Hands-On Design Projects in a Sophomore Mechanical Engineering Course

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HANDS-ON DESIGN PROJECTS IN A SOPHOMORE MECHANICAL ENGINEERING COURSE

Abstract:

This paper presents four projects initiated and implemented by sophomore students in their Mechanical Measurements course at Texas A&M University at Qatar. The projects aimed to help students understand how different course topics are interrelated and give them the opportunity to apply course concepts in practical settings. Students utilized engineering software packages such as LabVIEW and SolidWorks in an advanced manner and in diverse engineering specializations.

The students, in groups of three, were given the choice to choose among several projects provided by the instructor or propose their own, considering the different types of sensors available in the measurements laboratory. All groups preferred to choose their own ideas, which were partially inspired by project ideas provided to them by the instructor. After intensive consultation with the course instructor and the lab coordinator, the following four projects were approved by the course instructor: truss bridge structural analysis which lies in the field of constructional engineering, car safety system to monitor driver's heart rate which is considered to be an Industrial Engineering concept, virtual length measuring device, a computer engineering related project, and car parking system, a service oriented project. Although each of the projects was unique, all groups needed to complete approximately the same tasks such as investigating different options of sensor and data acquisition system characteristics, budget estimation, collecting data, implementing statistical analysis and measuring uncertainty on the acquired data.

The aforementioned projects were successfully implemented by the students who presented their work at the end of the semester in a PowerPoint presentation. By taking advantage of ready-made LabVIEW's hundreds of functions, students were able to focus on developing algorithms and building prototypes efficiently. Using Sensor Mapping LabVIEW VI in visualizing bridge stresses was a good example of such ready-made functions. Similarly, NI wireless sensor network devices used in the car parking project were fully compatible with LabVIEW and provided an easy drag-and-drop programming interface to extract high quality measurement data. Wireless devices from NI provided an opportunity to reduce installation and system costs, increase flexibility, simplify system deployments, and address a new set of applications that were previously challenging with a wired approach. LabVIEW flexible platform also allowed students in the car safety project to integrate hardware from NI with other commercial off-the-shelf hardware from Vernier. By using the hand grip heart rate sensor from Vernier, students easily built a LabVIEW code that monitors a driver's heart rate and triggers an SMS message to the operator when an abnormal heart rate occurs. The software's graphical drag-and-drop paradigm helped students learn key programming concepts and develop analytical skills while gaining experience with technology used in the professional world.

Introduction:

Sophomore mechanical engineering students at Texas A&M University at Qatar take Mechanical Measurements Course (MEEN 260) as the first course to provide a practical foundation for *designing and conducting engineering experiments*. The topics studied in this course (Figure 1) are: understanding and comparing sensor technologies, designing and analyzing signal processing circuits, understanding the process and potential problems of data acquisition and digital filters, and quantifying measurement uncertainty using statistical data analysis. Developing technical writing skills is a significant part of the course as well. The final objective of this course is to enable students to properly design, conduct an engineering experiment, report and evaluate the results in a clear, concise, and compelling manner.

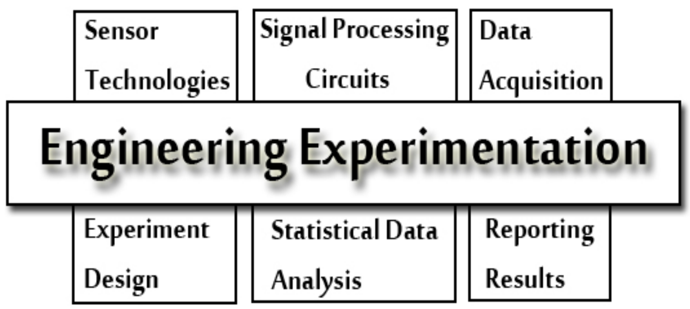


Figure 1: Topics covered in the course

In this course students are assigned homework to assess their ability to perform basic engineering analysis, laboratory exercises to assess their communication skills and ability to correctly conduct experiments and evaluate the results. Students also take quizzes to assess their understanding of fundamental ideas and analyzing techniques and take exams to assess their ability to analyze and evaluate methods of sensing and experimentation. Finally, a course project is assigned to assess their ability to synthesize course concepts to design, analyze and evaluate a complete experiment.

To help improve the instruction and to evaluate the course efficiency, the above student assessment methods are used in a more comprehensive evaluation prepared by the instructor. Such evaluation includes, relating the course learning outcomes to the program learning outcomes, determining their levels of relevance and importance, filling out the Assessment Results table to show the average level of performance of the students in each learning outcome, and providing suggestions/comments that the instructor feels will help improve the learning process and meet the course outcomes.

Aligned with the purpose of continuous assessment and improvement, the Mechanical Engineering Program takes an end of semester student survey to rate the level of proficiency in the areas covered in the course.

Project Guidelines:

The main objective of the course project, as stated previously, is to help students understand how different course topics are interrelated, and give them the opportunity to apply course concepts and techniques to solve a relevant engineering problem.

In the course project students are given the choice to choose their teammates after they have had the chance to experience at least two different groups in the laboratory. In the laboratory, students are assigned partners based on a random selection to give them the chance to work with a diverse group of people, both in terms of intellectual ability and personality type, helping them to learn what makes an effective team.

