Do Engineering: Graduating the Engineer of 2020

Dave Wilson¹, Yucel Ugurlu²

1. National Instruments, 11500 N Mopac Expwy Austin TX 78759, dave.wilson@ni.com
2. National Instruments Japan, 1-9-9 Shibadaimon, Minato-ku, Tokyo, Japan, yucel.ugurlu@ni.com

Abstract

The world needs engineers more than ever today. The National Academy of Engineering laid out 14 of the engineering grand challenges – these challenges are extremely complex, global and most of all, need engineers to build systems to solve them. From clean drinking water to managing the nitrogen cycle, the engineers of tomorrow need to be capable of either designing systems or participating in a team that is designing systems. However, traditional tools to teach engineering stop at merely teaching students to simulate concepts – what students need is to go beyond simulation and Do Engineering to combine the essential elements of engineering to build real-world systems. The Graphical System Design approach enables students to go beyond theory and simulation and combine the elements of engineering in a semester to build real systems. In this talk, we will explore how Graphical System Design has revolutionized engineering education worldwide and is poised to help graduate the engineer of 2020 who can build systems to address the grand engineering challenges.

Keywords: Graphical System Design, LabVIEW, Do Engineering

1. Introduction

The challenges facing the world around us are ominous, complex and critical in nature. The National Academy of Engineering has compiled a comprehensive list of the grand challenges [1] that face the world today – these fourteen challenges are global in nature and have one thing in common – they all need engineers to solve them. From clean drinking water to building a better infrastructure, these challenges, when solved will provide a monumental shift to their respective areas in our daily lives. Figure 1 shows the fourteen grand challenges.

Figure 1. The grand engineering challenges

The solutions to these problems are going to be comprised of an engineering system – or a system of sub-systems. In fact if one looks at the world around us they will observe that that increasingly, modern engineering solutions are comprised of systems. From a state-of-the-art smart grid system [2] that incorporates complex signal processing and control algorithms with mechanical and electrical components, to the humble insulin delivery system [3], comprised of microprocessors with sensors and actuators to ensure accurate delivery of life saving drugs, systems are at the heart of every engineering solution.

This systems-level approach to problem solving presents significant challenges to educators worldwide. They still

† 第61回年次大会国際セッションプロシーディングスより
著者の了解を得て転載しました。

have only four years of engineering instruction available to them and they have to incorporate a system level thinking among their students in Engineering. Traditional techniques of simulation-only approaches and theory-heavy courses cannot help disseminate the vast array of knowledge that a student needs to comprehend to build systems and be ready for the challenges of 2020. So how can the Educators graduate the engineer of 2020? The answer is to enable students to go beyond theory and simulation and Do Engineering. But to Do Engineering, one has to understand the essential elements of an engineering system.

2. Essential Elements of Measurement and Control Systems

All engineering systems comprise of essential elements that students need to master to be able to successfully build them. Because the authors experience is in measurement and control, we will break down the essential elements of measurement and control systems. Figure 2 shows the six essential elements of measurement and control systems.

Figure 2. The Essential elements of measurement and control systems

There are some key observations from these essential elements of measurement and control systems. When an engineer thinks about building measurement and control systems today, they naturally gravitate towards two of these key elements – the math and analysis that is required to ensure that the system accurately performs the operation it is designed for and the models of computation [4], which refers to the type of programming approach that can be chosen to solve a particular engineering problem. While both of these are essential elements to design a system, there are four other elements that need attention.

First is the hardware input/output – every measurement and control system needs to have a mechanism to interact with the real world. It needs to be able to measure from multiple sensors to bring information into the system and be able to connect to multiple actuators to send appropriate responses. Some systems that are purely measurement and monitoring based may only require the ability to acquire input from sensors, but any measurement and control system needs to be able to perform this function.

