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Mechatronics Education at Kettering University: Development of Learning- Specific Hardware and Software

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Abstract

A series of learning-specific electronic circuit boards and associated software has been developed to support mechatronics education in the Mechanical Engineering Department at Kettering University. The boards are designed to interface to the Toshiba TLCS-900H Microprocessor Trainer and Evaluation Board. The purpose of these boards is to provide mechanical engineering students of mechatronics with robust hardware that readily permits interfacing of sensors and actuators to microcontrollers used in mechatronic applications. Further, the boards feature signal conditioning circuits for use in conjunction with sensors, and driver circuits for operating high-current actuating devices. Supporting software has been written to permit ready use of the features of the hardware with only a functional knowledge of electronics, thus helping mechanical engineering students realize the full potential of mechatronics applications in an introductory course. Additionally, a stand-alone microprocessor board with flash memory has been designed and fabricated to permit students move out of the development laboratory and readily embed the electronics portion of a mechatronics device into their projects.

I. Introduction

Mechatronic devices and products are characterized by the integration of sensors, actuators and electronic control technologies in mechanical systems. The result is the potential for enhanced functionality and a degree of smartness and adaptability in the mechatronic system. The underlying philosophy of mechatronics is to incorporate the aforementioned elements at the onset of design, envisioning optimal functionality of the device in its earliest stages of development.

A unique program in mechatronics education at the undergraduate level has recently been implemented for mechanical engineering students at Kettering University[1,2]. The need to do so has been clearly dictated by an emphasis on integration at the undergraduate engineering level[3], as well as the simple fact that consumer and industrial markets demand it. Indeed, the need to apply knowledge in electronics, sensors, actuators, control strategies and other technologies inherent to mechatronic devices is absolutely critical for today's graduating mechanical engineer.

The exploding development and introduction of mechatronic devices is at least partially attributable to the ready availability of inexpensive and functional microcontrollers[4]. The application of these devices is indeed a very simple matter, especially when hardware and software tools specifically designed to aid in the process are used. As shown in an accompanying paper[1], the objective of the undergraduate mechatronics courses at Kettering University is to provide the student with a thorough appreciation of the power of utilizing microcontroller technologies. It is a further goal that the student learns that incorporating microcontroller technologies in mechatronic applications should be thought of as a routine thing, and should be considered whenever a mechatronic design is initiated.

In developing the mechatronics curriculum at Kettering University, it was desired to provide laboratory workstations with microprocessor trainers for each individual student. Because of the generosity of the Toshiba America Electronics Corporation, fifteen TLCS-900H Microprocessor Trainer and Evaluation Boards (EVB) were obtained for those workstations and the objective was accomplished. However, to teach mechanical engineering students how to utilize these microcontroller devices within the constraints of the 12-week semester system utilized at Kettering University would still be a daunting task. This is especially true considering that they are initially unfamiliar with the programming language used, as well as the software used for debugging and compiling source code. Further, to give a good representation of issues associated with mechatronics applications, the interfacing of sensors and actuators to these microcontrollers must be addressed. Of course, signal conditioning circuits for sensors and driver circuits for actuators must be considered to effectively utilize a number of devices. Finally, control strategies and their subsequent programming into the microcontroller environment must be accomplished.

To effectively develop prototypes of mechatronic applications in the laboratory environment, it was recognized in the earliest stages of the curriculum development process that precious time could not be lost while students developed interfacing circuits between their sensors/actuators and the microcontroller. An understanding of the nature and fundamental design of circuits such as filters, amplifiers and drivers is gained in the lecture portion of the mechatronics courses. However, as indicated, time could not be afforded designing and fabricating such circuits without dramatically diminishing the time spent on understanding and applying the sensors, actuators and microcontroller. Therefore, it was determined to obtain robust interface circuit boards that would permit the student to electronically couple a broad range of sensing devices and actuating devices to the microcontroller. The purpose of these boards would be to accomplish the functionality of signal conditioning and driving high-current actuating devices, while interfaced directly to I/O connections on the TLCS-900H EVB.