After team sign-ups, each group needs to get its proposal approved by the course instructor. They also can choose among project ideas proposed by the instructor. In either case, students are required to clearly state their project title, objective(s), and the significance of the project to industry, science, technology, health, etc. Upon approval, the projects start a three-phase process with due dates specified in the project guidelines given to the students. All groups need to complete approximately the same tasks.

In Phase One, they have to determine the sensing device required to transduce the desired measured quantity to an electrical signal, determine a complete data acquisition system to acquire and record the data from the sensor, justify selection, discuss aspects of cost and accuracy, determine the measured uncertainty, and potential sensor and DAQ errors.

In Phase Two, students are required to generate and collect a set of steady-state data, justify their choice of number of data points, measure uncertainty based on sample variation for each of the sensed/calculated quantities, determine the most appropriate model (regression) to characterize the steady state system performance and comment on any discrepancies.

In the third phase, they have to collect or generate a set of transient data, discuss the effect of sensor accuracy, resolution and sampling rate, discuss the impact of data acquisition system on the quality of time-varying data (noise, quantization, loss of information due to sampling, etc.) and discuss the observed time/frequency response of the system.

Students submit two technical memos, similar to the laboratory memos, covering the items of Phase I and Phase II respectively. These give students an opportunity to receive feedback on the technical content and the writing quality before submitting the final report. The final report is a stand-alone report that includes Phase I, II, and III results. Along with the final project, students are encouraged to submit a two-minute final presentation video to receive extra credit. Course instructor anticipates posting these videos on the e-Learning system for current and future students. The recommended content of video includes: course and semester, names of each group member, text or narration describing the objective of the project, picture slideshow or videos showing the highlights of experimentation process, text or narration of conclusions drew from the data and appropriate background music.

Results and Discussion:

The following describes four projects that were completed over the course of one semester.

Structural analysis using SolidWorks and Sensor mapping in LabVIEW:

The first group was interested in working on a truss-bridge structural analysis as a Constructional Engineering related project. The objective of this project was to perform static analysis on a truss bridge model using computer aided software, with an aim to obtain a design which has a better stress distribution. In this project students built a physical mock-up of the initial bridge design using PASCO bridge components$(Figure\ 2)_1$, placed five load sensors at different locations of the bridge then recorded the resulting stresses acting on the members using PASCO data acquisition system.

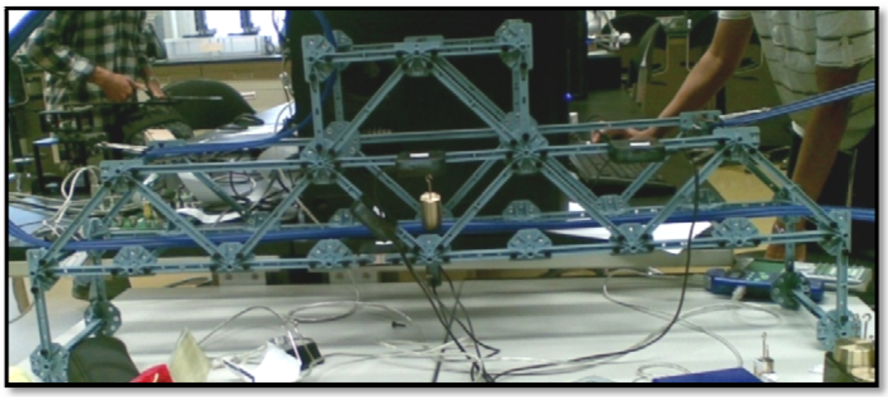
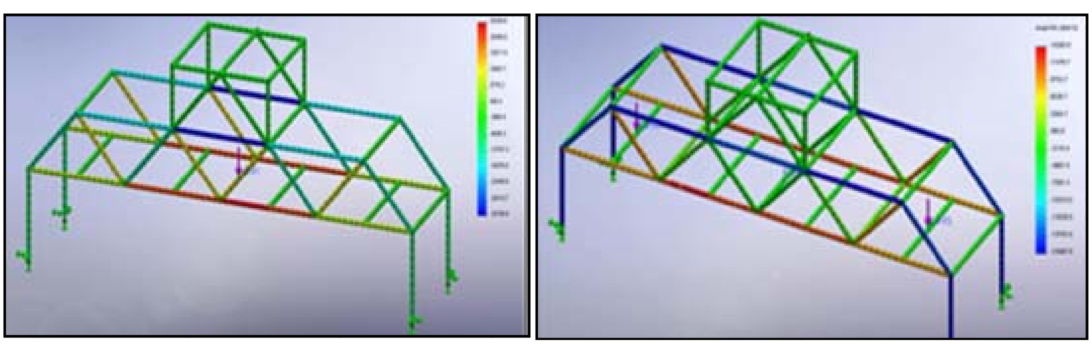
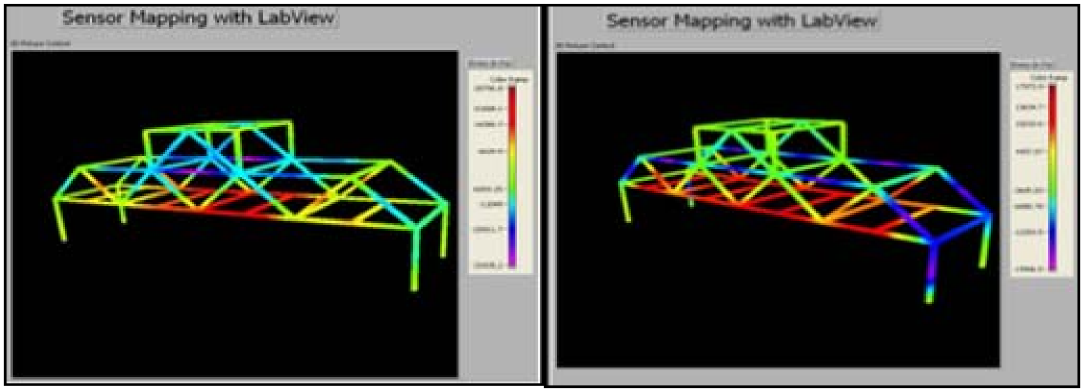