Next is the user interface. No matter what system is designed, there needs to be a way for humans to be able to interact with it. They should be able to view the information being received, the result of their algorithms as well as the appropriate actions that will be taken based on that information. They must also be able to make changes rapidly to their algorithms to ensure that the system performs appropriately. Also in cases of consumer facing systems, the user interface needs to be highly intuitive with easy to use controls such as knobs and buttons.

Another essential element of engineering systems is the deployment target. These can range from a laptop/desktop type solution to fully autonomous, hybrid embedded systems. The choice of deployment targets needs to be vast to ensure that the system that is developed can be deployed to different targets based on choice.

Last but not the least is the element of commercial technologies. Engineering systems must be able to scale with technology. Not too long ago, multi-core systems [5] were the subject of bleeding edge technology conversations, however, today, its not uncommon to find octo-core systems in a budget priced laptop or a quad-core powered smart phone. There are other more powerful development happening in the technology world where processing power from multiple domains are being combined. The latest FPGAs [6] bring together the power of an ARM processor with the versatility and speed of an FPGA fabric.

The challenge for educators is to be able to teach students to master these six elements of engineering. Each of these elements, taken by them is formidable topics with several tomes of literature behind them. How then can a student do engineering to combine and integrate these different elements in a semester to build engineering systems? The answer is Graphical System Design.

3. The Graphical System Design Advantage

Graphical System design is an approach that combines modular hardware and graphical software to integrate the essential elements of measurement and control systems. Its graphical nature complements the other steps in a system design process, namely Computer Aided Design (CAD) and Electronic Design Automation (EDA) as shown in Figure 3. When students design CAD systems, they do not use text-based approaches, rather they draw their CAD design out since it mimics the way their brain thinks about CAD design. Similarly when students are doing circuit design and simulation, they do not type in netlists or resistor and capacitor values, rather they draw out their circuit with EDA software such as Multisim. Likewise, when it comes to programming, graphical programming languages such as LabVIEW have an inherent advantage in that students can program the way they think, with blocks of functions that logically pass information from one to another.

Figure 3. EDA, CAD and ADE approaches are all graphical

The real power of this approach comes to fruition when it comes to building measurement and control systems. Successful systems that integrate the six key elements need to maintain two aspects of the elements – they should be able to co-exist logically in the same environment. This means that when the student wants to acquire data from a sensor, it does not violate the coexistence of their ability to deploy the code to a multi-core system as shown in Figure 4.

Figure 4. Elements must be compatible and coexist

The next aspect of being able to successfully combine the elements is that the different elements should be able to communicate and pass data between each other seamlessly – for example, when the sensor data needs to be processed in-line in real-time, it should not require that the student leave the current environment while trying to learn an entire new tool chain. Similarly, when the student wants to incorporate text-based math along with graphical code, they should be able to seamlessly add the functionality in. An illustration of this framework is shown in Figure 5.

Figure 5. Elements must be able to communicate (shown in LabVIEW)

Note that Figures 4 and 5 are actual system design snippets from LabVIEW Graphical System Design environment. As it can be observed, by enabling students to bring in the six elements and make them communicate seamlessly, professors can prepare students in the art of system design for the 21st century. We will now explore some models where Graphical System Design has been incorporated at different levels in universities across the world, from freshmen to senior design and research.

4. Do Engineering at the Freshmen/Sophomore Level: Manchester University

In 2009, the Electrical and Electronic Engineering department at Manchester University had an alarming problem to contend with. The National Student Survey [7] had ranked them a dismal 34 out of 36 in the nationwide rankings for Electrical and Electronic programs. This had a direct impact on student enrollment since students had to now pay tuition because of change in government laws.

To overcome this issue, Manchester University did a complete overhaul of their Electrical and Electronic Engineering program and incorporated graphical system design. Every engineering student that joined the program now got access to LabVIEW and myDAQ that enabled them to Do Engineering not just in their laboratory but also in their dorm room. Manchester also incorporated the NI ELVIS platform into their curriculum to teach circuits and expand to other courses given its modular nature.