Yet, this presented a set of distinct problems. First, the TLCS-900H EVB is designed to permit development engineers in industry to interface electronics to the circuit board in the most basic way – through busses of pins laid out in a unique pattern around the microprocessor chip. Typically, an application engineer utilizing this tool would build a specific interface connector for these pins that is suitable to the application. Thus, the PC board connectors do not lend well to broad, generalized application interfaces. Secondly, commercially available boards, in addition to interfacing problems, tend to have either too little functionality or too much functionality for the purposes intended in the laboratory. The needs of the lab exercises and the general development of mechatronic applications, that is, interfacing sensors and actuators through general signal conditioning and high-current drivers were not readily met. Additionally, expense for commercially available boards designed for education can be very high. Put simply, to equip the laboratory with commercially available devices would have meant spending a tremendous amount of funds to obtain devices that really did not serve the purposes intended.

As a result, it was determined to design and fabricate a series of customized PC boards to equip the Mechatronics Laboratory. Because quantities of these boards would be at least fifteen each, it would prove to be cost effective to produce them. The result was three specific boards to supplement the TLCS-900H EVB: a General Interface and Display Board (GIDB); a Signal Conditioning Board (SCB); and a High-Current Driver Board (HCDB).

It was further determined to design a PC board that would incorporate a microprocessor and flash memory to permit the students to embed real microprocessor control in design and fabrication projects associated with mechatronics courses and other courses that might include the opportunity to design and build mechatronic devices. For example, senior-level design projects in mechanical engineering courses at Kettering University such as “Medical Equipment Design” (ME-460) and “Vehicle Design Project” (ME-422) often present the student with opportunities to apply mechatronic principles and utilize embedded microprocessor controls. To accomplish this capability, an “Embeddable Microprocessor Board” (EMB) was designed and fabricated that would simply replace the processing capability of the TLCS-900H EVB. It has non-volatile memory that can easily be erased and re-written to, measures approximately 1.25 x 2.25 inches and is able to operate on batteries. Further, and perhaps most importantly, this board allows the student to develop software on the TLCS-900H EVB, utilizing the software and debugging tools that they are familiar with, and then literally download their code to the flash memory of the small “stand-alone” board.

Finally, specific software modules were written for inclusion in the student’s software code that address the custom boards and invoke certain functionality. For example, consider a student that chooses to utilize an analog sensor (e.g. linear hall effect sensor, potentiometer, etc.) and read the amplitude of the signal into a program. The sensor, as will be demonstrated below, is interfaced through the Signal Conditioning Board to the TLCS-900H EVB. To address the sensor, a student merely has to call a subroutine in the C code development software that has the format:

variable = read_analog_input(*argument*);

Here, *variable* is any previously defined character variable. The *argument* identifies the address channel that the sensor is attached to. This invokes software code that initializes the microprocessor, defines the specific addresses where the physical location of the sensor can be found, initializes and reads counts from the on-board analog-to-digital converters, and assigns the resulting value to the *variable*. Other examples relevant to common interfacing will be demonstrated later in this paper.

The result of this work is a combination of learning-specific PC boards and accompanying software, utilized to aid in the process of teaching mechanical engineering students the fundamentals of mechatronics. By taking advantage of these tools, the student is able to focus on the power and diversity of mechatronics applications through the use of the microprocessor, without committing an inordinate amount of time to producing the supporting electronics and circuits to make their designs a reality.

II. The General Interface and Display Board

Figure 1 shows the General Interface and Display Board (GIDB). This board attaches directly to the pin connections on the TLCS-900H EVB via connectors on its underside, and thus interfaces to all of its functionality. An external power source is utilized for this board to provide adequate current to drive all circuits and components. An LM7805 voltage regulator provides 5-volt power as defaults for all drivers. The central feature of the GIDB is that it has two 16-pin sockets that are used to connect the Signal Conditioning Board and the High-Current Driver Board. Circuits from these connectors pass through the GIDB to the pin connectors on the TLCS-900H EVB, thus completing the interface to the entire system.