Figure 2: The setup of the bridge with five sensors placement

The acquired data, which was related to its respective sensor, was displayed on the imported 3D model in LabVIEW where the VI was run and the empirical stress diagram was obtained. Two different situations were carried out on the bridge, placing 200g at each end and 200g at the center. Using SolidWorks®, a simulation of the same setup was done for static analysis, and a 3D stress diagram was therefore rendered. $(Figure\ 3)_1$ shows the empirical and simulated results in both SolidWorks and LabVIEW.



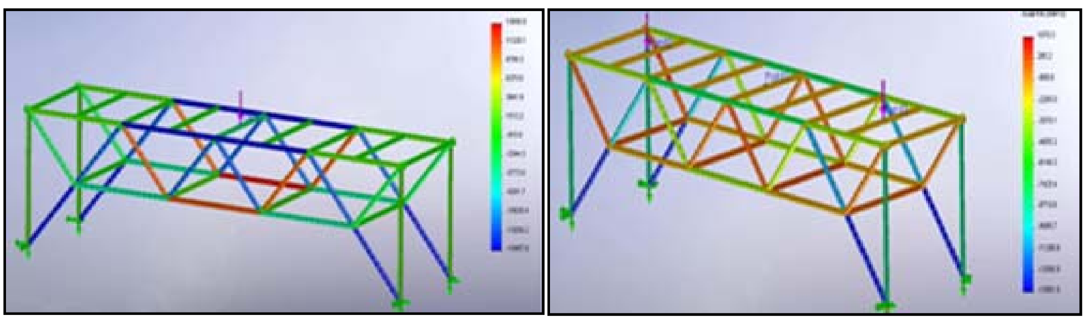
3–1: Initial Design, 1st Test, SolidWorks- simulated   3–2: Initial Design, 2nd Test, SolidWorks- simulated



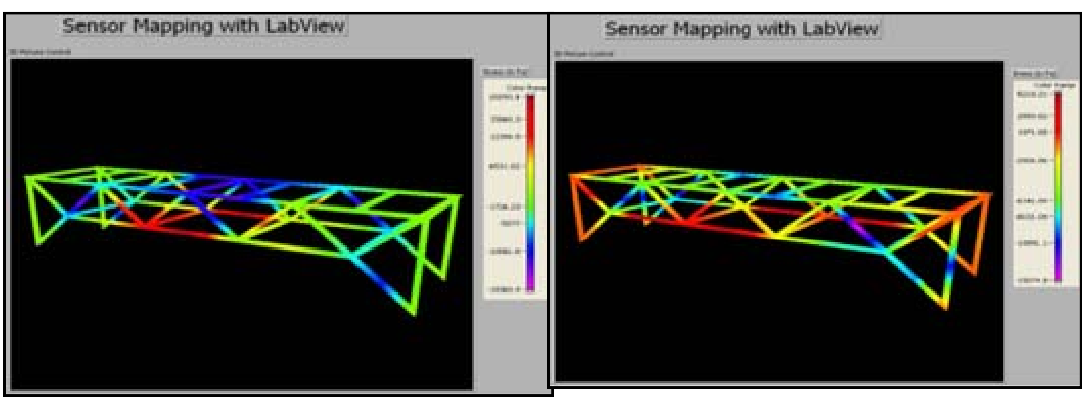
3–3: Initial Design, 1st Test, LabVIEW- empirical   3–4: Initial Design, 2nd Test, LabVIEW- empirical

Figure 3: The Initial Design

The simulated stress diagram was analyzed and the structure was modified in SolidWorks®. Members which serve no use to the structure were eliminated and the truss system was changed in order to dissipate and minimize the critical intensity of the stress. Other members were added in diagonals, different truss configurations were tried out, and the final design was chosen to be the Inverted Warren truss system$(Figure\ 4)_1$, since it was more efficient and easier to implement considering the present initial design.



4–1: Final Design, 1st Test, SolidWorks- simulated   4–2: Final Design, 2nd Test, SolidWorks- simulated



4–3: Final Design, 1st Test, LabVIEW- empirical   4–4: Final Design, 2nd Test, LabVIEW- empirical

Figure 4: The Final Design

A comparison between simulated and empirical results for both the initial and final designs in both cases of weight placement showed a percentage error of around 10.34%. This comparison was done by finding the difference in the maximum (tensile) and minimum (compressive) stresses that were developed in the structure. The results also showed that the overall maximum tensile stress of the final design structure was reduced substantially by 88% in the SolidWorks analysis and by 70% in the physical model. The maximum compressive stress was also decreased by 25% in SolidWorks and 24% in the physical model.

Students in this project concluded that doing structural analysis in SolidWorks is a very efficient, cost effective and time saving because it helps reduce the cost and time required to conduct tests on physical models.