Figure 6. Results of Manchester student satisfaction after incorporating graphical system design

The result of these moves along with a comprehensive overhaul of their teaching methods is shown in Figure 6. Student satisfaction went up from 67% to 98% in 2010. Their overall ranking went from 34/36 to 1/36. They also have continued to have a high student satisfaction of 96% [8] in the most recent survey.

5. Do Engineering at the Junior Level: Massachusetts Institute of Technology (MIT)

Before the Fall 2010 Semester, the MIT feedback control systems course for both undergraduate and graduate students spent a significant chunk of their time in setting up and debugging very confusing and convoluted real-time control setups. This meant that the already precious lab time was not being spent on actually learning the concepts of feedback control, but rather on setup of equipment. Additionally the software that they used previously did not have very many on-screen diagnostics that meant that more time was spent to manually debug all their algorithms.

In the fall of 2010, the class at MIT [9] switched over to a graphical system design approach that incorporated LabVIEW and NI CompactRIO, an embedded, real-time autonomous controller that could perform very sophisticated control algorithms. The system, as shown in figure 7, interfaced with Quanser plants for control systems.

Figure 7. MIT feedback control systems course setup after overhaul

The setup accelerated the pace of learning for students since the CompactRIO coupled with LabVIEW ensured that the setup was always up and running as needed. This enabled the students to focus more on their control algorithms rather than the hardware setup. Also, since the User Interface was highly customizable in LabVIEW, students could build their own debug interfaces that enabled them to detect issues with their algorithms faster and thereby rectify them. LabVIEW's graphical nature enabled them to probe issues at the signal level in their code and understand exactly how their algorithm was performing. The net result was an increased student participation that extended well beyond the completion of the course – a sign that students were engaged in the process of learning to design systems.

6. Do Engineering at the Senior Design/Research Level: Kitasato University

Optical Coherence Tomography (OCT) is a noninvasive imaging technique that provides subsurface, cross-sectional images of materials. Interest in OCT technology continues to grow because it provides much greater resolution than other imaging techniques such as Magnetic Resonance Imaging (MRI) or positron emission tomography (PET). Additionally, the method does not require much preparation and is extremely safe for the patient because it uses low laser outputs and does not require ionizing radiation.

Dr. Ohbayashi of Kitasato University developed the world's first Real-time 3D OCT system by incorporating LabVIEW and FlexRIO platform. The first generation system [10] was capable of an A-scan rate of 60 MHz. The key element of the OCT method was using optical demultiplexers to separate 256 narrow spectral bands from a broadband incident light source. This allowed simultaneous, parallel detection of an interference fringe signal (a critical requirement for OCT imaging) at all wavelengths in the measured spectrum. As a result, the A-scan rate was equal to the data acquisition speed of the Analog-to-Digital Converter (ADC) digitization rate in the system. However the first generation system had some limitations because of the onboard memory of the devices and hence one would have to wait for several hours before the reconstruction of the final image was done.

The next generation system architecture [11] made two major modifications – they chose a center wavelength of 1310 nanometer and incorporated real-time hardware/software framework. The result is the world's first real-time 3D OCT system. Figure 8 shows their experimental setup and its acquired image.

Figure 8. Dr. Ohbayashi's real-time 3D OCT setup and its acquired image

The key aspect of graphical system design in this case was the rapidity in which Dr. Ohbayashi was able to both conceive and modify their system. The evolution from their first generation to second generation system took only a year when compared with traditional techniques could have taken several man-years. Thus by incorporating graphical system design, they were able to quickly and rapidly, design prototype and deploy a medical system that has significant benefits for the community.

