Incorporating wireless data acquisition into the STEM Curriculum: A case study with Lean Six Sigma

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Abstract

Throughout the STEM curriculum, undergraduate and graduate students are confronted with managing data at all levels of their education. Using existing tools and pedagogies, students are taught how to visualize and present data, model and predict with data, as well as search, sort and store data. A critical component that is missing is teaching students how to use technology to acquire or collect data. An alternative approach is to automate the data taking process using off-the-shelf components combined with open-source software. In a Lean Six Sigma class taught at NC State University, a series of labs were written to automate the data taking process for subsequent analysis and data visualization with JMP®, a commercial statistical analysis package. Using the Raspberry Pi as a base platform, labs were designed to instantiate several core ideas taught in Lean Six Sigma such as Measurement Systems Analysis, Design of Experiment, and Analysis of Variance. By comparing results from taking data "by hand" verses a wireless automated method, students learned in an impactful way how to quantify the advantages of acquiring data more quickly and accurately.

Keywords

Wireless Data Acquisition, Lean Six Sigma

Introduction

Throughout the STEM curriculum, undergraduate and graduate students are confronted with managing data at all levels of their education. Using existing tools and pedagogies, students are taught how to visualize and present data, model and predict with data, as well as search, sort and store data. A critical component that is missing is teaching students how to use technology to acquire or collect data. Even in the most data driven classes in the Engineering curricula, data acquisition is often done manually (e.g. with a clipboard, stopwatch or ruler). An alternative approach is to automate the data taking process.

There are many benefits that are derived from using an open-source approach for data collection such as: cost, reliability, interoperability, portability, and maintainability. The Raspberry Pi is an inexpensive (<$50) SBC (single board computer) with built-in support for a variety of communication interfaces such as Wi-Fi, Bluetooth, USB, and Ethernet. The Raspberry Pi runs Linux, an open source operating system that is widely used in academia as well as in industry, and is especially well suited for IoT (Internet of things) applications.

In a Lean Six Sigma class taught at NC State University, a series of labs were written to automate the data taking process for subsequent analysis and data visualization with JMP®, a commercial statistical analysis package. Using the Raspberry Pi as a base platform, labs were designed to instantiate several core ideas taught in Lean Six Sigma such as Measurement Systems Analysis, Design of Experiment, and Analysis of Variance. For example, inexpensive peripherals such as magnetic cards readers and digital calipers were used to develop a lab on Gage R&R, a statistical technique to measure and quantify repeatability and reproducibility. By comparing results from taking data "by hand" verses a wireless automated method, students learned in an impactful way how to quantify the advantages of acquiring data more quickly and accurately.

Measurement Systems Analysis: Gage R&R

In Lean Six Sigma, one of the core methodologies is called DMAIC: Define, Measure, Analyze, Improve and Control. These five step constitute a process for improving quality and/or reducing waste. In the Measure phase of a Lean Six Sigma project[1], data is taken to acquire a baseline and later to ascertain the level of improvement. Every process has variation; the goal of Six Sigma is not to eliminate it, but to reduce process variation to manageable levels. In other words, one first needs to identify and quantify the amount of variation in a process, and based on the data, formulate a future course of action. That is a crux of a data driven process and is accomplished by sampling.

Sampling is a process of selecting a subset of a population and inferring statistics about the population from the sample. Samples are acquired through measurement. Although this sounds straightforward, there is one catch. Just as there is variation in the process we are trying to measure, called part-to-part variation, there is also variation in the measurement process itself [2]. Therefore, the data that is analyzed contains both process variation and measurement variation. Obviously, erroneous conclusions are drawn when the measurement variation (or experimental error) constitutes a sizeable percentage of the total variation.

As an example, consider the following scenario. Students were divided into groups of six and were given a bag of washers and asked to determine the mean and standard deviation of the washer's thickness in 30 minutes. Each team was given 3 calipers to measure the thickness. One group member was chosen to record the data in a spreadsheet from the three "inspectors". Of the remaining two students, one oversaw the whole process while the sixth student looked for areas of improvement.

