflection	0.002 [0.05] nom.
Cable	#29 AWG, 4 Conductor, Spiral Shielded Teflon Cable 10 ft [3 m] long
Accessories and Related Instruments Available Calibration (STD	5 pt. TENSION; 60.4 KΩ SHUNT CAL. VALUE 100KΩ FOR 250 lb SHUNT CAL. VALUE
Calibration Test Excitation	10 volts

Table 1 Load Cell specifications

C. Displacement Transducer

A displacement transducer will be used to measure the displacement of the material under testing as it starts to move slightly and deforms due to the pressure being applied on to it. The chosen model is the LD621 transducer from Omega.com; it reserves a linear relationship between the output voltage and its corresponding displacement in millimeter. The chosen model outputs 0-10 volts with a corresponding range of 0-15mm.

D. Motors

The motor to be chosen has to be small in size and effective in producing sudden changes that are in the force history file of the user and yet be powerful enough to produce the desired applied force on the material being tested. The motor also has to be controlled by a computer program, written in a desired language like C for example, through the use of a microcontroller; therefore, in searching for the motor, it was necessary to account for motor control circuit not by a switch or just a voltage applied. Another objective for the motor is that it will produce enough force up to approximately 50 pounds of pressure on the material being tested.

Linear actuators are considered another form mostly driven by DC motors that can provide rotational motion. The gearing and the cams inside the actuator are used to transform the rotary motion to a linear motion. This type of motors was the most favored to the sponsor of the project and it's the one that will be used for the application at hand. Based on the energy source, linear actuators are categorized primarily as electromechanical, mechanical, pneumatic and hydraulic. Electro-mechanical linear actuators utilize motors to produce rotational motion which is then converted into linear motion using screws, gears or other mechanical elements.

Linear electric actuators also vary in the way how the motor is integrated into the actuator body. Some actuators have the motors attached on the side, beside the main body and others have the motor integrated within the body in line with the rod. It was favored to use the ones without any motor attachment to the side to account for the upgrade of having eight actuators in parallel to each other and to limit space used to a smaller area.

A very important factor that should be considered regarding linear actuator is the usage time or in technical wording the duty cycle. The duty cycle indicates both how often an actuator will operate and how much time there is between operations. The duty cycle is listed among the specifications for linear actuators. It signifies how long the actuator should run before it comes to a complete brake. For example, a 20% duty cycle means that the actuator could only be used for 20% of the time; 2 minutes of continuous use should be followed by 8 minutes not in use. If duty cycle is increased, either load or speed must be reduced.

Firgelli automation was considered the number one source provider for linear actuators in this project. The website contains a lot of information and a variety of actuator types and it will probably be the one to order from. All Firgelli linear actuators use a lead screw driven by a PMDC motor to create linear motion from a DC voltage. So, by applying a voltage input the actuator will start moving, when power is removed they will hold their position. If a force large enough to overcome the internal friction is applied, the actuator will back drive.

The L12 type made by Firgelli automation seemed to be a good choice especially for its size. The project needed something small and compact like the L12 type. It is designed to move, push, or pull loads along its full stroke length. The speed of travel is determined by the gearing of the actuator and the load or force the actuator is working against at a given point in time. When power is applied to the actuator, it starts to move, if the power is reversed, it moves in the opposite direction. When power is totally removed, the actuator stops moving and holds its current position unless the applied load exceeds the back drive force, in which case the actuator will back drive and its life span might be shortened. Stalling the actuator under power for short periods of time (several seconds) should not have a big effect on the actuator.

A voltage regulator could do the job of lower the input voltage and consequently control the speed of the actuator stroke. Another way is to use a PWM wave and adjust for the duty cycle needed as it will affect the speed of the stroke and also how far it will reach. A consideration is taken regarding the minimum voltage required to overcome the friction inside the actuator, it will also depend on the load attached to it.

