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Sensor Integration in Mathematical Modeling

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Abstract

The increased affordability of micro-controllers and their ever-smaller components are leveling the playing field for any layperson to collect experimental data. Using an Arduino micro-controller and an array of sensors, students and teachers can replicate several important experiments studied in Ordinary Differential Equations. In this project, the use of a DS18B20 digital temperature, ultrasonic, infrared obstacle avoidance sensor, and a laser module will be employed to measure independent variables applied to important mathematical models. The sensors used in this demonstration will show how sensor data can be collected for Newton's Law of Cooling, Newton's Second Law of Motion for Free Fall, and Hooke's Law applied to springs. The data will then be interpreted with the aid of a computer and Wolfram Mathematica Software to demonstrate plotting and visualizing the data. This exploration of the scope of cost-effective technology is presented with the hopes that it will stimulate a student's curiosity and better facilitate STEM education, Standing for Science, Technology, Engineering and Mathematics in Education.

STEM subjects of study as they are known in school systems (science, technology, engineering, and mathematics respectively) require models and sets of data to find patterns and build comprehension on the principles being studied. Fostering and nurturing a resiliency in these subjects for students that may make a career out of these fields requires a sense of self efficacy for both teachers and students alike. (Faikhamta, 2018) Self-efficacy is defined as a person's belief that they can be successful when carrying out a particular task. (Cambridge, 2021). Teacher's contexts and experience level can influence belief, perceptions, and self-efficacy about STEM teaching. (Faikhamta, 2018), In particular, when attempting to integrate technology into their lessons plans, in-service teachers found that their self-efficacy was challenged when also trying to pose good discussion questions to their students in tandem (Faikhamta, 2018) Further, while STEM education has become an increasing priority with a demand to secure 3.5 million STEM jobs by 2025 (Manufacturers, National Association of, 2018) attrition from within undergraduate science fields can be a potential issue and is mitigated by earlier exposure in secondary and early post-secondary education. (Phillipus, 2016) In a report by the U.S. Department of Education, among bachelor's degree students entering STEM fields between 2003 and 2009, 48% of students either switched to a different major or dropped out of college entirely. (Chen, 2013) Introducing science experiments that are both compelling and approachable for students and teachers with integrated open-source hardware has the potential to build a strong foundation for the future of scientific careers. The question then remains how motivation can be sustained, and positive self-efficacy can be nourished early and often.

While demand for STEM education remains high, low-cost open-source hardware has become a topic of great interest just when measuring the amount of research content published on the uses and implications for its future. 667 research papers from 2005-2018 looked into the potential benefits and applications of open-source .hardware within secondary and post-secondary education. (Heradio, 2018) Arduino is an open-source micro-controller that allows for input and output connections to both digital and analog sensors which can then be read and programmed by a computer.

The board itself costs under 50 dollars and if one assembles the board from just its components and microchip, it is even less. (Arduino, 2018) Given that breadboards and jumper wires can be used, soldering skills are not required to implement and collect sensor data electronically. Furthermore, the data can be analyzed by both students and teachers through symbolic and numeric math software such as Wolfram Mathematica, which can reinforce and build an understanding of theory and practice. Given that only 39% of high schools in the United States teach computer science, generating interest by pairing it with current science education has many potential benefits for present and future student classrooms. (The Computer Science Teachers Association (CSTA), 2019) Wolfram Mathematica has the added benefit of having a notebook style interface that allows math, runnable code, image and text to be organized together. (Wolfram Mathematica, n.d.)

Experimental Procedure

The experimental procedure can be examined in two parts from 2020-2021. The first part was the impetus of this project, exploring how data measured for Newton's Law of Cooling could be analyzed in 2020. The second part involves two additional differential equation mathematical models, that being Hooke's Law for Simple Harmonic Motion and Newton's Second Law of Motion for Free Fall in 2021.

The first experiment measured the rate of water cooling down over the span of 10 minutes from a temperature close to 98.6℉. The data was collected using two sensor probes separated in the same hot water solution. (Figure 1) The setup was employed in a basement where the ambient temperature fluctuated between 74.5-75.4℉. To compensate for this variation, the bowl of water and the sensors were placed in a cooler where the probes were out of contact with each other to help keep a steadier temperature. It should be noted that the accuracy measured for this temperature sensor is between -0.5/+0.5℃ for the DS18B20 Temperature Sensor. (Best Engineering Projects, 2020) To further ensure top results, two sensors were used simultaneously for three trial runs. The setup is depicted below

The second part of the procedure occurred February-March of 2021, whereby a support rod and a wooden base was setup with an ultrasonic sensor for measuring the distance in inches every 500 milliseconds. (Figure 2) A series of 10-gram metal weights were placed on the spring and released one inch from the starting point. The distance would then be recorded until the spring returned to its starting point.

