On the Vertical Integration of Mechatronics at Virginia Tech

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Abstract

This paper focuses on the vertical integration of mechatronics in the mechanical engineering curriculum at Virginia Tech. It reports the details of an experimental strategy to integrate mechatronics at an early level in the education of engineers. A proposal was submitted to and accepted by NSF/SUCCEED to fund this experiment. Through this assistance, the experiment of vertically integrating mechatronics was initiated. This paper presents the methodology in which it was integrated -- through optional participation in a sophomore design class. Selected sections were exposed to the concepts of mechatronic design, along with the normal course material. Students in the mechatronics sections were also given an opportunity to incorporate the use of a custom-built VT Project Box and the PIC Visual Development (PVD) software, both of which were created specifically for the task of vertical integration of mechatronics. Throughout the semester, the students were given several demonstrations of mechatronic systems through the use of the project box and software. Many students decided to implement mechatronic concepts in their final design projects. A smaller number of students made a decision to use the project box and software to develop a prototype of their final design project. Candid remarks about the students experiences, obtained from a survey at the semester's end, indicated that the vertical integration of mechatronics was a motivational feature in the second-year curriculum.

Introduction:

In the past decade, the need for mechanical and electrical engineers to be able to utilize basic skills of each other's discipline has become increasingly important. It has become such a necessity that many educational institutions now include a senior-level technical elective covering this subject matter. Virginia Tech is one such university that offers a course in *mechatronics*; however, this is only one course on a subject that bridges four year curriculums. The digital age we are experiencing dictates that for engineering to prosper as a discipline we must become more multitalented. For example, mechanical engineers must be able to use microprocessors and many other of the traditional electrical engineer's tools. For this to occur, mechatronics needs to be sufficiently integrated in the curriculums. Therefore, a vertical integration of mechatronics in the Mechanical Engineering Department curriculum was proposed to begin this process. Through assistance provided by NSF/SUCCEED, an experiment to vertically integrate mechatronics at an earlier level in the mechanical engineering curriculum was initiated. The fundamental purpose of this project was to illustrate the essentials of mechatronics

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to an earlier academic level in the curriculum, more precisely to a sophomore level. The method of introduction was to create an optional part of a sophomore-level course in which the students would have exposure to various aspects of mechatronics. Custom program elements were designed and fabricated including the VT Project Box (Fig. 1), the PIC Visual Development (PVD) Software (Fig. 2), and various sensors and actuators. These assets were used in two ways, (1) as a demonstration aid to show some simple applications of mechatronics and (2) for student prototyping of their final design projects in the class. As a result, an entire section of the sophomore class was exposed to mechatronic design. Students who chose to do so worked with the research assistant (RA) to create a prototype of their final project, which involved some aspect of mechatronics.

Purpose:

A major motivation for the vertical integration project was that mechatronics has become an emerging field of engineering and today's students need to be aware that it exists. Vertically integrating mechatronics into the mechanical engineering curriculum exposes the students to concepts of mechatronics at an earlier level of their education and it gives the student a better understanding of the fundamentals of mechatronics. Then the student is able to observe throughout the remainder of their education where mechatronics can be implemented to give a better design solution. The vertical integration of mechatronics also serves to prepare the students for the senior mechatronics course in so much that they obtain an appreciation and interest in fundamentals presented later in the mechatronics course. Specifically, the project allows the student to obtain hands on experience in an early stage of education and also exposes them to microprocessors, sensors, and actuators.

Method:

Mechatronics material was incorporated as part of the ME 2024 sophomore design class lecture, and supported by various demonstrations of mechatronics presented in the classroom. The class periods were used mostly to prepare the students for five group-design projects the students were required to complete. The final project required the student groups to make a final product design based on the two previous design steps. At this point, the groups were encouraged to create a prototype of the product for a final presentation. The groups that had mechatronics-oriented projects were encouraged to approach the RA and request help with a mechatronic prototype. At this point the RA assisted the students in determining the level of detail required for the prototype to prove the product concept. Then, the necessary sensors and actuators were specified and purchased. Next, the groups used the PVD software to create a program that would control the actuators and sensors in their prototype. After the development of the program, the groups began construction of the physical prototype. Upon completion of the physical prototype, the project box was connected to it and the entire prototype was then tested along with the assistance of the RA. The project was then presented to the class and the prototype was used to demonstrate the product concept.