The most favored mode of control is the PWM mode that allows control over the actuator using a single digital output pin from an external microcontroller. The desired actuator position for this L12 type is encoded as the duty cycle of a 5-Volt 1 kHz square wave on wire two of the actuator. The percentage of the duty cycle of the wave sets the actuator position to the same percentage of full stroke extension. The waveform must be from 0 to 5 volts in order to achieve a full stroke range.

According to all the previous considerations, the model selection for the L12 is as follows: **L12-50-210-06-I.** The number 50 is stroke length in millimeter, 210 is the maximum gear ratio that the L12 offers, 06 is the voltage, and option I is for the integrated controller type. All the other specs and data for this actuator are shown in table 2 below.

Gearing option	210
Peak Power Point	45 N @ 2.5 mm/s
Peak Efficiency Point	18 N @ 4 mm/s
Max Speed (no load)	5 mm/s
Back drive Force	150 N
Stroke option	50 mm
Weight	56 g
Positional Accuracy	0.3 mm
Max Side Force	15 N
Feedback Potentiometer	2.75 kΩ/mm ±30%, 1% linearity
Duty Cycle	20%
Lifetime	1000 hours at rated duty cycle
Operating Temperature	-10 to +50 Celsius
Storage Temperature	-30 to +70 Celsius
Audible Noise	55 dB at 45 cm
Stall Current	450 mA at 5V & 6V, 200 mA at 12V

Table 2 Linear Actuator Specs

Pulse Width Modulation is the technique used to generate analogue signals from a digital device like an MCU. PWM is considered a very common method to control the speed of motors; therefore generating the PWM wave was essential as it will come useful in controlling the speed for the chosen motor. It is the process of switching the power to a device on and off at a given frequency, with varying on and off times. These on and off times are referred to as "duty cycle". A 10% duty cycle signal is on for 10% of the wavelength and off for 90%, while a 90% duty cycle signal is on for 90% and off for 10%. These signals are sent to the motor at a high enough frequency that the pulsing has no effect on the motor. The end result of the PWM process is that the overall power sent to the motor can be adjusted from off (0% duty cycle) to full on (100% duty cycle) with good efficiency and stable control.

The H-bridge circuit is another important part to consider for motor control. It will be connected in between the motor and the microcontroller to provide switching for the up and down movement or the clockwise and the counter-clockwise movement in the case of rotational motor. It simply acts as a switch to reverse the voltage polarity going into the motor resulting in a movement in the opposite direction. The H-bridge could be used with most DC and AC motors, it could also be used with linear actuators.

E. Display

To effectively operate the MTEC the user must be able to receive some feedback of the operation of the device through some form of display. The complexity of the information that must be delivered would determine the type of display implemented. However, regardless of this factor, the display must be able of notifying the user of the status of the testing equipment before, during, and after a test.

Prior to the start of the test, the display will indicate the current status of the testing equipment. That is, the user must be able to see if the device is ready to execute an instruction set. Immediately after an experiment begins, the display will notify the user there is an ongoing test. Also, it will show if the user inputs the pause or stop command. Most importantly; however, it will show information relevant to the status of the experiment such as the duration of the test, time remaining in the test, instruction being currently executed, and data being acquired. After the test, the display will notify the user that the experiment has concluded.

Because the MTEC would be powered through a wall outlet, power consumption was not a crucial aspect when researching the displays. However, reducing operation cost, and therefore power consumption, was an area of interest. Also, voltage and current requirements of the display would be of great importance when designing the device’s power supply. Therefore, choosing a display with standardized voltage and current requirements was desired as it would make the design of the power supply and the integration process less challenging. Even though the MTEC would mostly operate in a laboratory environment at reasonable temperatures and humidity levels, there is the possibility of implementation in a less than ideal field environment. As a result, the operational temperature range of the display was considered. Finally, backlight capabilities would make using the MTEC in a darker environment possible. Most importantly, however, it would make data delivered to the display more visible which is a convenience users would appreciate.