Finally, to study Newton's Second Law of Motion for Free Fall, change in time would be measured upon just after pressing a button to the moment it breaks a laser beam. (Figure 3) Upon pressing this button, a magnet would simultaneously release its hold on a mass with a metal disc and start a stopwatch. From this change in time velocity and position can be evaluated from the data measured.

Results and Discussion

To visualize the effectiveness of the data collected, data was first plotted in excel for formatting and then was overlayed with Wolfram Mathematica to examine its accuracy and fit from the projected models. (Figure 6) Newton's Law of Cooling showed the most accuracy, with a stronger R square value, closer to one than Hooke's Law or Newton's Second Law for Free Fall. Hooke's Law for Simple Harmonic Motion when overlayed with its model on the graph showed a similar form in a sinusoidal fashion but had a fair number of points that deviated from the model as well. (Figure 4) The sensors were taking data every half a second. Further data collection with less measurements may reveal a tighter fit to the model with fewer errors. When examining Newton's Second Law of Motion for Free Fall, we note the data was taken and averaged for increased accuracy. When comparing to the model, it was close to the amount of time we would expect when dropped from 1.25 meters. (Figure 6).

Conclusion

In conclusion, while results may vary, the potential to be able to model and compare respective mathematical models with support from open-source hardware and cloud computational software would prove to be an excellent supplement to the current STEM Education curriculums.

With earlier exposure to these fundamental math models, students in STEM disciplines would be in a stronger position to understand them in higher education. The ability to graph actual experimental data whether as a demonstration or for use in science labs is more accessible than ever. The given models that are illustrated are standards for higher level mathematics demonstrating first and second order differential equations in their solution form. They are not necessarily the ones a student will encounter in their particular career path. They are however frequently used as they are simple but effective models to demonstrate the power of differential equations with mathematical models. As STEM education continues to increase in demand and studies show earlier exposure leads to less attrition upon entering post-secondary education, it is important that both students and teachers can have the access to this technology to better prepare future students hoping to make a career in STEM.

