

**AC 2009-2513: A BLOOM'S ONLINE ASSESSMENT TEST (BOAT) TO ASSESS  
STUDENT LEARNING OUTCOME IN A DISTANCE ENGINEERING  
EDUCATION COURSE**

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# Using DAQ boards to communicate with NXT in measurements and Instrumentation applications

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**Abstract** - This paper focuses on a new approach to teach electrical engineering principles and how to promote student learning through different innovative projects that can be developed with the use of the LEGO MINDSTORMS NXT kit powered by a customized National Instruments LabView program. Even though, the use of LEGO NXT brick has been in practice and prevails in today's K-12 classrooms, this paper will primarily focus on how the use of NXT can be expanded to students in colleges and universities at freshmen and Sophomore levels using simple DAQ board and prototype interface unit. Originally, NXT was intended for use by children at home or in the classroom, but the LEGO MINDSTORMS NXT system has been acquired by tens of thousands of adults. Engineers, academic researchers, and hobbyists have reverse-engineered its firmware, hacked together new programming environments, and shared recipes for unanticipated ways of connecting it to the outside world.

**Keywords:** Critical thinking, LabView, LEGO, NXT Sensors

## I. Introduction

While there are many environments that may promote the development of problem solving and critical thinking, the use of an environment that involves robotics may be appropriate for young students due to its student friendly environment and ability to support data collection [1] [2]. The University of North Dakota (UND) has adopted the approach of introducing the LEGO MINDSTORMS NXT kit to our EE 101 - Introduction to Electrical Engineering freshmen course to teach sensor circuits and LabView programming, thereby fostering creativity and developing smart and optimized strategies when dealing engineering design challenges. The use of NXT in promoting circuitry and programming concepts through creative problem solving projects will be thoroughly investigated, and its effectiveness will be documented and compared to other preliminary approaches adapted to reach and promote engineering education. This paper will showcase these strengths and the LEGO NXT bricks enormous potential to promote engineering education in universities world-wide. The paper will also explain to implement universities educators how to make the best use of the NXT kit to design and implement several creative projects in different platforms, which can be integrated into our freshmen engineering curriculum together with other outreach measures.

## II. NXT in Electrical Engineering course

At the University of North Dakota (UND), we introduce the LEGO MINDSTORMS NXT kit as part of our EE 101 freshmen course. EE 101 is an

introductory level Electrical Engineering (EE) course, where the students are introduced to foundational concepts and principles of Electrical Engineering. The students in the course have to use the NXT kit for a few weeks and to devise a group project on a specific robotic design, including a realistic mission coupled with different sensors. The project proposals received from the students are initially assessed by the course instructor, and the students are informed about their project approval status before they start their work on design, building, and programming the robot.

The learning objectives of using the NXT kit will vary tremendously and they will be quite broad depending on the course objectives and focus in Electrical or Mechanical or Computer Science engineering fields. Many course objectives involve gaining knowledge of various electronic sensors, the mechanics of robot design, understanding programming concepts such as iteration, conditional statements, and object-oriented programming.

### III. Mindstorms NXT

#### 3.1 The Software

The LEGO MINDSTORMS NXT software is powered by NI LabVIEW, an intuitive graphical programming software used by scientists and engineers worldwide to design, control, and test consumer products and systems such as MP3 and DVD players, cell phones, and vehicle air bag safety systems. Applications include helping to control the NASA Mars Pathfinder to testing the Microsoft Xbox. The LEGO MINDSTORMS NXT software enables you to program your NXT robotic inventions and upload programs to the NXT brick via USB or Bluetooth connectivity. The intuitive Mac and PC compatible drag and drop software, powered by National Instruments LabVIEW, comes with building instructions and programming guides to easily begin constructing and programming the MINDSTORMS NXT [3].

#### 3.2. Programming blocks

Developing programs with the LEGO MINDSTORMS NXT software is fun and simple.