F. Storage

For the MTEC, data storage is crucial to the application towards various experiments. As the MTEC progresses through each experiment, data is collected from sensors into the MTEC and is placed onto a storage device for later use. It is important for the user to be able to access during all times of an experiment.

There are several instances in which the MTEC should be able to recall data. Preliminary data is called into the experiment in the form of initial conditions and expositional experimental data. The user has multiple ways of inputting the initial conditions through the use of storage devices: flash drive, SD card, or embedded flash memory. One method of storing test data for initial experiment startup is through the use of USB flash drive. Data is written onto the flash drive through the use of a host computer (interfaced through our proprietary software). Additionally, the same method can be applied towards the use of an SD card. In terms of application, the MTEC will need to record massive amounts of data per experimental session. Primarily, the MTEC will need to copious amount of storage capacity to ensure all data can be read from each testing case. Basically, data storage can range within the extremes the storage modules can be compatible with. Depending on the type of storage, whether USB flash disk or SD card, the user will be able to increase data storage.

Storage capacity proves to be an essential factor in data logging. As the user goes through multiple tests each with varying parameters and materials, a significant amount of data will be accumulated with which the user may need to analyze. The high capacity of the SD card will allow the user to maintain large amounts of data at a time per SD card, reducing costs in purchasing multiple storage devices. The SD cards come in various sizes ranging up to 4 GB. Another format called SDHC, Secure Digital High Capacity, is rated from 4GB to 32GB capacities but unfortunately is not fully compatible with all SD adapters. Additionally, there is the SDXC (Secure Digital Extended Capacity) format which can theoretically have a capacity of up to 2TB. For the purpose of testing and design, a 2GB to 4GB SD card will suffice with the amount of data that will be collected for initial testing as well as offer a more realistic price option, as capacity is proportional to cost. If the user were to need larger capacities for longer testing period, it would be easier to swap out different SD cards for each testing requirement. Figure 3 below shows a typical interface between flash memory and a microcontroller.

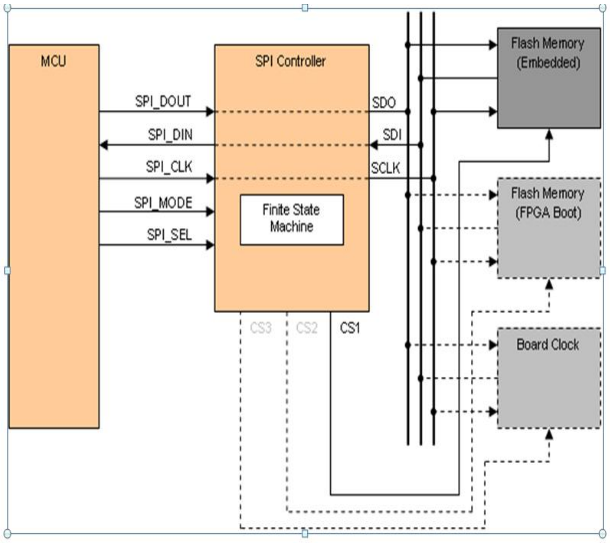

Fig.3 Microcontroller to flash memory communication

Introducing the SD card interface with the MTEC must be run through SPI mode by the microcontroller. SPI will provide a way to transmit data serially back and worth between the MTEC and the SD card. In SPI mode the maximum clock rate is 25 MHz, The speed must be considered when interfacing with a microcontroller of a certain operating frequency. Depending if the frequency is out of tolerance of the microcontroller, data will be unusable to the user.

Providing power to the SD card interface will be important for use. As input voltage will be 5V after step down and processing through the rectifier. However, the SD card will need 3.3V to operate. The socket provided will allow the following connections: COM, WP, CD P9, IRQ, DO, GND, CLK, VCC, DI, and CS. Connections will be made from the SD card socket to the microcontroller at pins CS, DI, CLK, DO, CD, and WP. Chip select will connect to the microcontroller. Serial data in and serial data out will provide transportation of information between the experiment and the SD card. Serial cock, card detect switch, and write protect detect switch will also interact with the microcontroller.