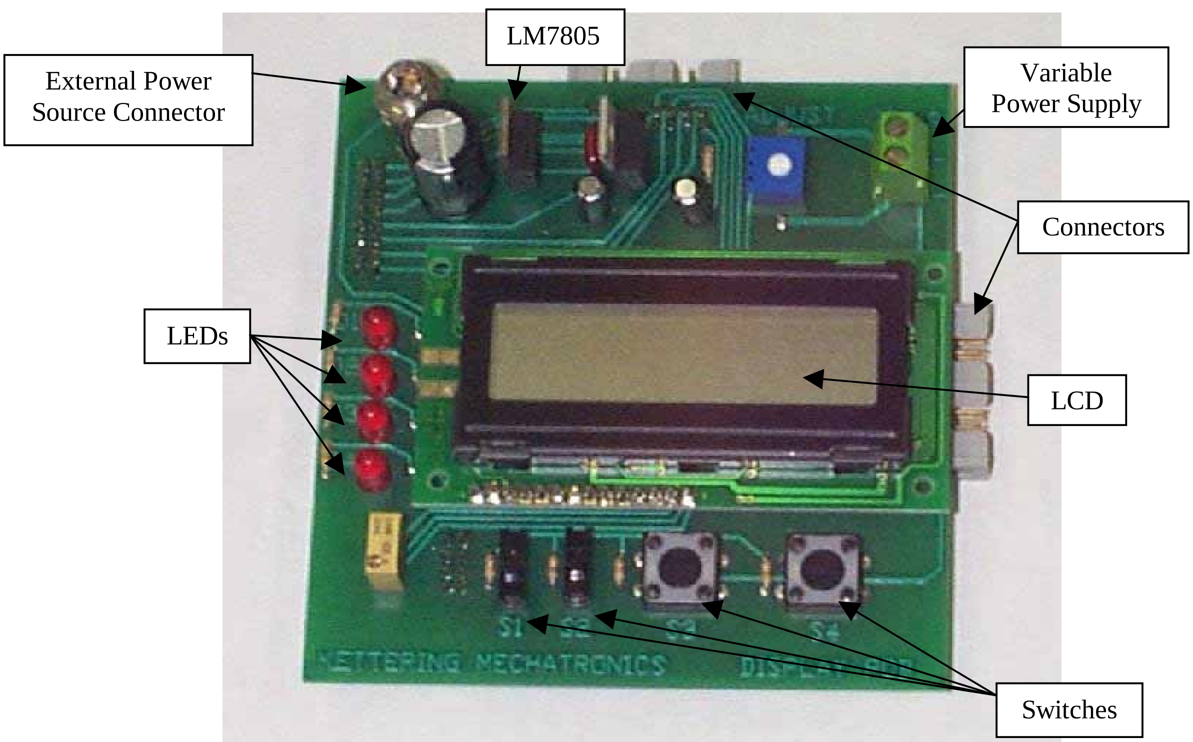

Figure 1 – General Interface and Display Board

Another key feature of this board is the 2 x 16 dot matrix LCD screen. This not only provides the student with display functionality but also with a mechanism to help troubleshoot their programs. For example, if an equation is utilized to relate the number of analog-to-digital (A/D) conversion counts from a sensor's input signal to some form of measurand, the display board can be used to confirm the number of A/D counts and the outcome of the programmed relationship.

Additionally, some of the laboratory experiments devised for the classes require the students to develop “help screens” that provide a guide for how to use the mechatronic device they have developed. These help screens can be actuated by toggling any one of the four switches present on the GIDB. These switches can also be used for other functionality in the student’s mechatronic system. There are two slide switches and two momentary contact push-button switches present. In a lab exercise, the student is shown how to create “smart” switches using the push-button switches. For example, if a switch is pressed and released immediately then a certain function is initiated. If the same switch is pressed and held for a few seconds, then another function is initiated. If two switches are pressed at the same time, then a yet different function is initiated, and so on. The GIDB also features four LEDs that are used as indicators as needed, and a variable voltage supply for powering peripheral devices via an LM317 voltage regulator.

III. The Signal Conditioning Board

To facilitate interfacing sensors to the TLCS-900H EVB, a Signal Conditioning Board (SCB) was developed, and is shown in Figure 2. As earlier noted, the SCB interfaces to the GIDB via 16-pin connectors. The SCB features three different filters: a low-pass, high-pass and band-pass filter; all of which are 2-pole devices. The high-pass and low-pass filters have a preset cutoff frequency at 100 Hz. The band-pass filter’s center frequency is adjustable from 10 – 10,000 Hz.