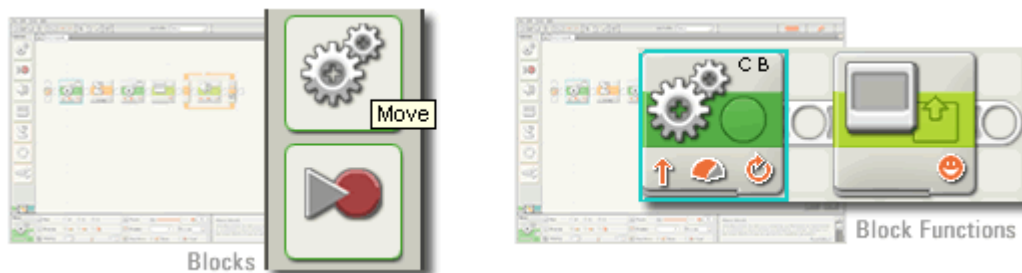


Figure 1. NXT Block Move

There are also variety of other built-in blocks within NXT that serves specific purposes for programming creative design [3].

### 3.3. Drag-and-Drop Environment

Drag and drop blocks from the left side of the screen onto the diagram. Each block performs a unique function such as moving the motors, displaying a message, detecting a sound, or measuring a distance.



Figure 2.1. Download and Run Icon



Figure. 2.2 Connecting to USB port (PC)

### 3.4. Download and Run

Once you have written your program, download it onto your NXT. The compiled program is sent to the NXT brick using the wireless Bluetooth link or the connected USB cable. The NXT then executes the code that it receives from your host computer. You can create multiple programs and download them to your NXT robot.

### 3.5. THE NXT

The NXT is the brain of a MINDSTORMS robot. It is an intelligent, built-in computer-controlled (ARM 7 processor) LEGO brick that lets a MINDSTORMS robot come alive and perform different operations. The hardware architecture of Advance Risk Machine (ARM) processor and its features are available at the LEGO NXT website [4].

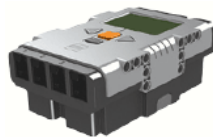


Figure 3.5. THE NXT Brick

## IV. Student design projects

### Where and how do I begin building and programming the robot

There are many NXT robot design projects that students can start working on to get started. A good resource is from the [www.legomindstorms.com](http://www.legomindstorms.com) webpage. The webpage has a blog section that discusses various creative robot designs, programming approaches, and discussion threads for troubleshooting failures. The students can try out those simple programs to get a sense of familiarity with the NXT kit. This paper does not

address how to build these projects; rather it directs you to these resources and how one can initiate working on projects.

Although the goal of this paper is to address educators on how to promote engineering education through NXT, but not to focus too much on the building and programming instructions or procedural steps involved in a robot design, as the NXT kit comes with very clear and user friendly instructions[2][5][6]. However, the author(s) would like to cite one specific “Multi –NXT robot design” that students at University of North Dakota built and programmed, because it is definitely worth mentioning.

The author (s) would like to address this project in particular in two different Phases:

Phase I – To get to know the NXT kit and its programming blocks by doing a simple design with programming.

Phase II – Ways electrical engineering concepts can be expanded and taught using NXT through an interface.

#### **4.1. Phase I - Preliminary design to get started with NXT**

##### **4.1.1 Multi - NXT Robot**

One of the student designs team at UND during the 2008 spring semester, came up with an idea of using multiple NXTs or multiple robots to perform specific missions or tasks. The goal of this project is to integrate multiple sensors with multiple NXTs to perform specific mission. This team has used two NXT robots, one that shoots a ball they called the robot “super pitcher” and the other NXT robot that catapults the ball called “bat-mo-palt”.

First, the students ended up using nearly all the parts from the two LEGO MINDSTORMS kits. The action or mission steps for the ball shooter includes: press the touch sensor to initiate the launch, then a robotic arm rotates to release the ball, finally the attached two wheels rotate, propelling the ball to move forward. In addition to that, there is a color (shade) sensor that the students have used on their design to distinguish the blue color from the red color ball. To illustrate further, say, if the red ball is sent through the robot, then the wheels spin backward and it is programmed in such a way that it does not shoot the ball. After that, the NXT brick is programmed to say “no” to indicate that it cannot accept this ball color. On the other hand, if the blue ball is sent through, then the wheels spin in the right direction and shoot the ball towards the catapult causing the NXT brick to end its action by saying “good job”. The NXT software configuration has pre-built-in sounds for the users to select some specific sound actions that they wish to include in their programs.