Car Safety System:

The second group was interested in designing a car safety system which is considered to be an Industrial Engineering related project. They developed a computer program that detects abnormal heart rate of a driver and alerts, by sending an SMS message, an operator who can contact the driver and take necessary action if no response is made. The objective was to design a new car safety system which would help prevent accidents caused due to driver stress and/or due to excessive alcohol consumption.

This car safety system consisted of two parts $(Figure\ 5)_2$ – the *In-Vehicle unit (IVU)*, and the 'communication link' between the driver and an *Operator*. The IVU consisted of the Vernier® Heart Beat Heart Rate sensor and the Vernier® Sensor DAQ. The signal transmitter embedded inside the Vernier® Hand Grip Heart Rate sensor sends analog signals wirelessly to the signal receiver. The receiver is connected to the Vernier® sensor DAQ which provides the interface between the analog heart rate signal and the computer.

Figure 5: Flow Chart Presenting the Mechanism

The driver's mobile phone acts as a Wi-Fi router for the data being sent from the computer. Once the mobile receives the signal, the LabVIEW 2009® mobile module (which enables the use of LabVIEW 2009® VIs in mobiles) is activated, and hence, the VI starts acquiring data and recording the heart rate of the driver and the information is displayed on the mobile's screen. If the heart rate of the driver goes above or below a certain range, the VI sends an SMS notification to an operator who then calls and alerts the driver of the condition and advises the driver to rehabilitate as soon as possible. If the driver fails to respond, the operator, who can also locate the position of the car using GPS, can even switch off the car's engine.

One of the challenges students had to overcome in this project was to tackle the changes in pattern of the heart beat rate, which was managed by modifying the code to take the average of five consecutive readings of the heart beat rate. This average of the current heart beat rate of the person would then be compared with the resting heart rate of the person.

Students found that the data obtained from the Vernier® Hand Grip Heart Rate Monitor follows a straight line regression as the best model that characterizes their data. $(Figure\ 6)_2$ shows the variation in heart beat rate per minute (HBM) with time for a person with a normal resting heart rate of 62 HBM obtained from the sensor.

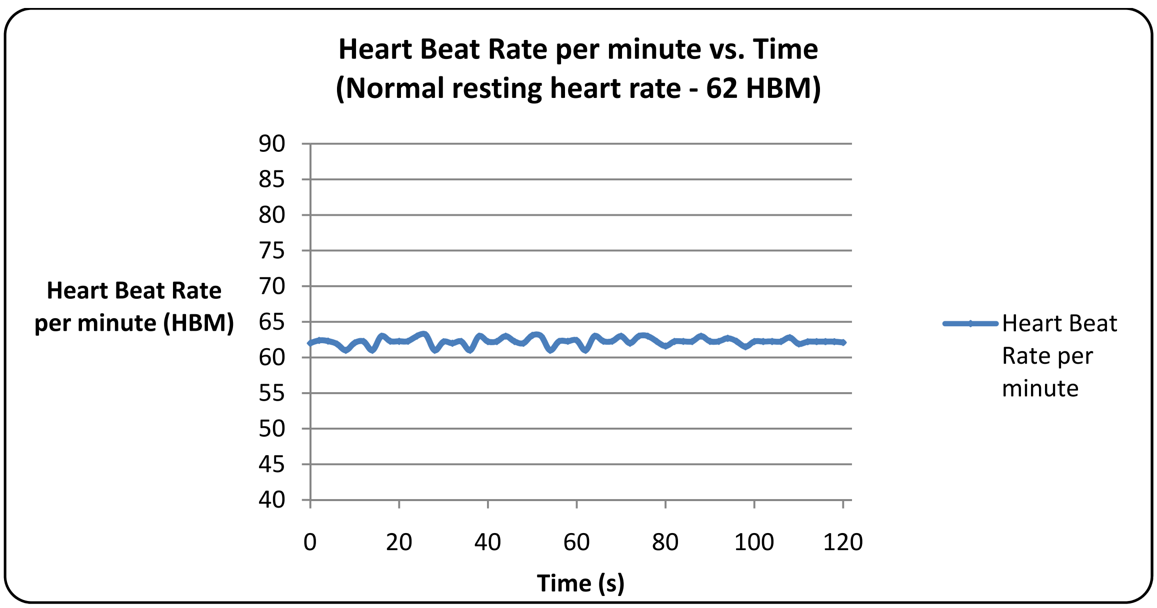


Figure 6: Flow Chart Presenting the Mechanism

What was really distinct about this group of students was their fast reaction to learn how to use shared variables which is considered to be an advanced programing technique in LabVIEW. Shared variables provide an easy method for sharing data among different targets over the network. In particular between a 'host target' (in this case – it is the computer that has the VI and acquires the data from the sensor) and a 'receiver target' (in this case - it is the PDA device which will display the aquired data throught the mobile module). $(Figure\ 7)_2$ shows the front panel and the block diagram of the receiver target VI which runs in the driver's mobile phone.

In their conclusion, students reiterated that car safety system is a low cost, highly efficient and an easy-to-use safety system and variations of such systems in the future help towards an accident free future.