Hardware and Software:

One key objective for the vertical integration project was to make the use of the PIC microprocessor and the accompanying integrated circuits accessible to the average second-year student. This was accomplished through the creation of a project box and a block diagram coding environment. The project box needed to accommodate multiple signal types: analog inputs, digital inputs/outputs, and analog output. The centerpiece for the project box was the VT84 board (Fig. 3). The VT84 board is built by each of the students in the fourth year mechatronics course. The relevant IC's on the VT84 include the PIC16F84 microprocessor (PIC), an 8 channel analog-to-digital converter (ADC) and an H-Bridge. Eight channels of the PIC served as digital inputs and outputs while the remaining channels were used to communicate with the other IC's. The H-Bridge acted as an analog output in so much that it delivers a pulse-width-modulated signal that varies the signal power. Then, four channels of the 8-channel ADC were used for data acquisition. Making these IC's work in concert with the microprocessor is relatively complicated; therefore, the creation of a programming environment accessible to the typical second-year student was a necessity. The software that was created so that one could easily program the microprocessor was named the PIC Visual Development (PVD) software. The C++ programming environment was characterized by the visual interconnection of blocks that define various operations for the Project Box to perform. Each block had specific parameters associated with it that determined how its operation was carried out (e.g. which variables to add). This software then takes the block diagram code, converts it to assembly language, and compiles it for download to the PIC. The types of blocks used for programming included single-ended reads, differential-ended reads, 4-bit digital input, 4-bit digital output, 4-bit AND, millisecond delay, one-second delay, add, subtract, multiply, speed, and several others. With these combinations of commands many useful programs could be written for the PIC. In order to utilize the capabilities of the project box and the PVD software, various sensors and actuators were made available for the purpose of demonstration and use in the prototypes. The sensors available for use included potentiometers, temperature-sensing IC's, accelerometers, microphones, thermistors and a frequency to voltage converter. The actuators used for demonstrations and projects included motors, fans, piezoelectric buzzers, light bulbs, LED's, solenoids, and speakers.

Demonstrations & Example:

During the course two examples of mechatronic devices were demonstrated and the students created one sample program. The first in-class demonstration was the position control of a link. The PVD code written for this application is shown in Figure 4. The link was mounted to a motor on a stand that used a potentiometer to sense position. Another potentiometer supplied the reference position to be achieved. With this example, the ease of programming the PIC with the PVD software was demonstrated along with some of the capabilities of the Project Box. The aspects of the software demonstrated was the ease of creation and the simple components needed to make such a block diagram. The Project Box's capabilities demonstrated were single-ended reads and the actuation of the motor. The second in-class demonstration given was the temperature control of an IC by a fan. The IC being cooled was a temperature sensor. The premise of this example was when the IC heated up beyond a certain temperature a fan would activate to cool the IC. The fan speed was proportional to the temperature difference between the desired temperature and the actual temperature of the IC. The PVD block diagram program is shown in Figure 5. The code for the temperature control was, in general, similar to that of the position control, but this demonstration exposed the students to another sensor (the temperature sensing IC) and another actuator (the fan). After showing students these two examples, those students who planned to do a mechatronics prototype created their own sample program. The sample program that the students created was a simple program just to get them familiar with the programming environment. This program blinked LED's on and off in one second intervals on the digital output. The PVD block diagram program is shown in Figure 6. This program demonstrated two programming blocks not seen in the other examples. These blocks were the one-second delay and the digital output. These examples and the sample program were intended to help orient students with the PVD software, the project box, and several sensors and actuators.

ME 2024 Student Projects:

When it came time for the students to prototype their final product design, six design teams inquired about the mechatronics prototyping hardware. The projects were constant temperature/pressure showerhead, a bird deterrent system for vineyards, an efficient dorm fan, automatic headlight tilt mechanism, public washer/dryer security system, and a car locator. Three of the six projects were finally prototyped: the bird deterrent system for vineyards, the efficient dorm fan, and the automatic headlight tilt mechanism.

The concept for the bird deterrent system for vineyards was to create a mobile unit that would travel on a track in a vineyard. The unit would stop at specified time intervals and activate a motion sensor. The motion sensor would then signal if there was motion. If motion was detected a loudspeaker system would activate in order to scare the birds. Since the terrain varies in the vineyard the motor running the unit would need at least three speeds: slow (downhill), average (flat terrain), and fast (uphill). The project used a switch to mimic a motion detector, a gravity sensitive switch for the terrain decision, and an off-the-shelf loudspeaker system designed for the purpose of deterring birds (supplied by student). To prove the concept, the microcontroller recognized different terrains using the gravity sensitive switch, then actuated the motor accordingly, and the loudspeaker system was activated when the motion detector switch was tripped.