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Appendix

Figure 1: Setup for Newton's Law Of Cooling

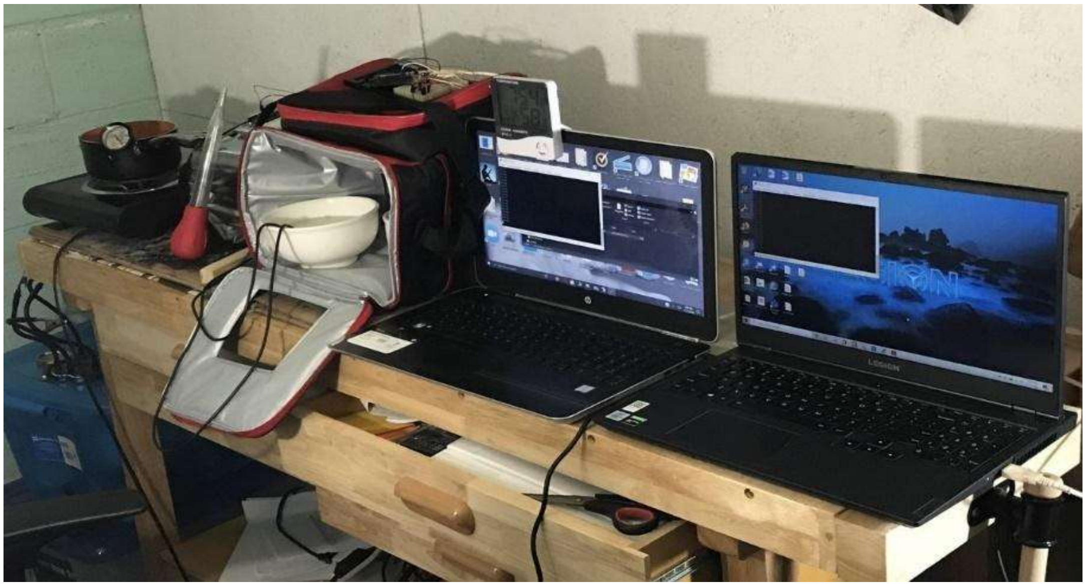


Figure 2: Setup for Hooke's Law of Simple Harmonic Motion

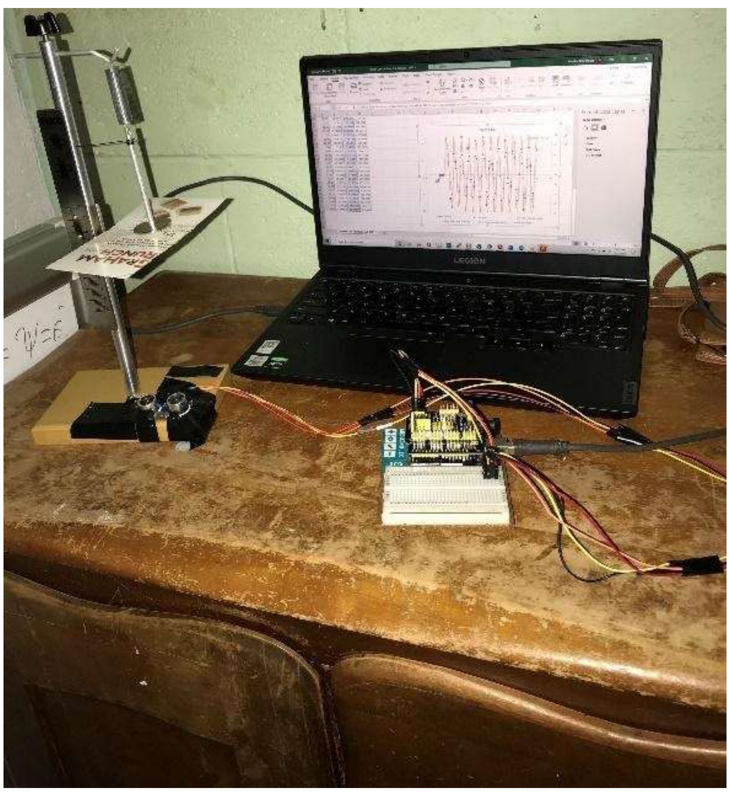


Figure 3: Setup for Newton's Second Law of Motion for Free Fall

Figure 4: Sensor Data Plot of Hooke's Law Compared with Projected Mathematical Modal