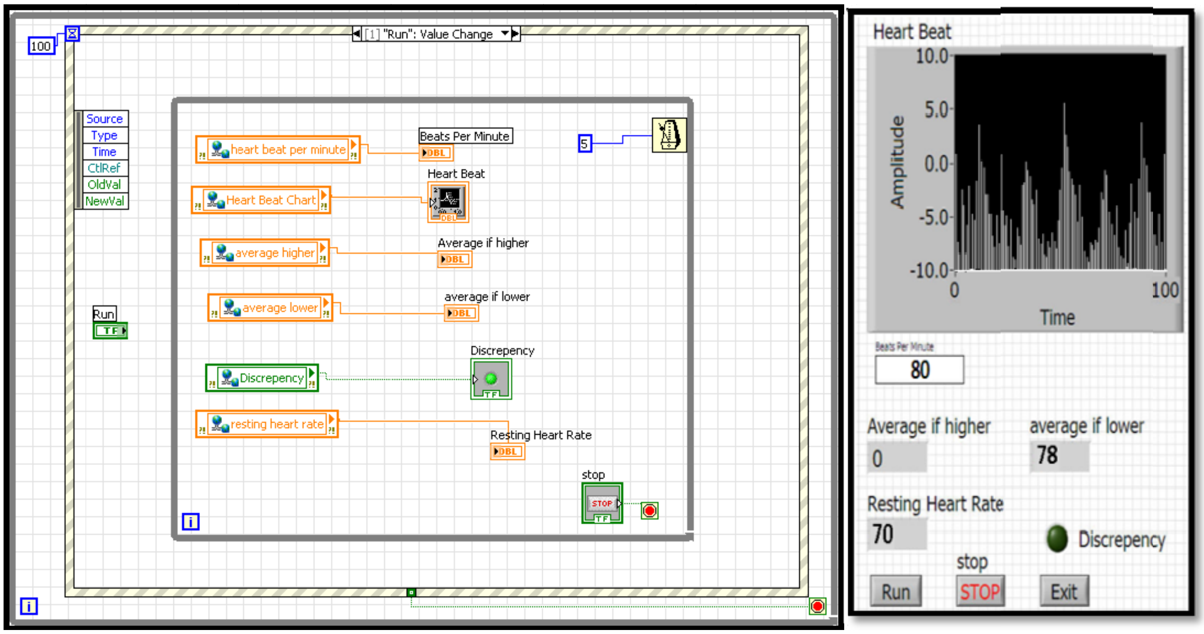


Figure 7: Block Diagram and Front Panel of the Receiver Target VI

Using an Optical mouse as a Virtual Ruler:

The third group was interested in designing a LabVIEW code that works as a virtual length measuring device which can measure any distance/length using an optical computer mouse. The objective of this project was to introduce new real life measuring applications of a computer optical mouse to measure physical quantities. This project involved measuring any two dimensional distance of a flat surfaced object using an optical Dell mouse. The VI design consisted of two Phases: the Calibration Phase (Figure 8-1) and the Measurement Phase (Figure 8-2).

At the beginning, students had to establish a relationship between the distance covered by the pointer and the distance covered by the mouse itself. From the Windows control panel, the pointer was adjusted such that 1 inch of displacement of the mouse in real life gives 1 inch of the displacement of its cursor.

In order to calibrate the VI to get the constant conversion factor from pixels (Dots) to inches, two small squares, placed one inch apart from each other, were set on the VI *Front Panel*. They are referred to as “Button 1” and “Button 2”. When the VI runs, the user is asked to click on “Button 1” and “Button 2” respectively. Upon doing that, the user triggers an event which records the mouse horizontal axis data of points ‘1’ and ‘2’ for later use. Finally, the user is offered the choice to end the calibration phase and go to the next one (the Measurement Phase), or to redo the calibration in case he was not sure about his previous inputs.