The motivation for the efficient dormitory fan was that many dormitories do not have a temperature regulation system; thus, having a smart fan would give the resident some ability to regulate the temperature. The concept for the efficient dorm fan was to create a smart fan that would open a shutter and turn on when the temperature inside was hotter than the desired temperature and the temperature outside was cooler than the desired temperature. The fan would then run until the temperature inside met the desired temperature, the fan would then turn off and the shutter would close. The proof of concept for this project was through the creation of a mockup that opened a shutter and turned on the fan.

The automatic headlight tilt project was centered on the need to reduce headlight glare in rear-view mirrors. The concept of this project was to have headlights tilt downward the closer the vehicle approached another vehicle. The proof of concept for this project used a potentiometer to mimic a range finding instrument, and a motor that tilted the headlight mockup depending on the distance specified by the potentiometer.

The hardware purchased and developed for the vertical integration of mechatronics was utilized in various ways for each project. The project box and the PVD software were used for all of the prototypes. In the case of the bird deterrent system for vineyards the additional hardware used was the loudspeaker system, a DC motor, a momentary switch to simulate the motion detector, and the gravity sensitive switch. The DC motor was attached to the H-Bridge output, the momentary switch was wired to one of the digital inputs of the project box, the gravity sensitive switch was wired to two of the digital inputs, and the loudspeaker system was ran from one of the digital outputs.

The efficient dormitory fan was constructed of cardboard, used a DC motor to open and close a shutter, used a small fan to demonstrate the cooling, a potentiometer to set the desired temperature, and used two temperature sensing IC's. For this project the DC motor and the fan were connected to the H-bridge output via two relays. The two relays were used to direct the signal to the motor or fan. The two temperature sensing IC's were attached to two channels of the ADC. The potentiometer was attached to another channel of the ADC for a desired reference temperature. The microcontroller was used to read the inside and outside temperatures and to compare their values to the reference temperature determined by the potentiometer. Depending on the values of the potentiometer and the temperature sensing IC's the fan and the DC motor may be activated.

The prototype of the headlight tilt mechanism used two potentiometers, two small light bulbs as headlights, and a DC motor to adjust the headlight angle. The PVD code used was the same as the code for position control example. One potentiometer was used to measure the headlight angle and the other was used to mimic a range finding sensor, i.e. the system input. The mechanism was driven by a DC motor that tilted light bulbs up and down. The microcontroller then used input of the two potentiometers to drive the motor, and thus controlling the headlight angle.

The bird deterrent system prototype performed as designed and demonstrated the concept of the product. The automatic headlight tilt mechanism also demonstrated the desired concept. The mechanical system for the efficient dormitory fan worked as intended and was demonstrated at the final presentation; however, necessary code for the microcontroller could not be developed in time to demonstrate the entire concept. The PVD code developed for the efficient dormitory fan needed modifications done to the resulting assembly code. The problem was that the logic necessary for the project could not be created using the PVD software. The modifications to the PVD's resulting assembly code could not be completed in time for the final presentation.

At the end of the semester when the final projects were presented two groups from each of the 5 sections of the design course were selected to compete against one another for the best product and presentation. The bird deterrent system was selected as one of the projects to compete. This project received third place among all of the competing teams.

Questionnaire:

At the close of the semester the PI and the RA composed a list of questions for the students to answer concerning the vertical integration of mechatronics project. The questions and their responses are shown below.

1) What were the advantages and disadvantages of incorporating a mechatronics perspective in this course's curriculum?

The students had the following responses to this question. One student's response was that the rudimentary implementation of the design project with mechatronics put the design process in perspective; it also demonstrated the necessity to perform each step of the design process carefully and to a tangible end. Another response was that the mechatronics approach provided an excellent perspective of what is available in the laboratory for prototype development. Yet another student pointed out that the mechatronics approach promoted greater interest of real world applications of one's knowledge. There were no real disadvantages noted.

2) Why did you choose to work on a mechatronics project?

The reasons students cited for wanting to work on a mechatronics project varied. One reason was to increase their understanding of how the design project would actually function. Another reason was the hands-on implementation and creation of the prototype from a basic design. One student cited that many of today's mechanical devices were augmented by electronics and that it is a good idea to gain exposure to the electronics.