In the first phase of the lab, students measured the washer's thicknesses using calipers which were conveyed to another student who recorded the values by typing them into a spreadsheet. This process was repeated three times for each washer for all three inspectors for a total of 36 measurements. Table 1 shows the results for a typical group which are plotted in Figure 1. This type of analysis is called Gage R&R or Gage Repeatability and Reproducibility[2]. Repeatability measure how consistent an inspector is in measuring the same part multiple times, while reproducibility measures the differences between inspectors. As shown in Figure 1, there is quite a bit a variability both between and among the inspectors. Figure 2 shown the final analysis, where 76% of the variation in the measurement is due to Gage R&R while only 24% of the measured variation can be attributed to part-to-part variation. Usually, the lab ended there, without a clear understanding by the student as to how to improve the measurement process.

Collected Data:

Table 1: Data from a manual process of collecting data

Part ID	Part #	Measurer	Measurer Name	Measurement Method	Measurement (inches)
2.3	1	200057508	Alec	Manual	0.815
2.4	2	200057508	Alec	Manual	0.818
2.5	3	200057508	Alec	Manual	0.816
2.8	4	200057508	Alec	Manual	0.814
2.3	1	200208740	Nikhil	Manual	0.816
2.4	2	200208740	Nikhil	Manual	0.81
2.5	3	200208740	Nikhil	Manual	0.812
2.8	4	200208740	Nikhil	Manual	0.811
2.3	1	200178351	Stitha	Manual	0.807
2.4	2	200178351	Stitha	Manual	0.818
2.5	3	200178351	Stitha	Manual	0.815
2.8	4	200178351	Stitha	Manual	0.802
2.3	1	200057508	Alec	Manual	0.815
2.4	2	200057508	Alec	Manual	0.818
2.5	3	200057508	Alec	Manual	0.817
2.8	4	200057508	Alec	Manual	0.814
2.3	1	200208740	Nikhil	Manual	0.814
2.4	2	200208740	Nikhil	Manual	0.821
2.5	3	200208740	Nikhil	Manual	0.815
2.8	4	200208740	Nikhil	Manual	0.815
2.3	1	200178351	Stitha	Manual	0.814
2.4	2	200178351	Stitha	Manual	0.803
2.5	3	200178351	Stitha	Manual	0.825
2.8	4	200178351	Stitha	Manual	0.806
2.3	1	200057508	Alec	Manual	0.815
2.4	2	200057508	Alec	Manual	0.819
2.5	3	200057508	Alec	Manual	0.816
2.8	4	200057508	Alec	Manual	0.814
2.3	1	200208740	Nikhil	Manual	0.815
2.4	2	200208740	Nikhil	Manual	0.812
2.5	3	200208740	Nikhil	Manual	0.808
2.8	4	200208740	Nikhil	Manual	0.815
2.3	1	200178351	Stitha	Manual	0.805
2.4	2	200178351	Stitha	Manual	0.821
2.5	3	200178351	Stitha	Manual	0.814
2.8	4	200178351	Stitha	Manual	0.81