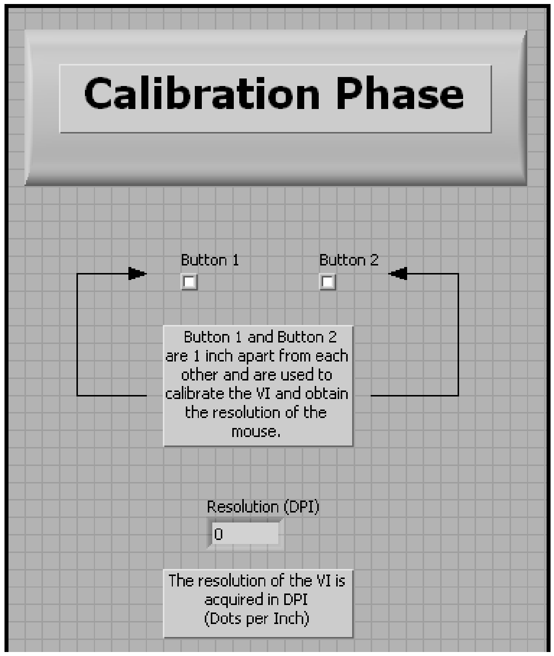


Figure 8 - 1: Virtual Ruler Front Panel, Calibration Phase

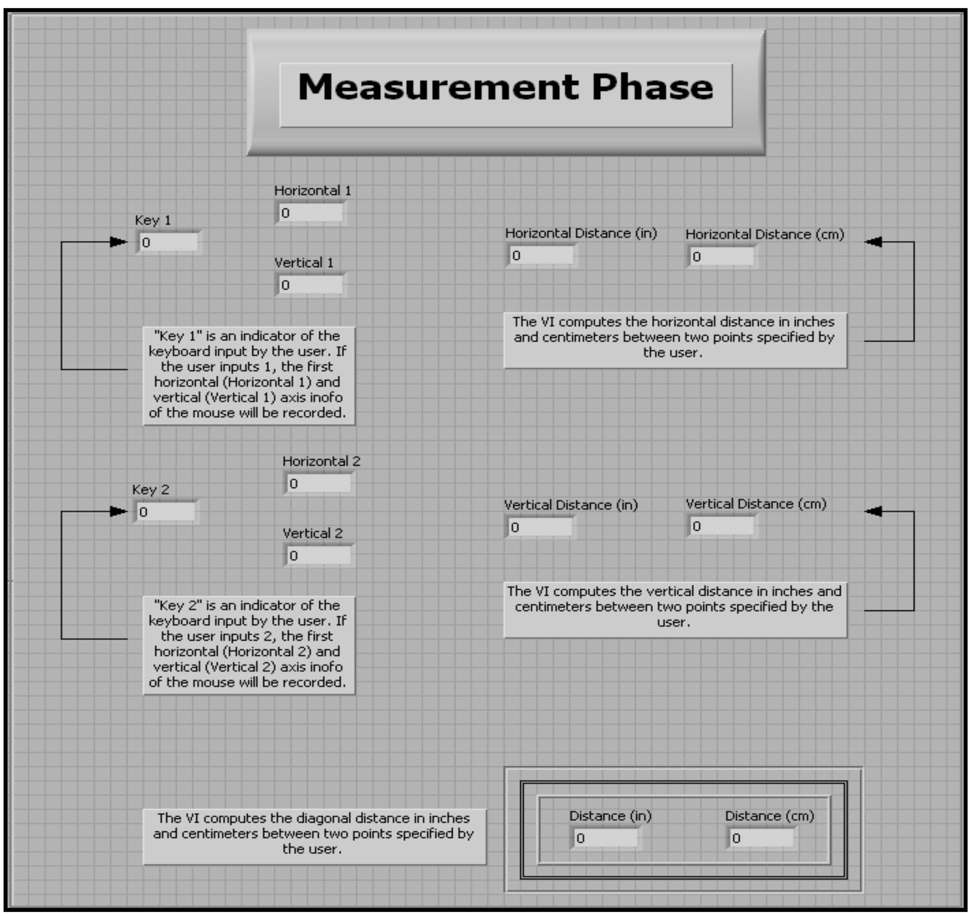


Figure 8 - 2: Virtual Ruler Front Panel, Measurement Phase

In the measurement phase, the user is informed that the “Measurement Phase” will start. Consequently, a message providing instructions on how to measure the distance between two points is displayed. Finally, horizontal and vertical axis coordinates of the mouse at the start and end points are recorded and the corresponding measuring operations are implemented along with the mouse resolution previously acquired in order to obtain the required distance. Another conversion operation was also used to obtain and display the measured distance in centimeters. As a final step, a message is displayed asking the user if he wants to take another measurement or not. If he chooses to do so, a True logic answer will be transferred to the conditional terminal and the while loop will continue running. If the user chooses not to take another measurement, the while loop terminates and the while loop containing the main sequence structure also terminates causing the VI to stop. (Figure 9) shows part of this VI block diagram.