3) Do you have any suggestions for continued inclusion (or not) of a mechatronics perspective in the curriculum of this course?

The students suggested having more time to work on the prototype of their projects, spending more time on mechatronics, and making a mandatory project for the students to complete. They also suggested that doing another example more complicated than the flashing LED would help with the understanding of the PVD software and capabilities of the project box. And another suggestion was that the instructor could use several lectures to allow the students to work in the lab with the project box, the PVD software, sensors, and actuators.

Conclusions:

The purpose of this experiment was to expose a percentage of second-year mechanical engineering students at Virginia Tech to the basic ideas that make up mechatronics and to give them hands-on experience by prototyping their final project. Integrating mechatronics into the second-year design class was an effective method for introducing mechatronics to the sophomore student. The use of the PVD software, the project box, the sensors, and the actuators were also instrumental in introducing the students to mechatronics. The students who participated in the prototyping of their projects received the most from this attempt to vertically integrate. These students were able to build their prototype, operate the project box, and make a program that would run their physical prototype. Many of the students who responded to the questionnaire were those who worked on prototypes of their projects. It can be seen from the candid responses to the questionnaire that the inclusion of mechatronics was a success with the students. Many of the students were excited by the opportunity to apply their knowledge to designs in a hands-on way.

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DONALD GROVE
Donald Grove recently completed his MS degree requirements in mechanical engineering at Virginia Tech. As an undergraduate (BS, Va Tech) he participated in research with Dr. Saunders, and worked closely with Dr. Reinholtz, as a team leader of the Autonomous Vehicle Team (AVT). Donald's research assistantship was funded by the NSF SUCCEED campus program under the "Vertical Integration of Mechatronics" project. That research focused on integrating mechatronics into the undergraduate curriculum, as discussed in this article. Donald also worked as a graduate teaching assistant in the Mechatronics Laboratory. His academic studies were concentrated in the field of control systems and mechatronics. Donald Grove is now an employee of Pratt-Whitney's Propulsion Systems Analysis group in East Hartford, CT.

WILLIAM SAUNDERS
William Saunders is an Associate Professor in the Department of Mechanical Engineering at Virginia Tech. During the Fall 1996 semester, he launched the first mechatronics course at Virginia Tech. That senior-level technical elective is cross-listed in Electrical & Computer Engineering and Mechanical Engineering. Since that time, Dr. Saunders has been very interested in promoting mechatronics in undergraduate education. His research interests have been primarily in the areas of adaptive structures, active noise reduction, and active combustion control. Currently, this research has resulted in three U.S. patents for unique design approaches to personal ANR systems, more than thirty journal and conference articles, and a textbook on adaptive structures. He is a member of the SPIE and Tau Beta Pi.

CHARLES REINHOLTZ
Dr. Charles F. Reinholtz is Professor and Assistant Head of the Department of Mechanical Engineering at Virginia Tech. He is the co-author of *Mechanisms and Dynamics of Machinery*, a popular textbook published by John Wiley. He holds two U.S. patents and has authored or co-authored over one hundred technical papers in the areas of mechanisms, robotics and mechanical design. Professor Reinholtz received a National Science Foundation Presidential Young Investigator Award, Virginia Tech's William E. Wine Award for outstanding teaching and the ASME National Faculty Advisor Award. Professor Reinholtz is currently faculty advisor to the student section of the American Society of Mechanical Engineers and the Autonomous Vehicle Team.