Variability and R&R Analysis: Manual and Automated Data Combined

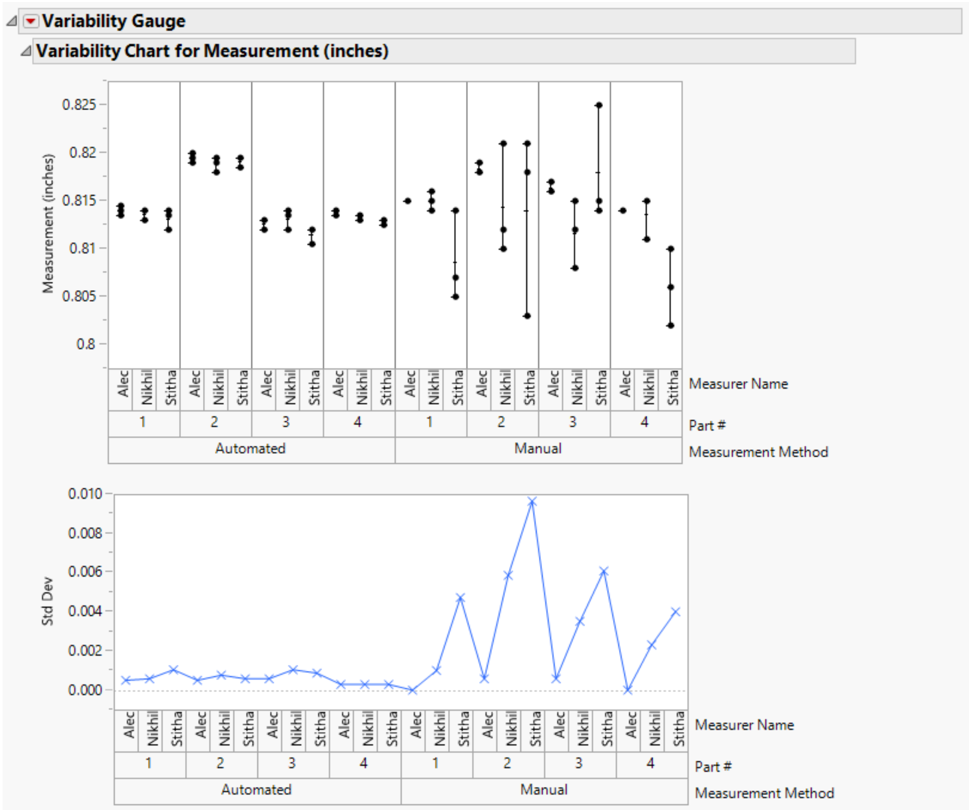
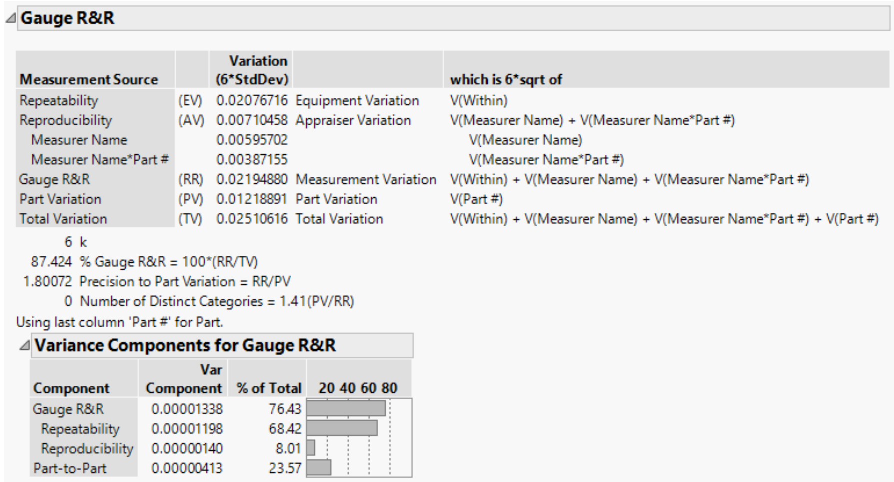


Figure 1. Gage R& R Plot

Last year, a follow-on lab was developed using wireless technology[4-7] to improve both the accuracy and reliability of the measurement process. First, each inspector was tracked electronically by having them swipe their student identification card through a magnetic card reader which was connected to a Raspberry Pi. In addition, the measurements from the calipers were conveyed wirelessly to the Raspberry Pi via a wireless USB transponder, as shown in Figure 3. These two changes alone reduced the measurement variability from 76% to under 6% of the total variability of the process, while the part-to-part variability accounted for over 94% of the total variability. This change can be seen graphically in Figure 1, which compares the manual method on the right to the automated wireless method on the left. Once the all the data was acquired by the Raspberry Pi, it was uploaded to the student's laptops and analyzed using JMP®, a statistical software package. Students accessed the Raspberry Pi via remote desktop, a graphical program found on Windows, OS X (Apple) and Linux to remotely run a desktop on another computer.