The second NXT robot consists of a catapult, with its action steps given as follows: Once the blue ball has been sent through the shooter, the ball lands on the catapult basket, the motion sensor arm realizes this action, and then the whole catapult

travels a few feet and it shoots the ball. After this task of catapulting the ball gets completed, the sound sensor gets invoked by clapping your hands, which in turn puts the next set of actions in motion. This is what the students would like to call as the robot performing a “victory dance”. The students define the term “victory dance” as extra space the catapult going back to its previous position and its arm doing a series of up and down movements. To complete the sense of mission, the robot finishes off with a “hooray” sound selected from the NXT software configuration.

The readers of this paper can watch the action of this Multi-NXT robot uploaded into [www.youtube.com](http://www.youtube.com) [7].

The students have used a variety of programming blocks for this robot design. Both NXT robots are made to repeat their actions by using a “loop” functional block available within the NXT brick. A total of 10 actions were used for the “super-pitcher”, and 14 actions were used on the “bat-mo-palt”. The students have used just the right number of software actions in order to carry out an objective that is not only fun, but also creative. All four available sensors (color, motion, touch, sound) within the NXT were used in this project. The students also used a total of six motors altogether for this design.

The students spent about eight hours as a group to complete this initial design project. Overall, the robot turned out really well resulting in achieving their goals combined with a very good design, neat programming, and well integrated sensors. The project is a good example of what one can come-up with using the multiple NXT LEGO sets rather than using simply one NXT kit, and it is worth trying out as a starting project for freshmen students in engineering schools at the university level [7] .

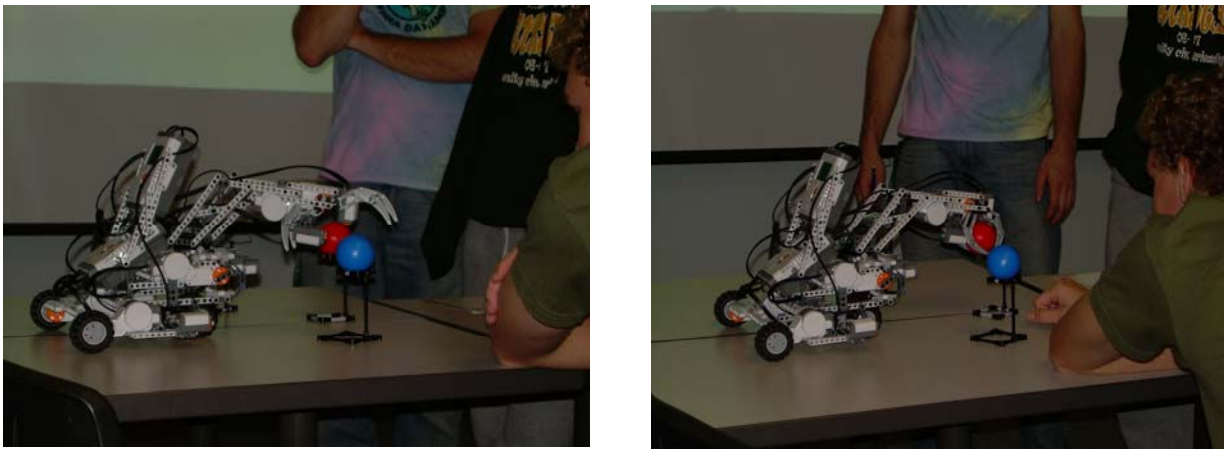


Figure 4.1 (a) and (b) multi- NXT Ball Grabber robot UND design team

## 4.2. Phase II – Promoting programming and circuitry concepts

### 4.2.1 – Building programming experience

There are several items that should interest educators here – first, the entire customized LabView program is completely graphical, which effectively helps the students focus on the programming design by mere simple drag and drop programming blocks. This enhances the understanding of programming logic, as an introductory overview to first- time programmers rather than asking them to spend hours and days to learn, debug the various syntaxes in a freshmen level programming course, as in other higher–level text based programming courses that educators use to teach at the freshmen/sophomore level!