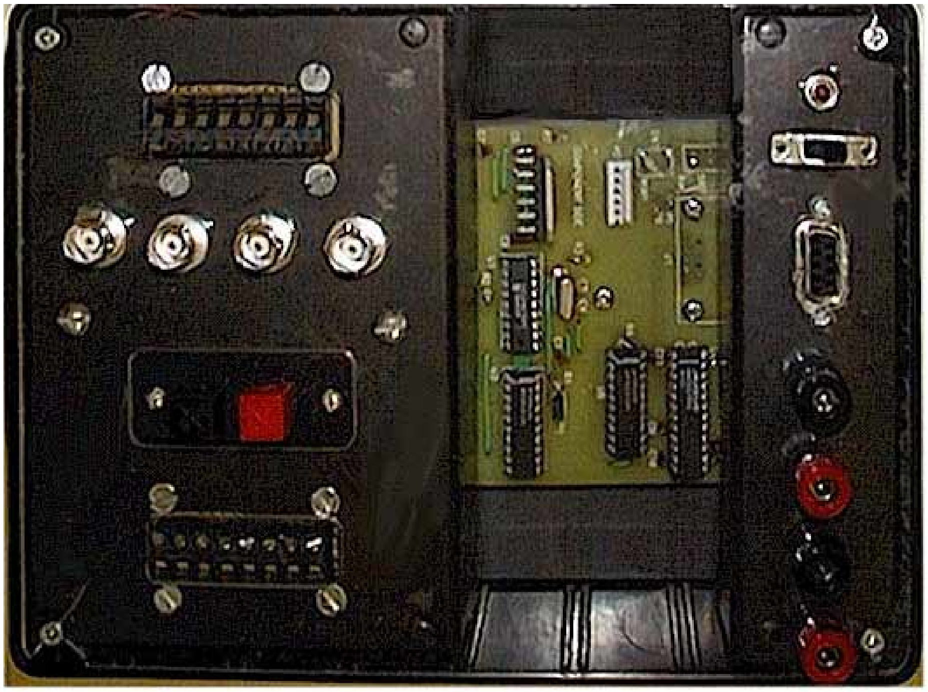

Figure 1: Picture of VT Project Box used in vertical integration of mechatronics experiment.