7. Conclusion

Students of tomorrow need to be well versed in building systems. They will either be leading a team that is building a system or will be part of a team that is building one. Either way, the future engineers will have to build highly sophisticated engineering systems to solve the engineering grand challenges. Educators are faced with the challenge of teaching the future engineers how to build systems by incorporate the essential elements of engineering. Traditional tools and techniques simply cannot overcome the complexity of the individual pieces to create a seamless environment for system design. The answer is Graphical System Design, an approach that combines modular hardware and graphical software to integrate the essential elements of engineering. This approach is already started to be integrated in various universities worldwide to enable students to Do Engineering. We walked through three examples that span all the way from freshmen to research where Universities have realized substantial improvement in student satisfaction, participation and innovation. Approaches like Graphical System Design hold the key to creating the next generation of innovators that will design the systems to overcome the grand engineering challenges.

References

1. National academy of engineering grand challenges [Online]. Available: <http://www.engineeringchallenges.org>,
2. Smart grid systems overview from Energy.gov [Online]. Available: <http://energy.gov/oe/technology-development/smart-grid>
3. US Patent application for insulin delivery system [Online]. Available: <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p=1&u=/netahtml/PTO/search-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN/4398908>
4. A Goderis, C. Brooks, I. Altintas, E.A. Lee and C. Goble, Heterogeneous composition of models of computation, Technical report No. UCB/EECS-2007-139, 2007 [Online]. Available: <http://www.eecs.berkeley.edu/Pubs/TechRpts/2007/EECS-2007-139.html>
5. B. Chapman, The multicore programming challenge, 2007 [Online]. Available: <http://www.multicoreinfo.com/research/papers/appt07-chapman-mc-prog.pdf>
6. Xilinx Zynq architecture [Online]. Available: <http://www.xilinx.com/content/xilinx/en/products/silicon-devices/soc/zynq-7000.html>
7. The national student survey for UK [Online]. Available: <http://www.thestudentsurvey.com>
8. 2012 results for Manchester University for NSS [Online]. Available: <http://unistats.direct.gov.uk/subjects/satisfaction/10007798-132>
9. MIT incorporates graphical system design [Online]. Available: <http://www.ni.com/white-paper/13158/en/>
10. First generation OCT system by Dr. Ohbayashi [Online]. Available: <http://sine.ni.com/cs/app/doc/p/id/cs-11321>
11. Next Generation OCT system by Dr. Ohbayashi [Online]. Available: <http://sine.ni.com/cs/app/doc/p/id/cs-13387>

Biography

Dave Wilson

Director for Academic Programs

As the Director of Corporate Marketing and Academic Programs for National Instruments, Dave Wilson works with the both NI headquarters and more than 45 NI branches around the globe. He ensures the most effective marketing strategies and tactics are implemented while messaging consistency is maintained worldwide.

Before joining NI, Dave worked for the Xerox Corporation and Keithley Instruments as a research engineer and software developer. Upon joining NI in 1991 as a Michigan-area district sales manager, he began driving the adoption of NI measurement and automation solutions throughout the automotive industry. In this role, he presented more than 50 technical seminars, wrote hundreds of applications with customers, and received multiple industry recognition awards.

In 1995, Wilson became the director of data acquisition marketing where he led several successful launches for products that have become key parts of the NI product line including motion control, Vision, DAQ boards, and PXI. He also developed product and corporate messages and led initiatives to work with R&D to incorporate customer-recommended features into new products. In 2000, Wilson became the international sales director for NI Japan where he led the branch to record growth.

Wilson has delivered more than 60 keynotes about the application of next-generation technologies in 30 countries in Asia, Europe and the Americas. He has met with the ministers of education in both Russia and Kosovo and many Deans of engineering to discuss ways to adopt new generation technologies for science and engineering in university curricula. He has also authored numerous articles and interviewed with multiple domestic and international publications including EE Times Asia, Bits & Chips, Evaluation Engineering, Desktop Engineering, and Sensors.

Additionally, Wilson has chaired the most successful customer recognition event held by NI, the Graphical System Design Achievement Awards. For nine years, this event has recognized NI customers around the world for accomplishments in engineering and science.

Wilson holds a Bachelor of Science degree in applied physics from the State University of New York.