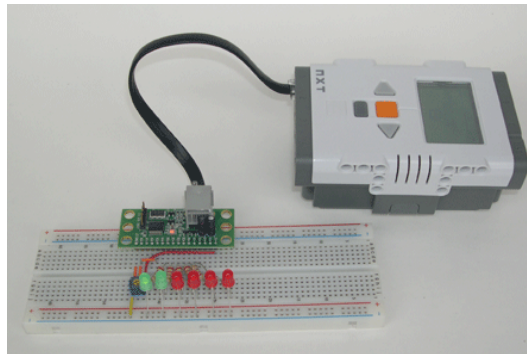
This may be one of the reason why educators see high student drop-out rates in STEM courses: students get afraid of enrolling in higher level technology based programming courses, causing them to be unable to complete four year engineering or computer science programs [8]. We can certainly prevent or improve these drop out rates by adopting and effectively integrating the LEGO NXT kit into our engineering curricula. The user – friendly customized NXT software helped the design team to focus their attention on this introductory class, covering basic sensor circuitry and logical concepts. This will also help the students to come prepared and make them ready for comprehensive object oriented programming language courses such as C, C++, Java or problem solving courses which use software design tools such as Matlab / Simulink, Mathematica, SAS etc., as now they have experienced a thorough background on the overview of programming logics via NXT.

The efficacy that customized NXT LabVIEW offers will be better known to the author(s) to investigate further during at the end of this fall 2008 semester, when we analyze the performance of these freshmen students who are now (will be) either Sophomores or Juniors taking our EE 304 - Computer Aided Measurements and Controls course. EE 304 is a problem solving course which introduces the students to different programming platforms (LABVIEW, C++, MATLAB) from an engineering perspective. The author(s) strongly believe that having experience with the customized LabView interface will better prepare the students and make them ready to learn the comprehensive version of LabView version 8.0 or later.

#### **4.2.2. Circuitry experience - connecting the NXT brick to real world sensors**

The LEGO MINDSTORMS NXT kit can be connect to any external sensors and even custom sensors, through its and its External Analog Interface Unit (EAIU). There are a few companies who do sell these analog interface units, as readymade kits. One such interesting unit is worth mentioning here, and it available from HiTechnic, Inc.[9]. The HiTechnic prototype board contains all the electronics and I2C code to communicate with the NXT. Using the 14 x 16 hole PCB prototype area on the board, you can build your own analog and digital designs and access them from your NXT program. Programming is easy with the HiTechnic NXT-G prototype programming blocks or the students can use any one of the other programming languages (C/C++/Java/MATLAB) available to develop programs that can read five analog inputs and read and write six digital ports [9].

For example, the solderless prototype board shown below (Model NPS1055), was designed to connect to a solderless breadboard, so that the students can come up with their own unique circuit design using the NXT and can possibly re-use the electronic circuitry components (LEDS, resistors, capacitors, diodes, photo transistors, photo diodes, etc.,). The approach of using the EAIU coupled with NXT offers far better performance and more advanced design than simply using one NXT or multiple LEGO NXTs.



**Figure 4.1 Connecting NXT to an external prototype**

Photo Credit → Hi Technic

This is really an outstanding potential tool that educators can use to teach students how these electronic sensor circuits behave, as well as their operating principles or programming learning environments. This is clearly an efficient approach when compared to other preliminary approaches using earlier version of RCX NXT robots. The RCX version of MINDSTORMS does not have the capabilities that NXT's newer versions offer.

The HiTechnic prototype sensor block adds support for the prototype sensors (both versions) to the LEGO MINDSTORMS NXT software. This read / write block provides features that enable the NXT program to read all analog channels and read / write all digital channels on the prototype board.

This prototype sensor kit from HiTechnic comes with variety of other new types of sensors, and its programming blocks include a compass sensor, color sensors, acceleration sensors, IR seeker sensors, and the gyro sensors. The authors encourage enthusiastic NXT readers to explore this kit and evaluate its performance.

### **4.2.3 Assessing Enrollment data of EE 101 with LEGO NXT kit:**

Looking back at the enrollment data over the last two years, the following chart clearly depicts an increase in enrollment for Fall 2008 session (59 students), when



compared to Fall 2007 (40 students) and Fall 2006 (44 students) sessions, although spring 2007 and 2008 data remain stable for this EE 101 course to be 12 students. The students enrolled in the EE 101 course includes transfer students from other departments such as Mechanical, Chemical, Computer Science, Commercial Aviation and (new) Electrical Engineering students at freshmen and Sophomore levels. This is a clear indication on the use LEGO NXT course in Engineering education.