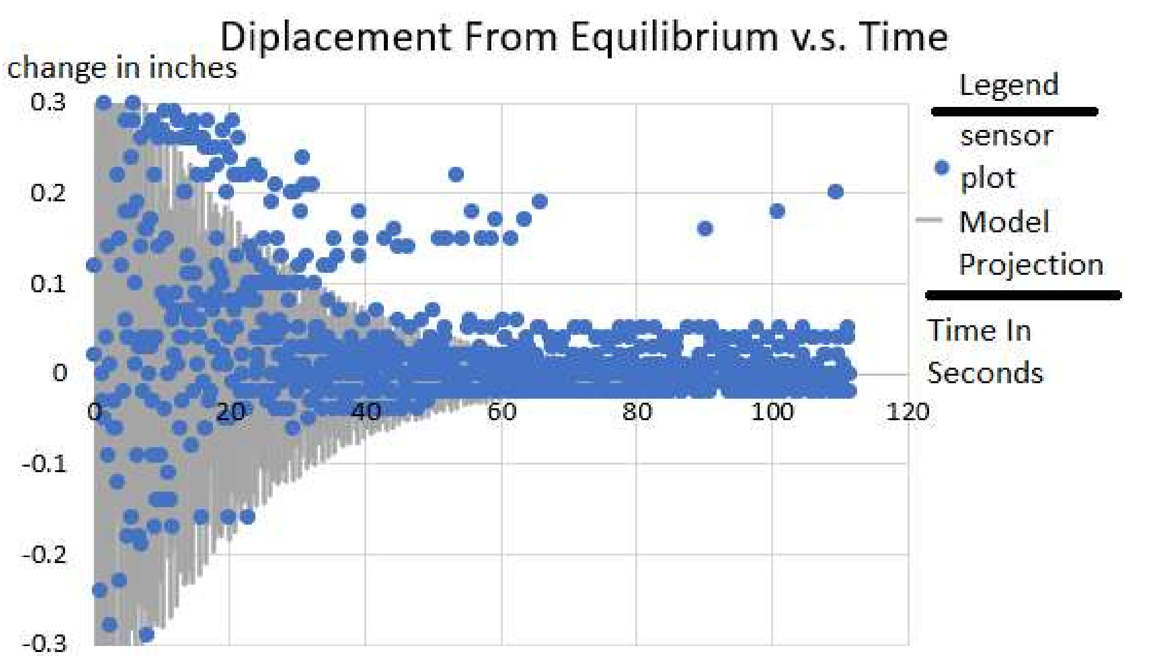


Figure 5: Newton's Law of Cooling Data Fitted to Trendline

Time (min)	Trial 1	Trial 2	Trial 3
0	100.62	100.51	100.74
1	100.4	100.06	100.17
1.5	100.06	99.61	99.61
2	99.84	99.27	99.27
2.5	99.5	98.82	98.82
3	99.27	98.37	98.49
3.5	99.05	98.04	98.15
4	98.71	97.7	97.7
4.5	98.37	97.36	97.36
5	98.15	96.91	97.02
5.5	97.92	96.57	96.57
6	97.59	96.35	96.24
6.5	97.47	95.9	95.79
7	97.14	95.45	95.34
7.5	97.02	95.22	95
8	96.8	94.89	94.66
8.5	96.57	94.55	94.21
9	96.24	94.32	93.99
9.5	96.01	93.99	93.54
10	95.79	93.65	93.31

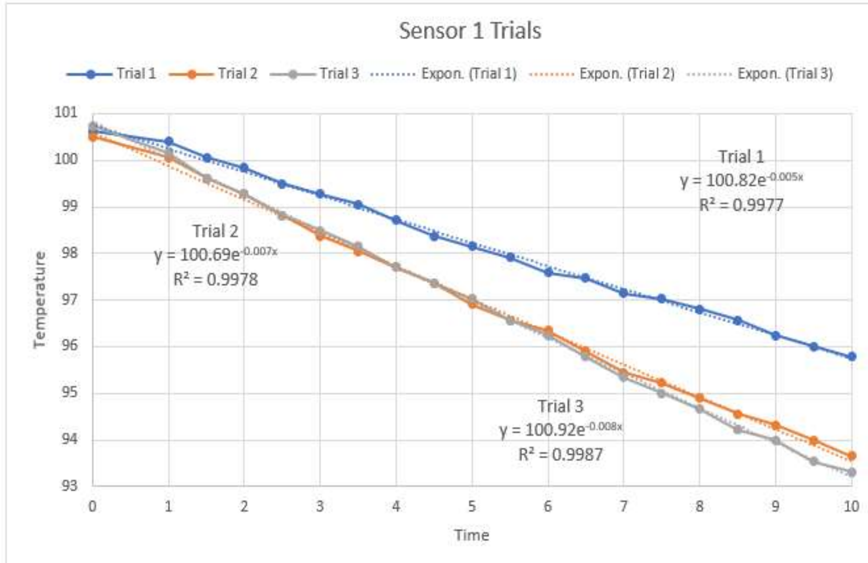
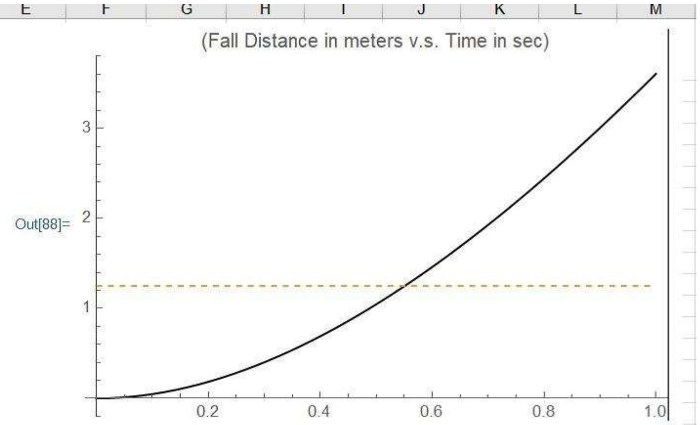


Figure 6: Newton's Second Law For Free Fall sensor data and projected time of fall

	A	B	C	D
1	Trial	Delta	acceleration (2h)/(Deltat)^2	velocity (v = v_0 + gt = 0 + 9.8* t)
2	1.00	0.7	5.13	6.85
3	2.00	0.5	9.99	4.91
4	3.00	0.7	5.1	6.87
5	4.00	0.6	6.97	5.88
6	5.00	0.5	9.99	4.91
7	6.00	0.5	10.07	4.89
8	7.00	0.6	6.97	5.88
9	8.00	0.6	6.97	5.88
10	9.00	0.5	10.03	4.9
11	10.00	0.6	6.97	5.88
12	Averages	**0.58**	**7.819**	**5.685**
13				
14				
15				
16				
17				



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