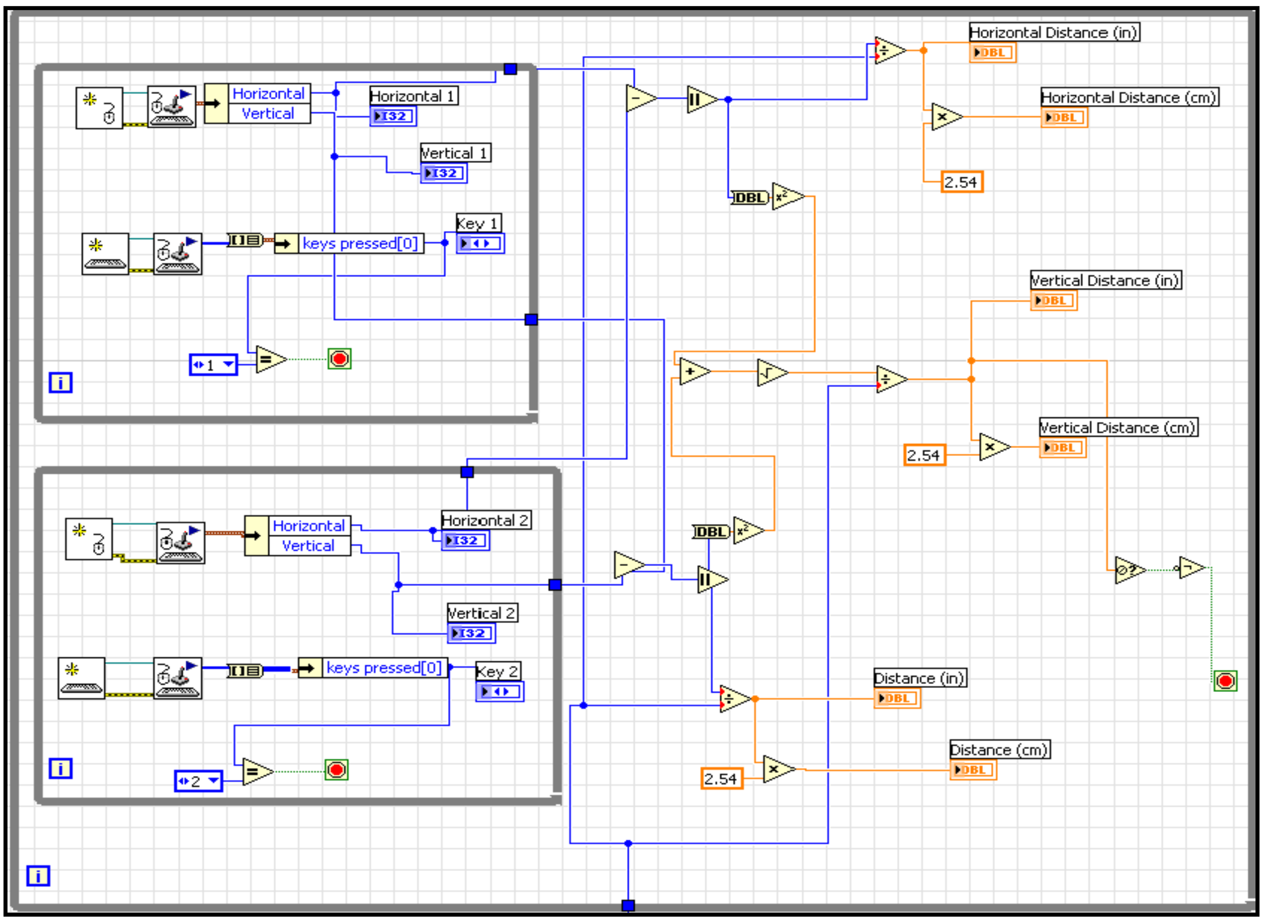


Figure 9: Measurement Phase Block Diagram (partial)

An obvious source of error in this project was the lack of the appropriate tools to hold the mouse tight while performing the experiment and while dragging it on the object’s flat surface. Also, many limitations were imposed on the designed VI, all of which were crucial. The first one was that the corresponding measured object had to be flat and with a relatively rough surface. If the object subject to measurement had a smooth surface, it would be harder for the mouse to function normally knowing that the reflection of the emitted light from the mouse will be influenced and will affect its tracking performance.

Another issue that threatened this VI's performance was the maximum length it could measure. It is known that the mouse can move a maximum distance equal to the dimension of the computer screen. If the mouse cursor attains the edge of the screen, no updated input will be provided by the mouse, thus no further distance can be measured. It should be noted that the maximum horizontal and vertical distances that can be measured by the mouse were found to equal $37.43\ cm$ and $28.07\ cm$ respectively.

Car Parking Counting System:

The fourth group designed a counting system that monitors and counts the number of cars entering and leaving a parking lot, and therefore computes the total number of cars within that parking. The Texas A&M University at Qatar parking lot was used to test and demonstrate the work in this project. Students started with developing a LabVIEW code that reads from only one photogate sensor, after that the code was modified to read from two Photogate sensors, then to count up or down according to the sensor from which the pulses were received. A Vernier Sensor DAQ was used to interface the photogate sensors to the computer.

Following the successful in-lab testing, students worked on replacing the wired DAQ by a wireless one that can transfer the data over a long distance. At this stage, the Vernier Sensor DAQ was replaced by NI WSN-3202 DAQ which has the proper digital channels to acquire the digital signals that the photogate sensors generate. Figuring out that NI WSN-3202 DAQ doesn't have counters; students had to write a new code to do counting without using built-in counters.

The figure below (Figure 10) presents the block diagram of the new VI designed. The WSN-9791 Ethernet gateway was configured with the TAMUQ network and the WSN-3202 DAQ was connected to the gateway so it could transfer the data wirelessly. An experiment was carried out to check how the system worked; the results showed that the system experimentally had 100% accurate data and 90% efficiently. As the outcome of this stage was pretty significant, the system was ready to be implemented in TAMUQ building's parking lot.

Results in this project showed increase in the empty parking spaces during the lunch time as employees leave the campus for lunch and fast decrease just after about 45 minutes from lunch start, as people start to come back to their offices. The results also showed that this number of empty spaces increase (Figure 11) as the time gets closer to the end of working hours. Such statistical analysis for the occupancy of the parking lot can be of a great help to facilities and building operations and something needs to be considered when they organize events throughout the academic year.