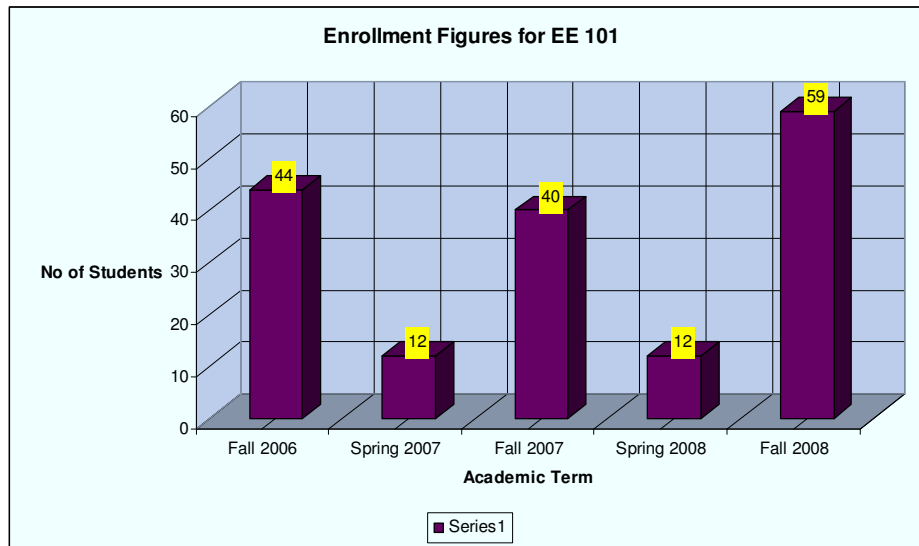


Figure 4.2 Enrollment figures for Introduction to Electrical Engineering

### 4.3. Beyond the MINDSTORMS NXT

#### 4.3.1. LEGO tool kit

An intuitive software environment is important and critical to unleashing the creativity of the students. On the other hand, students should be able to extend this knowledge to other industry standard platforms and eventually be able to leverage more powerful design environments. The LEGO MINDSTORMS NXT provides hooks for developers to create supporting software that can be used by more advanced developers. For example, National Instruments has created a toolkit that can be used to program the LEGO MINDSTORMS NXT and is available as a complimentary download from the company website [10]. This is something that educators should start in incorporating into their course projects and possibly ask their students to explore!

#### 4.3.2. Introduce advance NXT challenges

Some of the NXT concepts that educators can adopt to broaden their missions include:

1. Designing and programming a robot using multiple NXTs and to design much more realistic missions.
2. Designing a robot which can communicate through multiple NXTs (real challenge!).
3. Going wireless!- Designing and building a robot that runs completely wireless.
4. Doing the same missions/tasks via alternative programming platforms such as MATLAB and C programming.
5. Utilize the LEGO tool kit.
6. Use external analog Interface module.

#### **4.3.3. Alternative tools to program LEGO NXT bricks**

The LEGO NXT bricks can also be programmed using other platforms. One such platform is using the MATLAB NXT software, a LEGO tool released recently by Mathworks, Inc. [11]. MATLAB has been very popular in recent years in many engineering colleges and universities to foster problem solving skills because of its user friendly environment and its availability with a variety of toolboxes that has application specific uses.

Although you have to learn some new syntax to communicate with NXT using this LEGO MATLAB tool, it is something different that university educators can try in higher level programming courses at the junior level, and this is also something fun to work with for enthusiastic MATLAB programmers or learners to try. The MATLAB NXT tool comes with two new features – MATLAB based code for remote control and Simulink based code solutions for embedded control. Using these control solutions, the students can learn new programming concepts such as iteration, conditional statements, and object-oriented programming, as well as avoid Bluetooth range limitations because the program runs directly on the NXT. This allows the students to program sensors precisely for coordinated, real-time execution, and to model, visualize, and test the robot's behavior using Virtual Reality Toolbox software.

#### **V. Promoting Engineering Education - Some tips for College and University faculty / administrators on how to promote engineering concepts through outreach workshops**

One of our core goals is to let the word out to college/university educators on how we could spread the information across colleges and universities in the country on expanding the use of NXT to freshmen engineering courses by coming up with creative projects through the use of LEGO MINDSTORMS NXT kit. We felt that the 2009 ASEE conference opportunity is an appropriate venue for disseminating this information.