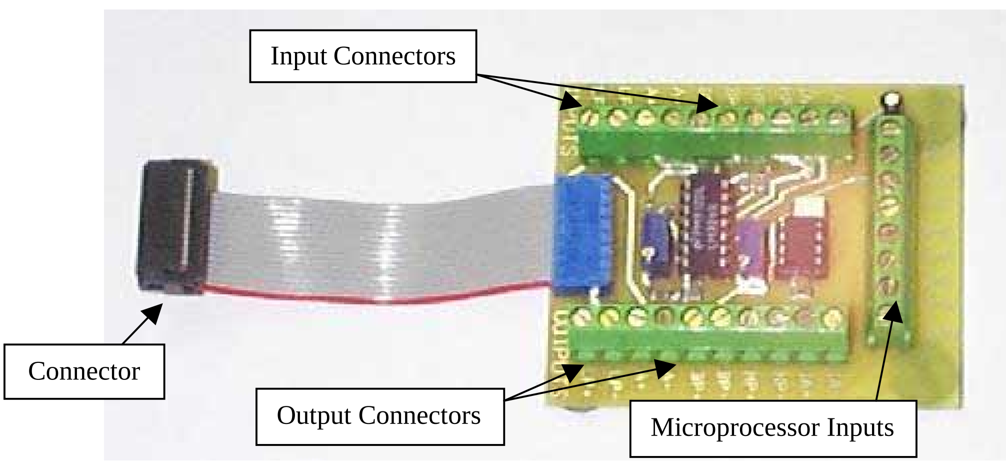

Figure 2 – The Signal Conditioning Board

The SCB also features one unipolar non-inverting amplifier and one instrumentation amplifier (bipolar). The non-inverting amplifier has adjustable gain from 1-1000, and the instrumentation amplifier has a fixed gain of 1000. Further the SCB has four 10-bit A/D inputs, which is concurrent with the number of input channels to the microprocessor. It also has two TTL-level inputs and outputs, one of which is used for the input capture channel, which permits the reading of time-based parameters of a signal (i.e. pulse width, signal frequency, etc.).

The SCB is designed so that sensor leads are interfaced through terminal strips. Signals ultimately reach the microprocessor by connecting to one of either the four A/D inputs or the two

TTL I/O lines. However, a signal can first be fed to signal conditioners via the appropriate input terminals, and then be connected from the signal conditioner output terminals to the microprocessor inputs (analog or TTL).

IV. The High-Current Driver Board

The High-Current Driver Board (HCDB) features a ten-output driver IC (Toshiba TD6337P) and two dual H-bridge driver IC chips (Toshiba TA8083P). Standard 5 volt power is attained from the LM7805 voltage regulator on the GIDB, and used to power peripheral devices. However, any alternate power source up to a maximum of 12 volts can be attached if desired via terminal connections (one set for the motor drivers, one set for the driver IC). Two switches on the board can then be toggled to isolate the voltage from the LM7805 and divert externally supplied power to the appropriate driver. Both drivers are capable of sourcing 100 milliamp loads. If more current is needed, simple transistor switches or relays can be used. The board is shown in Figure 3.

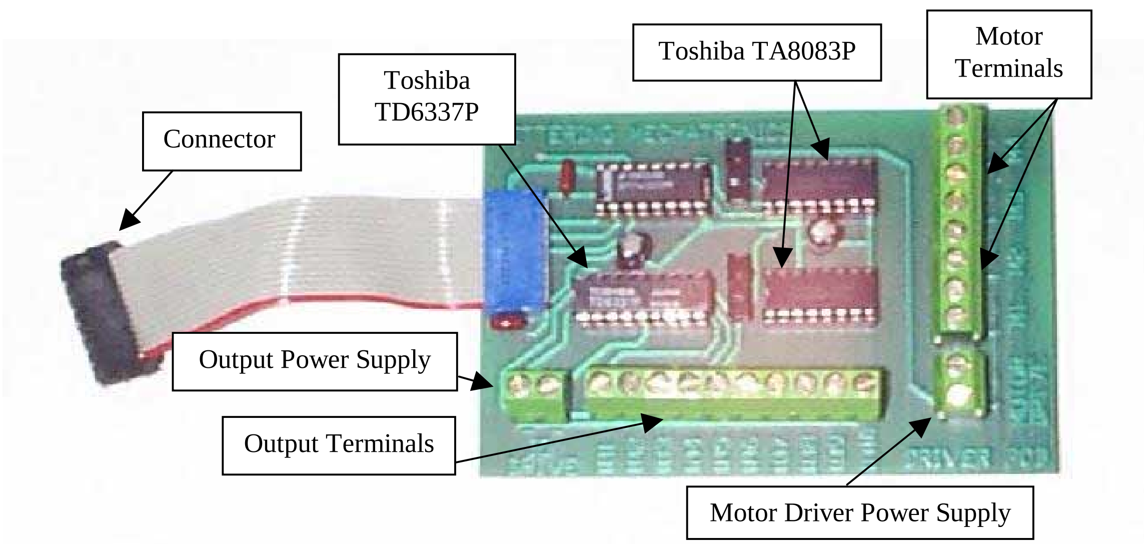

Figure 3 – High-Current Driver Board

Thus, up to four DC motors can be driven through the H-Bridge drivers. These drivers permit the functionality of driving the motors either clockwise, counterclockwise, stopping and braking the motor. This is all driven by signals from the TLCS-900H EVB microprocessor. Programming language commands used by the students to accomplish this are of the form:

MOTOR_control(*n*,*argument*);

where *n* corresponds to which motor terminals are being addressed, and is either a 1, 2, 3 or 4; and *argument* is the desired command to be sent to the motor. Acceptable arguments are *CW* for clockwise rotation, *CCW* for counter-clockwise rotation, *stop* to stop the motor and *brake* to apply opposite polarity voltages and brake the motor. When the command "MOTOR_control…"

is called, a software subroutine already written for the students is executed. This performs all the correct initialization of the outputs from the microprocessor to the HCDB.

Similarly, any of the ten outputs from the driver IC can be addressed by the students by using the command:

drive_output(*n*,*argument*);

where *n* is the number corresponding to the output terminal used (*n* = 1..10) and *argument* is either *high* or *low*. The argument "low" means that the output is at zero volts, while and argument "high" drives the output to the value of the voltage supply. Common actuators can easily be driven from these outputs, including relays, solenoids and DC motors. In each case one coil wire is connected to the output terminal and the other to ground. Pulse width modulation can be easily accomplished in software by alternating the driver states with variable duty cycles. A unipolar stepper motor can be driven by connecting each of four phase wires to four different output terminals and driving the terminals in the proper sequence to actuate the stepper motor. The center tap wires must be connected to ground. A bipolar stepper motor can also be driven from these outputs. The simplest way is to utilize a bipolar stepper motor driver IC such as a Motorola MC3479P. Clearly, utilizing this PC board and simple programming commands allows the students to readily interface and control a number of common actuating devices.

Figure 4 shows all circuit board hooked together and attached to the TLCS-900H EVB.