Additional labs were developed to perform regression analysis that correlated the thickness of pennies with age (two sample t-test) [3], as well as a lab that measured reaction time. In that lab, student's reaction time to either a change in LED state (off to on or on to off) or a buzzer going off were measured, and conclusions were drawn as to which factors were statistically significant in the design of the experiment.



Gauge R&R

Measurement Source		Variation (6*StdDev)		which is 6*sqrt of
Repeatability	(EV)	0.02076716	Equipment Variation	V(Within)
Reproducibility	(AV)	0.00710458	Appraiser Variation	V(Measurer Name) + V(Measurer Name*Part #)
Measurer Name		0.00595702		V(Measurer Name)
Measurer Name*Part #		0.00387155		V(Measurer Name*Part #)
Gauge R&R	(RR)	0.02194880	Measurement Variation	V(Within) + V(Measurer Name) + V(Measurer Name*Part #)
Part Variation	(PV)	0.01218891	Part Variation	V(Part #)
Total Variation	(TV)	0.02510616	Total Variation	V(Within) + V(Measurer Name) + V(Measurer Name*Part #) + V(Part #)

6 k
87.424 % Gauge R&R = 100*(RR/TV)
1.80072 Precision to Part Variation = RR/PV
0 Number of Distinct Categories = 1.41(PV/RR)
Using last column 'Part #' for Part.

Variance Components for Gauge R&R

Component	Var Component	% of Total	20 40 60 80
Gauge R&R	0.00001338	76.43	
Repeatability	0.00001198	68.42	
Reproducibility	0.00000140	8.01	
Part-to-Part	0.00000413	23.57	

Figure 2: Gauge R&R analysis

Figure 3: Raspberry Pi with magnetic card reader and wireless caliper

Conclusions

Using inexpensive wireless technology such as the Raspberry Pi, a series of labs were developed which demonstrated various aspects of Lean Six Sigma and the DMAIC methodology. Specifically, Gage R&R (Measurement Systems Analysis), two sample t-tests, ANOVA, and regressions analysis were demonstrated using data acquired by the students in real-time. This enhanced their understanding of the importance of quantifying and minimizing measurement error in the data acquisition process.

References

1 Breygogle, Forrest W., Implementing Six Sigma: Smarter Solutions Using Statistical Methods, John Wiley & Sons, New Jersey, 2003, p. 96.

2 Wheeler, Donald J. and Richard W. Lyday, Evaluating the Measurement Process, 2nd edition, SPC Press, Knoxville TN, 1989, p. 49.

3 Levine, David M., Six Sigma Statistics For Green Belts, Pearson Prentice Hall, New Jersey, 2006, p. 218

4 Vilros Raspberry Pi 3 Complete Starter Kit – Clear case edition, www.amazon.com

5 Yosoo MSR90 Magnetic Strip Card Reader 3 Tracks Mini Mag Hi-Co Swiper, www.amazon.com

6 iGaging Absolute Origin 0-6" Digital Electronic Caliper IP54 Protection, www.amazon.com

7 iGaging SPC USB Wireless for Absolute Electronic Measuring Tool, www.amazon.com

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Dr. Jasper is currently a Professor in the Textile Engineering program at North Carolina State University. He received his BS and MS degrees in Aeronautics and Astronautics from MIT and his PhD in Aeronautics and Astronautics from Stanford University. He maintains a very rich set of open-source drivers at https://github.com/wjasper/Linux_Drivers and develops teaching demos and labs for electronics and Six Sigma courses. His research interests include nano-particle filtration, real-time measurement and control of the dyeing process, and wireless power transfer for wearable garments. He was awarded a Fulbright grant in 2015 in Engineering Education hosted by Shenkar College in Ramat Gan and was the recipient of the Gertrude M. Cox Award for innovation excellence in teaching and learning in 2010.