The use of the NXT kit can be extended from K-12 to community colleges and universities targeting freshmen engineering courses. Some universities have already started to understand the effectiveness by introducing the NXT kit at their institutions [10]. Community colleges and universities can use robotics in their science and technology classrooms to build a solid foundation on robotics in introductory engineering classrooms as they build with Lego Mindstorms™ NXT and then watch

their creations come alive using the interactive LEGO MINDSTORMS Education Software designed for easy point-and-click programming.

Possible ways that educators can promote the concept of using NXT is either through an introductory course in your engineering program with one or two credit hours or by creating a mandatory freshmen seminar for your engineering curriculum. The concept of using NXT in engineering education can also be used for recruiting and outreach purpose by developing a three-to-five day workshop session for juniors and seniors in high schools, which will help the participants investigate the following key components of LEGO NXT robotics: LEGO MINDSTORMS NXT brick, LEGO MINDSTORMS education software, design journal, robot construction, programming, and problem solving strategies.



Figure 6.1: Typical LEGO NXT design- build- test team

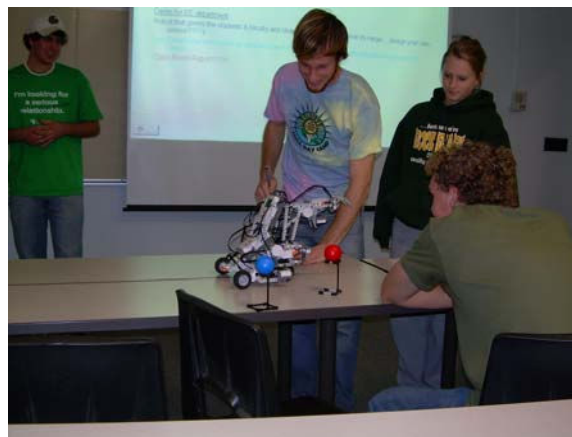


Figure 6.2: Typical LEGO NXT design- build- test team

## VI. NXT and DAQ applications:

LabVIEW's data acquisition capabilities can be tested using an external data acquisition (DAQ) board NI USB-6009 which connects to your computer via a USB cable. The DAQ board provides many functions: a 14 bit A/D converter with programmable gain, a 12 bit D/A converter that generates outputs from 0 – 5 V, a 4 bit and an 8 bit digital I/O port, and counter/timer capability. In this lab, you will use the A/D and D/A using LabVIEW (8.1 or higher) programs that you write.

Sample lab that addresses Signal and Spectrum analysis problems that can be tried at Introductory level:

### **Problem 1: Improving the waveform by increasing the number of samples per cycle**

Input a sinusoidal waveform of frequency 100 Hz and amplitude 1 Volt using the function generator. Select the number of scans so that you have an integer number of cycles. Inspect the waveforms on both the VI and the oscilloscope and record your observations at each step.

1. Set the LabVIEW execution target to Real-Time (RT) target to verify that LabVIEW is acquiring data via the PXI system that is external to the PC.

2. Use the Analog Input VI that was made in the previous lab. Sample the signal at 50 Hz. Observe the waveform.
3. Set the sampling rate to be equal to the frequency of the signal. Visualize the waveform on both the scope and the VI.
4. Set the sampling rate to the Nyquist frequency (i.e., twice the frequency of the signal);
5. Change the sampling rates to three, five, ten and fifteen times the frequency of the sine wave and note your observations. Save the data. To change the sampling rate, stop the VI, make the change in sampling rate, and run the VI again.
6. Replace the sine wave with a square wave. Repeat steps (2) through (4) for the square wave signal. Do not forget to save the data again.
7. Use the Analog Input-Output VI from the previous lab. Set different update rates as above and observe both the input and output waveforms on the scope. Notice the effect of zero-order hold on the output.

**Note 1:** The sampling rate experiment is very sensitive to the input frequency. The frequency of the input signal has to be properly tuned in the function generator to the required value. Make sure you do this every time you change the signal from a sine wave to a square wave and vice versa.

### **Problem 2: Effect of sampling on the spectrum of the signal**

8. Switch the LabVIEW execution target to LabVIEW for Windows so that LabVIEW commands are executed on the local PC rather than the PXI system.
9. Use the aliasing VI provided and repeat steps 2 through 6 of Problem 1. Notice what happens to the 100 Hz component in the spectrum every time. See Note 2 below.