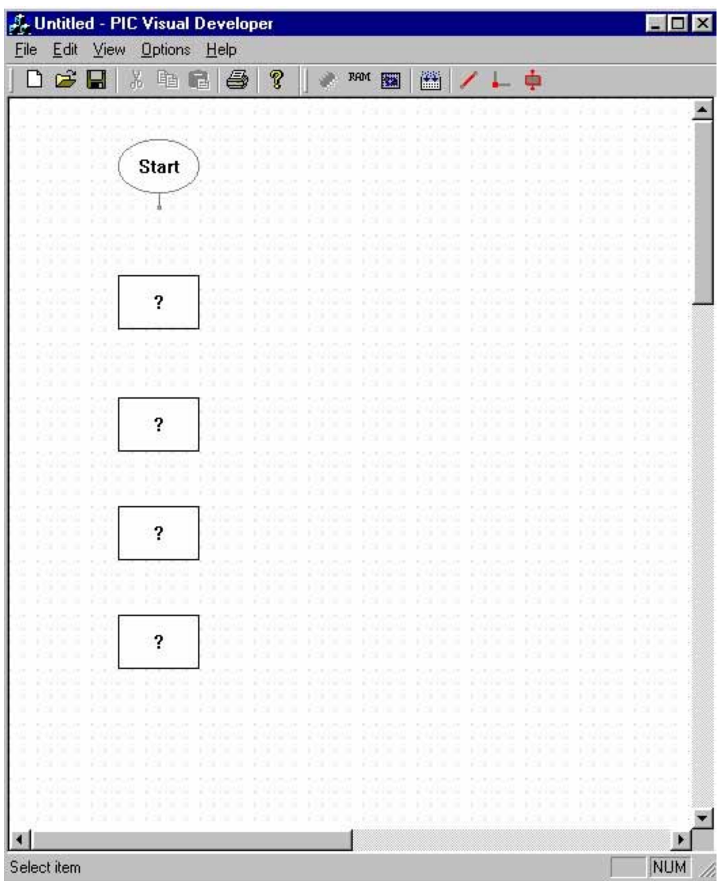

Figure 2: Example of PIC Visual Development (PVD) programming environment

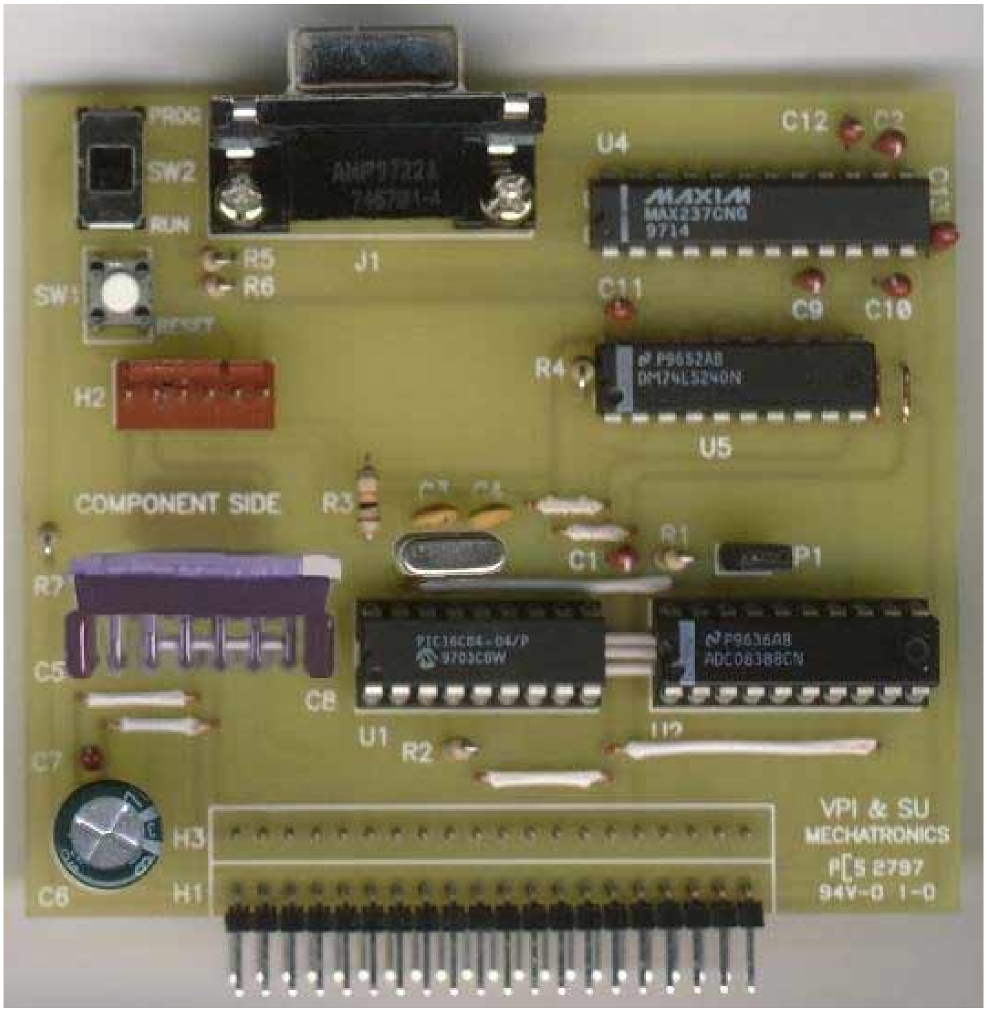

Figure 3: Picture of VT84 prototyping board assembled by fourth-year mechatronics students.