The SD card is one of the main sources of data transfer of the MTEC that allows the user to store the data remotely to be read elsewhere on any other computer device. Interfacing the SD card requires a simpler connection design than the USB to be implemented into the MTEC. By exploring data connectivity options through the MTEC, a better experience will be provided to the user when executing material tests.

G. Microcontroller

One of the very difficult tasks of this project was choosing the microcontroller ship that will allow for the application to work. The reason behind the complexity of choosing a microcontroller is because it should work for all the parts of this project. All components that include data transfer, LCD in addition to the motor and the sensors should be managed by one microcontroller.

The PIC microcontrollers were chosen for the design due to their small sizes, fast speed, and cheap cost with strong I/O capabilities. PIC stands for "Peripheral Interface Controller" and it’s a RISC (Reduced Instruction Set Computer) design, with only thirty odd instructions to remember; its code is efficient, and easy to understand allowing it to run with typically less program memory. The PIC micros are found in many projects that include motor controls, sensors, and a lot of other applications that require programmable logic.

IV. Software

Due to the coding environment of this project, there is an operating system needed to develop and utilize the software developed for the microcontroller. Language-wise, C is the choice for programming and also the program most familiar to code with (Dev C++) is only available for Windows. Even so, this is just considering the coding environment, so it is for the programmer’s comfort. As for the user, the objective is to allow the MTEC to interact with both Windows and Mac OSX operating systems. The MTEC has to be able to make a serial connection with either one and be able to run its display. The microcontroller should only be concerned about the programming, as it will host the software needed to interact with the MTEC’s other components such as the load cell and the LCD screen.

The software uses C language for the code to be written in for its ease of use and familiarity. For calculating the sensors, basic C and math is integrated to calculate the desired values.

The GUI heavily uses the graphics.h library to be able to perform functions that will be displayed onto the LCD screen. The draw functions allow the user to edit what and how objects appear on the screen to act as the buttons or menus of the screen interface. The windows/graphics functions are for manipulating the graphics on the screen, how they work and interact with one another. Basically, the function does some basic management with the interface. The text functions allow the user to edit how the text looks, whether it’s the font, size, or spacing.

V. POWER SUPPLY

In order for all components to work, power needs to be generated and transferred to all the components of the project. The table shown next as table 2 illustrates all the components of the project and the minimum voltage required for operating.

Component	**Power Requirement**
Microcontroller	5v DC @ 50 mA
Motor	6v DC @ 50 mA
LM-555	3-18v DC
USB	5v DC
SD	3.3v DC @ 250 mA
Load Cell	<15v DC excitation
LCD Backlight	3.1v DC @ 180 mA
LCD Display Logic	5v DC @ 50 mA
INA-114 amplifier	12v DC excitation

Table 3 Power Requirements

Traditionally, with the current design, the plan was to have access to an external power source located near the back face of the MTEC. Whether or not the power source will be located externally or internally depends on available components and current weight distribution. Locating the power source within the MTEC would increase weight dramatically as well as increase internal temperature as power transformers generate copious amounts of heat when operating. PCB design will alter depending on the location of the power source and various components. USB flash input and USB-COM ports can be added on any of the sides--as the user would most likely place the MTEC adjacent to a testing environment due to sensor inputs.

VI. Enclosure

Housing will be needed to contain all the necessary components of the MTEC. Electronic components will need a secure place in which foreign object debris (FOD) cannot degrade or alter the sensitive circuitry located on the printed circuit board. Also, housing serves as an insulator to the components so that they prevent shock and do not short other components. For the use of the MTEC, it was decided to utilize a standardized enclosure. Custom housings tend to be very expensive depending upon the manufacturing technique used to create them. Custom enclosures mass produced offset manufacturing costs; for the MTEC, it will need to use a simple, cheap housing that readily available to purchase. The following figure shows the chosen enclosure for the electrical device.