**Note 2:** Try sampling the signal at values slightly higher or lower than the frequencies given in Problem 1, and note the changes in the sampled signal for sampling frequencies below the Nyquist frequency

### **Problem 3: Effect of saturation**

10. Switch the LabVIEW execution target back to the Real-Time (RT) target.
11. Open the VI used step 7 of Problem 1.
12. Input a sinusoidal signal as in part (1) but of amplitude equal to or less than 9 Volts, zero to peak. Exceeding a 9 Volt amplitude can cause damage to the DAQ system. Inspect the waveforms on both the scope and the VI and record your observations. If saturation is not visible for a 100Hz signal, try reducing the generated signal frequency to 10 Hz on a triangle signal. To observe the saturation of the waveform signal, adjust the scale on the oscilloscope so that the waveform signal appears to be “cut-off” or “clipped” in the sense that the peak positive or negative points of the waveform are not visible on the oscilloscope. This is called saturation of the signal and it is typified by the cut-off of the signal above a certain threshold value depending upon the equipment specifications.

Some of the questions through this sample lab can be explored are:

- Was there any difference between the sinusoidal waveforms on the scope and the VI in step 5 of the previous lab? What was the measured frequency? What was the input frequency?
- Was there any difference between the sinusoidal waveforms on scope and the VI in steps 2, 3, 4 and 5 of this lab? Can you now explain why the difference was not there in the last lab?
- In step 3 how many samples per cycle do you have? This can be found out by dividing the sampling rate by the frequency of the signal. What kind of signal do you expect when you sample at this rate? Did you get the expected signal? Explain why or why not.
- What happens to the 100 Hz frequency component when you change the sampling rate in step 9?
- From steps 4, 5, 7, and 9, what can you infer regarding the sampling rate required to reconstruct a signal?
- From step 9 what can you say about the minimum sampling rate required to reconstruct a signal with many frequency components?
- Can you guess how you would reconstruct a square wave?
- What was your observation when you input a signal outside the input limit range of the DAQ board (an 11V signal)?
- What is the resolution of the DAQ board you are using at  $\pm 10V$  range?

**New DAQ Devices:** National Instruments (NI) expanded its USB-9000 series of high-performance USB data acquisition (DAQ) line-up with the release of eight new USB 2.0 DAQ devices which can also be used in conjunction with NXT.

With sampling rates up to 800kS/s, these new products not only offer the fastest DAQ speeds currently available for USB-compatible devices, but also simplify system setup and programming with powerful measurement services software, said the press release. In addition, the USB 2.0 devices include free interactive data-logging software (valued at \$295) for analysis that can log data and export it to spreadsheet applications such as Microsoft Excel.



By using the new devices with the included NI-DAQmx driver software, engineers and scientists can develop NXT applications more efficiently using the company's measurement tools for hardware configuration and testing, take advantage of easier application programming with the step-by-step DAQ Assistant, and use automatic code generation and custom channel scaling.

## VII. CONCLUSIONS

While many papers have been presented to include the LEGO NXT kit in Science, Technology, Engineering, Mathematics (STEM) curricula [12][1][2], the challenges of having the NXT to communicate with the external environment remains worth exploring to develop any future (new) creative robotic projects such as using a DAQ board. This paper strengthens the need of requiring such an additional interface to develop those projects and how the NXT brick would be used to connect and communicate to any external prototype/other communicating instruments, which will help both the educators to develop any new lesson plans/projects and students to explore these tools to learn electrical, programming, or other engineering concepts.

The authors strongly believe that the future of NXT looks very promising and the use of the LEGO MINDSTORMS NXT brick is an effective way to introduce and teach the concepts of any engineering field, certainly not restricted to electronic sensor circuits and sensor applications but in areas such as robotics, logical programming, traditional concepts of mechanics, and much more. The authors strongly believe by incorporating these LEGO NXT kits into our freshmen engineering courses, we can promote electrical engineering and computer science concepts, thereby enhance students critical thinking skills, provide hands - on learning exposure, and inspire more and more high school seniors to choose engineering majors and careers to meet our nations growing needs on the “engineering sector”.

## VIII. ACKNOWLEDGEMENTS

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## X. BIOGRAPHICAL INFORMATION

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