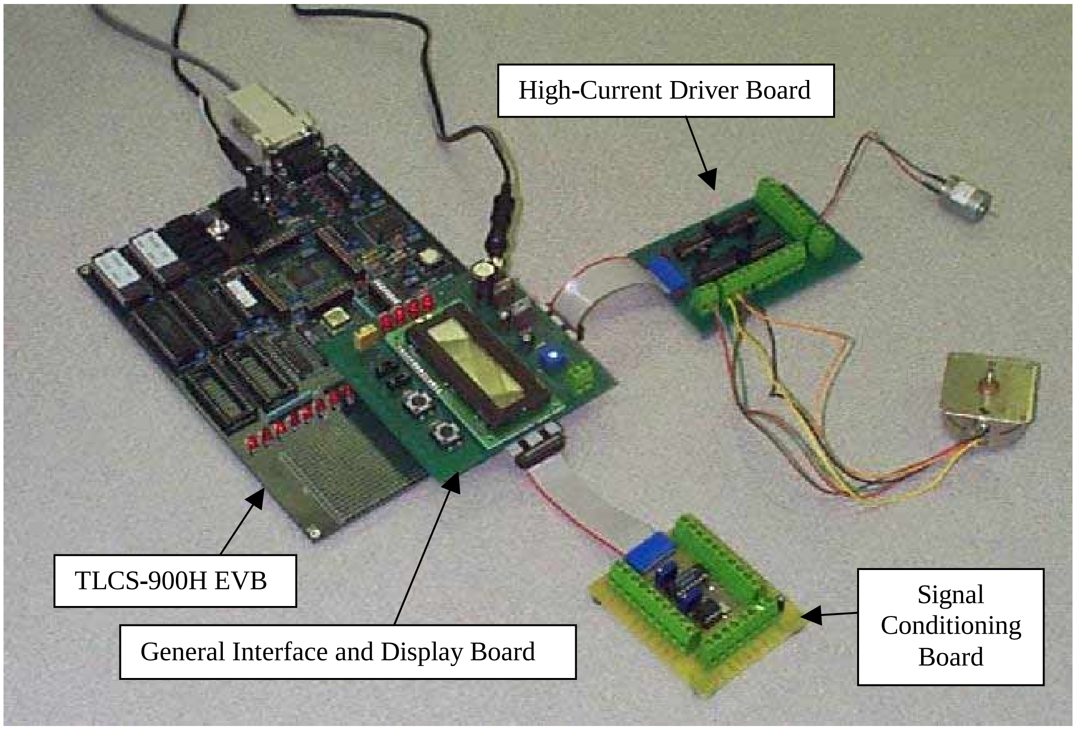

Figure 4 – TLCS900H EVB with Supporting Circuit Boards

V. The Embeddable Microprocessor Board

To facilitate embedding microprocessor controls in student-developed mechatronic prototypes, an Embeddable Microprocessor Board (EMB), which is shown in Figure 5. It features a highly integrated Toshiba TMP95FY64F microcontroller. This device includes 256k x 8 (or alternately can be configured as 128k x 16) on-board FLASH memory for program storage, and 8k x 16 SRAM memory for variable storage. It also features functionality that includes eight channels of 10-bit A/D inputs, two 8-bit D/A outputs, two 8-bit pulse-width modulated outputs and two 16-bit pulse-width modulated outputs. It also has 32 general-purpose I/O lines that can be user configured. The EMB is powered by batteries, but utilizes an on-board low drop-out voltage regulator, permitting the system to be powered by source voltages ranging from 5.3-18 volts. The EMB is designed to communicate with a host PC for code download to the FLASH memory via a RS-232 serial port. Critical to this is an on-board RS-232 interface IC, which permits direct connection to the PC serial port via 4-pin Molex connector.

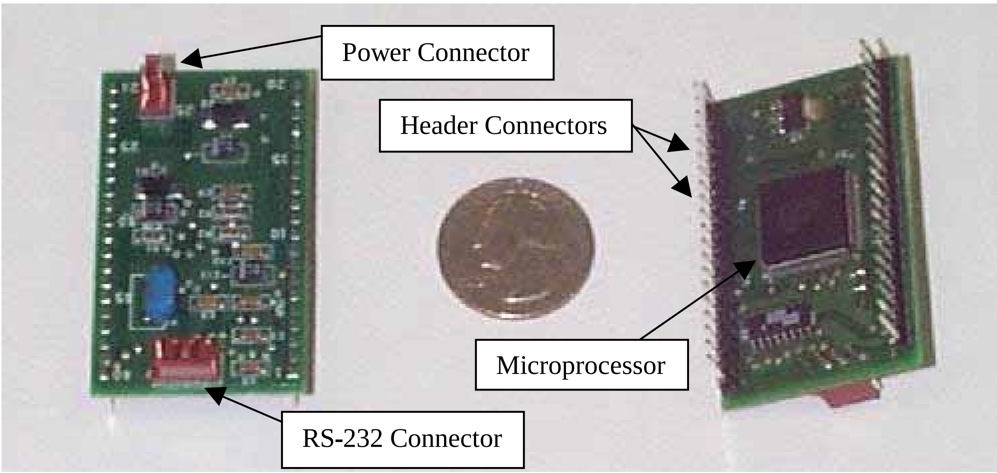

Figure 5 - Embeddable Microprocessor Board (Front and Back)

The EMB is designed so that students can develop microprocessor-based software and hardware for mechatronic systems on the TLCS-900H EVB, taking advantage of its development and debugging capabilities. Once the system has been developed, the software can be directly downloaded to the FLASH memory on the EMB, effectively allowing it to replace the TLCS-900H EVB in the student-developed system. Furthermore, since the FLASH memory is non-volatile, the program will remain in memory with or without power on the EMB but can be erased and re-written at the user's discretion.

In operation, the EMB is fabricated with two single in-line 20-pin header connectors with 0.100 inch pitch. This permits ready interfacing to standard breadboards or prototype boards. Thus, the EMB becomes the central controller of circuits designed to operate mechatronic device prototypes developed by students, and is configured for physical connection to standard circuit prototyping devices. The final result is a readily embeddable microprocessor, fabricated in the basic form of an IC chip that can be integrated with student-developed applications circuits for mechatronic device prototypes.

VI. Summary

To facilitate education of mechatronics at Kettering University, a series of learning-specific circuit boards have been designed and fabricated. These boards permit mechanical engineering students to quickly interface sensors and actuators to microprocessors in support of a very broad and innovative educational experience in mechatronics. In addition, an Embeddable Microprocessor Board has been developed for use with student prototypes of mechatronic devices. This board is compatible with the Toshiba TLCS-900H Microprocessor Trainer and Evaluation Boards used in laboratory experiences. This is in partial fulfillment of commitments made as part of an NSF sponsored award for development of mechatronics education at Kettering University.

VII. Acknowledgments

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