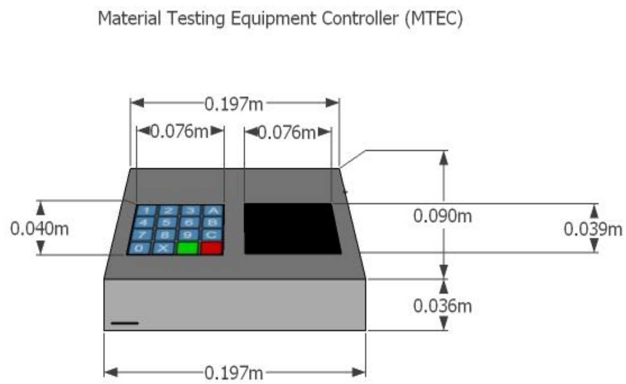

Fig.4 View of the MTEC enclosure

Assembly of the enclosure must be sturdy, as work conditions may be unpredictable depending on each test condition. The user will move the MTEC from several different workstations, so the base holding the entire component must be resilient to friction from other surfaces. Construction material of the housing can be not limited to acrylonitrile-butadiene-styrene (ABS), aluminum, or polycarbonate. ABS provides a solid candidate for the enclosure as it is strong, rigid, commonly available, and very durable. Other characteristics that can be applied to the housing are electromagnetic shielding, or non-flammability. For the purpose of the MTEC, electromagnetic shielding and flame retardant material is relevant in testing load on a material. Depending on available resources, however, a dark opaque housing will suffice.

VII. Conclusion

The MTEC is a device in which data is constantly streaming towards the end user during a testing environment sequence. In material testing, it is important for the user to rely on the equipment he or she uses. In order to improve data gathering, the sponsor has envisioned a device that could be run independently of the host computers. The MTEC provides storage for important information, which can be viewed and analyzed at the discretion of the end user. In order for the MTEC to fulfill its current objectives, data storage remains an important aspect of the MTEC. By reaching goals towards SD and USB interfacing, the MTEC can become a more useful tool in material testing and provide a more whole and easier experience compared one bounded by proprietary hardware.

It was the goal of the group to learn about the design and implementation of electronic devices. The Materials Testing Equipment Controller (MTEC) allowed us to gain experience in this area of interest. Researching and designing the actual device have proven a exiting process. Because there are many aspects to designing a controller such as the MTEC, each member has become specialized in one or two of projects requirements and how to address them. However, all the members of the group have learned the essentials of the components necessary to make this device and how to incorporate them.

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IX. Biography

Francis Bato is a senior at the University of Central Florida that will graduate with a B.S. in Electrical Engineering (May 2011). He currently is a participant of the Cooperative Work Experience Program at UCF with Lockheed Martin. He plans to continue his education in the field of electrical engineering, as well as beginning a career in the industry.

Nghia Nguyen is a student in the College of Engineering and Computer Science at the University of Central Florida. He is currently studying Computer Engineering with a minor in math.

Erich Dondyk is currently a senior at the University of Central Florida and will receive his Bachelor’s of Science in Electrical Engineering on December of 2011 and his Bachelor’s of Science in Computer Engineering on August of 2012. He has attended the University of Central Florida for four years and plans to continue his graduate studies here. He is currently working with the UCF/Lockheed Martin Work Experience Program. His primary interests lie in embedded systems, networks and security, and physics.

Bishoy Iskander is a senior student in the College of Engineering and Computer Science at the University of Central Florida. He is going to graduate with a BS degree in Electrical Engineering in spring of 2011; he will be pursuing a master degree in Business Administration while kicking off a working engineering career towards real life applications.