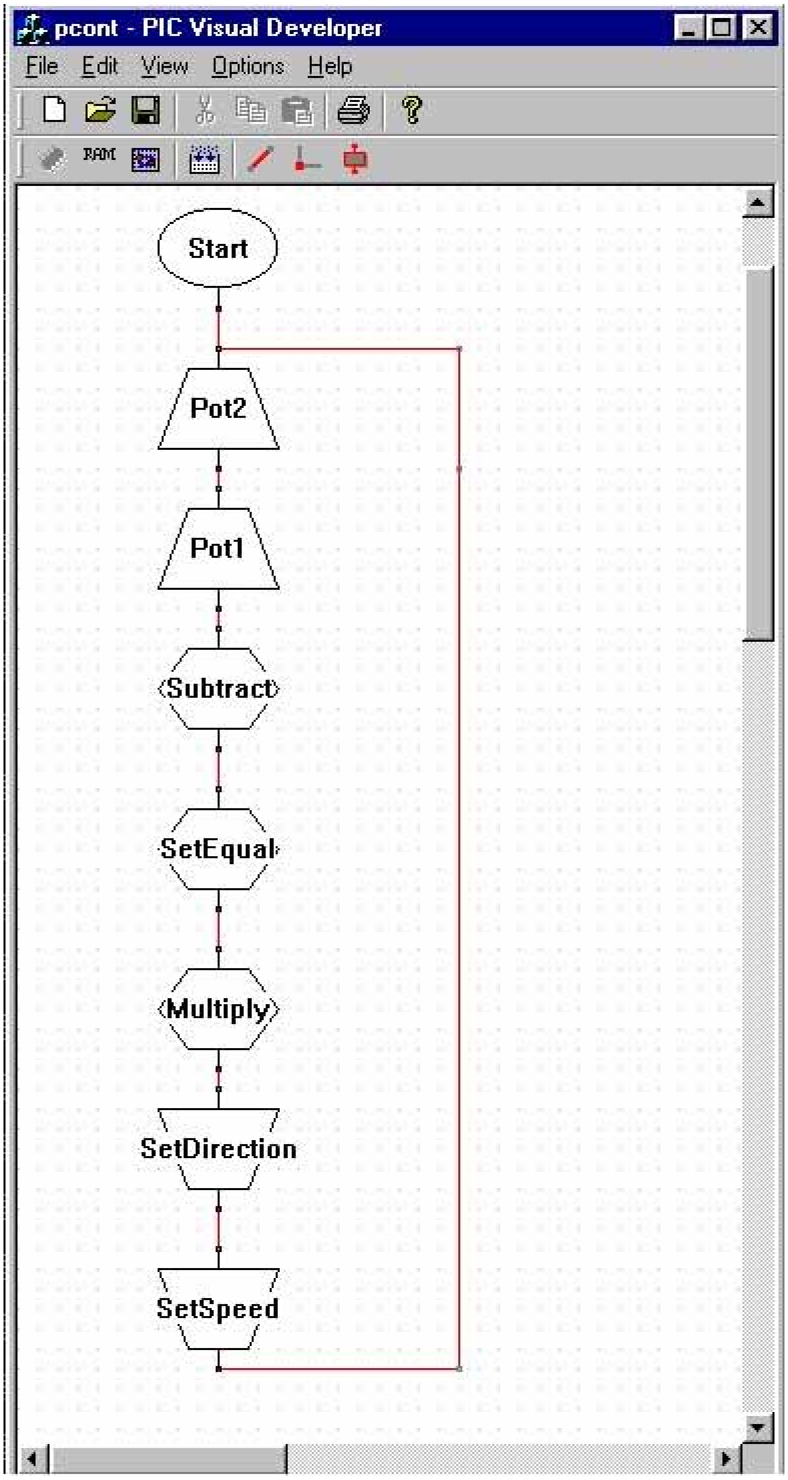

Figure 4: Position control program created in the PVD environment

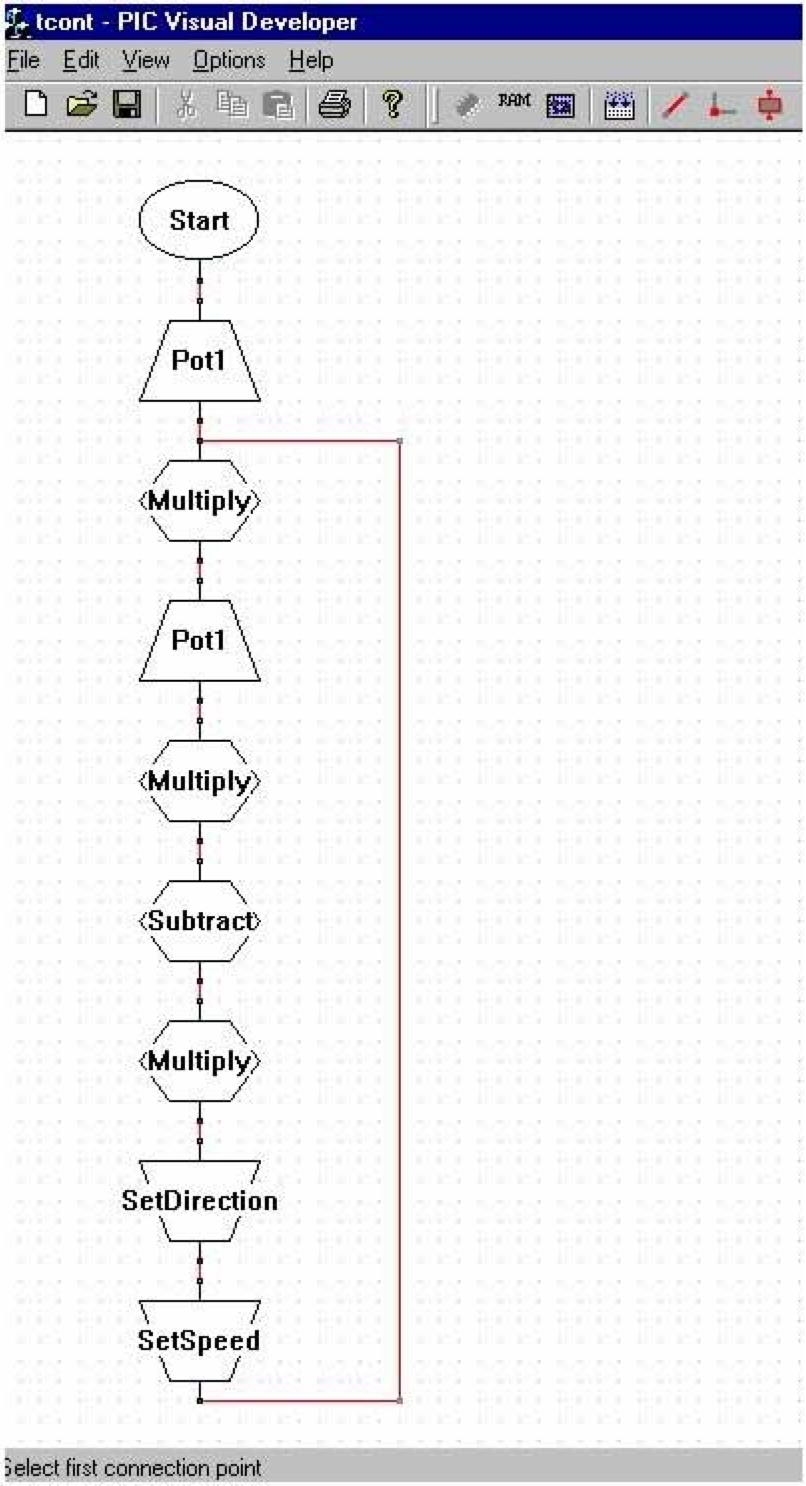