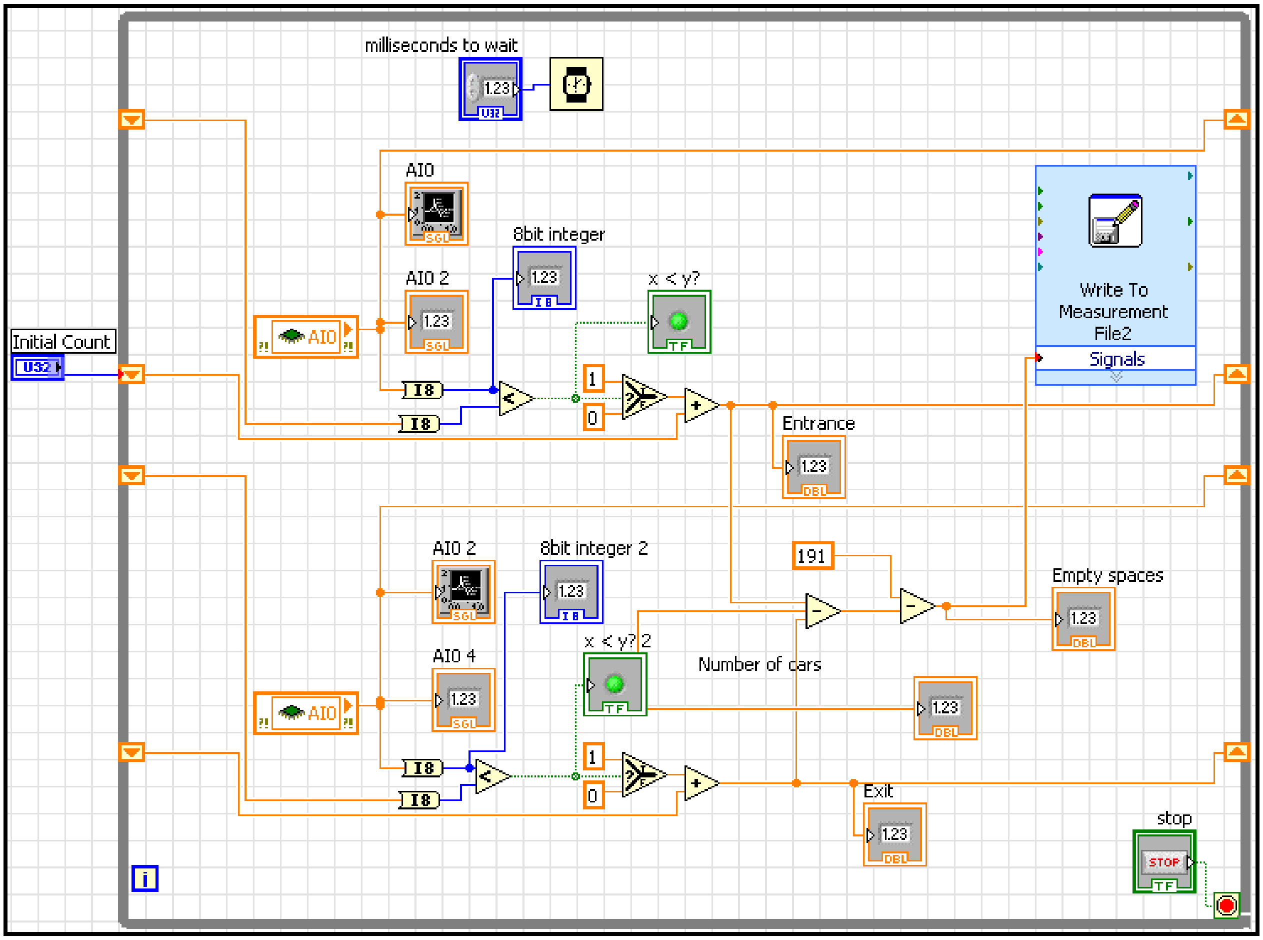


Figure 10: New Designed VI Block Diagram

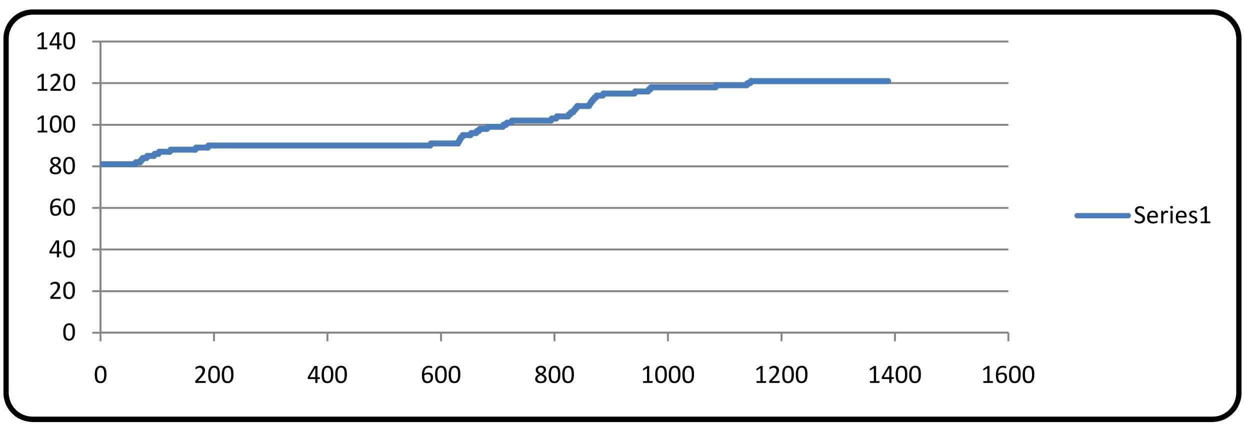


Figure 11: Empty Parking Spaces in the Last Working Hour

Conclusion:

Students in each group worked together as a team to accomplish their tasks in a limited time while completing the tasks individually seemed impossible to them. Students completed all of the projects successfully within the allotted time. Two groups participated in an undergraduate research conference; one of them got the best poster. In a summary, the bridge project was a good example for students to learn how software engineering packages can be used to prototype and improve system design. Additionally students had the opportunity to apply the knowledge they gained in previous courses, such as statics, on a real structure setup. In the car safety system, students practiced system integration skills which have a big demand in the engineering market; they learned how to put together system components from different vendors to build a complete functional system. They learned also how LabVIEW as a software engineering package can be leveraged to develop algorithms and shorten the building time. In the car parking system, the experience that the students gained made them better prepared for the types of challenges they are likely to encounter as practicing engineers. The virtual ruler project allowed students in this group to learn key programming concepts and techniques which can be used to improve overall system design by interaction with other tools.

The projects described in this paper are currently used as an in-class demonstration projects to help students come up with another new ideas, new approach to implement the same project or even building on top of it.

Acknowledgement:

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