Figure 5: Temperature control program created in the PVD environment

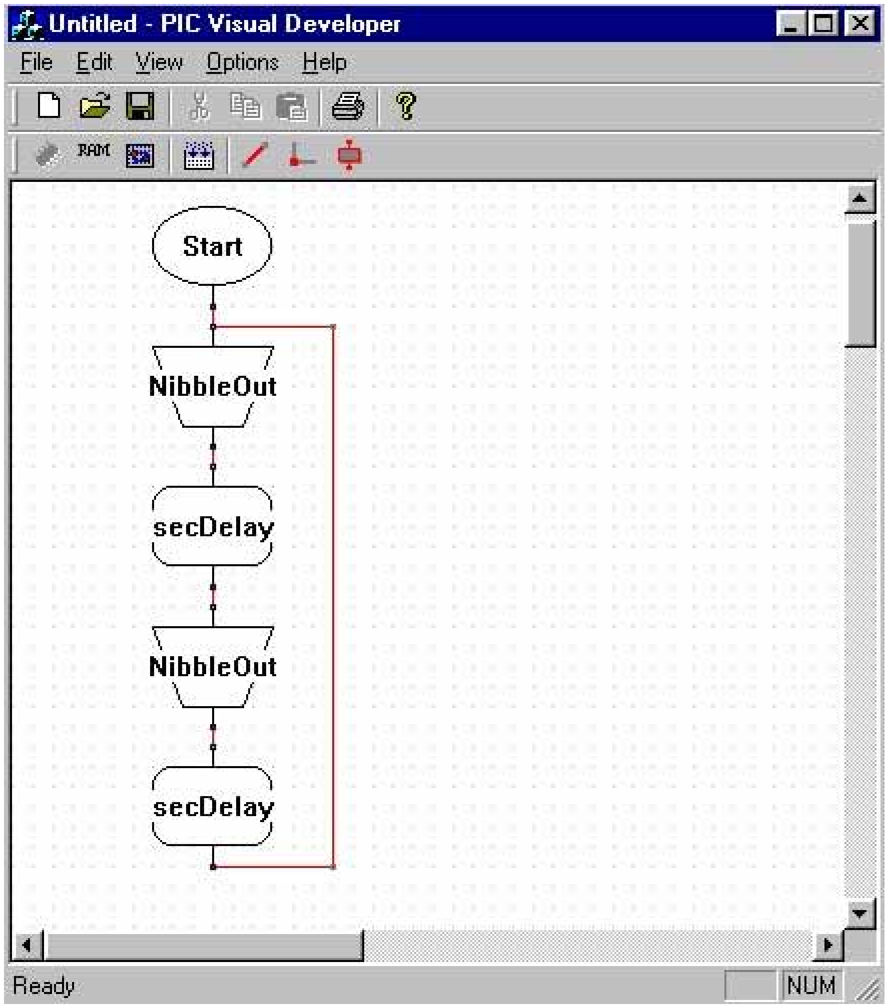

Figure 6: Flashing LED example programmed by the students