2018 ASEE Zone IV Conference: Boulder, Colorado Mar 25

Incorporating Motion Capture Technology in Undergraduate Engineering Dynamics

Ms. Katherine Mavrommati, California Polytechnic State University

I am a senior Biomedical Engineering major and have been working at the Human Motion Biomechanics Lab at Cal Poly for the past two years. As a research assistant I work on several projects including calculating knee contact forces during different types of exercise and creating educational modules that incorporate our motion tracking technology in various classes. The classes range from kinesiology to dynamics to biomechanics classes. The labs that we create help enhance the student's experience in the class with a real life application while allowing them to use state of the art technology.

Ms. Eileen W. Rossman, California Polytechnic State University, San Luis Obispo

Eileen Rossman has a worked in various industries for over 14 years before starting a career teaching engineering. Here industry experience includes field support for Navy Nuclear refueling with Westinghouse, analysis and programming of pipeline flow solutions with Stoner Associates, and design of elevator structures and drive components with Schindler Elevator.

Since 2002, Eileen has taught in the Mechanical Engineering Department at California Polytechnic State University. Her teaching experience includes Basic and Intermediate Fluids, Basic and Intermediate Dynamics, Statics, Machine Design, and Thermal Measurements.

Dr. Brian P. Self, California Polytechnic State University, San Luis Obispo

Brian Self obtained his B.S. and M.S. degrees in Engineering Mechanics from Virginia Tech, and his Ph.D. in Bioengineering from the University of Utah. He worked in the Air Force Research Laboratories before teaching at the U.S. Air Force Academy for seven years. Brian has taught in the Mechanical Engineering Department at Cal Poly, San Luis Obispo since 2006. During the 2011-2012 academic year he participated in a professor exchange, teaching at the Munich University of Applied Sciences. His engineering education interests include collaborating on the Dynamics Concept Inventory, developing model-eliciting activities in mechanical engineering courses, inquiry-based learning in mechanics, and design projects to help promote adapted physical activities. Other professional interests include aviation physiology and biomechanics.

Mr. Jay Tyler Davis II

Incorporating Motion Capture Technology in Undergraduate Engineering Dynamics

Katherine Mavrommati, Jay Davis, Sonya Dick, Eileen Rossman, Brian P. Self
California Polytechnic State University, San Luis Obispo

Introduction

In typical dynamics courses, little is done to connect the methods and theories being taught to practical applications a student may encounter in an engineering job. As a result, students are often insufficiently motivated in their study of dynamics. Numerous authors have discussed the benefits of problem-based learning (see [1] for a review), including longer retention, increased motivation, and improved transfer. Instructors have incorporated projects involving catapults [2], Legos [3,4], and roller coasters [5] in their dynamics courses to provide engineering context and hopefully improve student learning. Previous studies have shown that contextualization, personalization, and choice produce a dramatic increase in students' motivation and engagement in the subject [6]. This paper examines the effects of introducing students in an undergraduate dynamics course to motion analysis technology.

Motion capture experiments are used in a variety of engineering fields, including sports biomechanics [7], visualization and computer animation [8], and pediatric gait analysis [9]. In previous study [10], motion capture technology was used in an upper division dynamics class. In that assignment, however, all students had to analyze the same data and had the same objectives [10]. In this study, the students utilized the live motion capture technology of the Human Motion Biomechanics Lab at Cal Poly to analyze the kinematics of a real-life application. The objectives of this study were to (1) increase the motivation of students in the study of dynamics, (2) provide engineering context for dynamics students, (3) provide choice to analyze a kinematic project of their interest and (4) introduce students to state-of-the-art motion capture technology.

Methods

Sixty-four dynamics students of various engineering majors ranging, including mechanical, civil, aerospace, and biomedical engineering, were first introduced to the project through a presentation about the capabilities of the motion capture technology available at the Human Motion Biomechanics Lab at Cal Poly (Figure 1). The motion capture system (Motion Analysis Corporation, Santa Rosa, CA) consists of near infrared cameras that track the location of retroreflective markers. The students were introduced to the practice of appropriate marker placement to track the kinematics of any object as well as to the idea of modeling the human body as a rigid body system. The students self-selected their groups (3-4 per team) and chose a real-life application whose kinematics they would like to analyze. The project was open ended and could involve both particle and rigid body kinematics.

Their first requirement was to submit a project proposal that included their top three ideas along with their main objective for each idea. One idea was then selected based on safety, ease of analysis, and overall variety of projects. A list of the final projects can be seen in Table 1.

Figure 1. Panoramic Image of HMB Lab with near InfraRed cameras mounted on the walls to capture live motion.

Table 1. List of final projects by dynamics students. Groups consisted of up to 4 students.

Group #	**Project Description**
1	Calculate the angular velocity of a frisbee using the change in linear displacement over a time interval at its point of release.
2	Consider that the leg has two segments, the thigh and the shank. Find the angular velocity of the shank while pushing off a skateboard.
3	Drone S is hovering over at a particular point while the drone B is flying towards drone M. The drones collide and the blades bind creating a plastic collision. Find the final velocity of the drones after impact and the initial velocity of drone M.
4	Modeling the linkage of a full suspension mountain bike, find the angular acceleration of one of the links and the acceleration at a point while applying a downward force.
5	Find the length of string unraveled when a yo-yo is released from rest and reaches maximum speed.
6	Find the coefficient of kinetic friction between a block and a wooden ramp.
7	Find the velocity at a particular point on a frisbee, knowing angular velocity and overall distance and time of travel.
8	Calculate coefficient of restitution and final bounce height of a ball after free fall from a known height.
9	Find the acceleration at a particular point and time on a bike wheel while the bike comes to a sudden stop assuming no slip conditions.
10	Model the arm of a tennis player as a 3 linkage rigid body and find the angular velocity of the racquet, knowing the angular velocity of the upper arm.
11	Find the acceleration of a tire rolling down a grassy hill.
12	Modeling the human arm as a 2 linkage rigid body, find the velocity of the wrist while a pitcher throws the ball at a known speed. The angular velocity of the forearm is also known.
13	Find the coefficient of a spring as a ball of known mass is compressed against it and then is released.
14	Modeling the leg as a 2 link rigid body, find the angular velocity of the two links knowing the velocity of the knee and ankle while the subject is kicking a punching bag.
15	Find the velocity of a frisbee at a particular point knowing velocity at the center, radius and angular velocity of the frisbee.
16	Find the velocity of the subject’s clavicle while performing military-style push-ups. The angular velocity of the forearm and upper arm are known.
17	Find the final velocities after a collision of a baseball and ping pong ball.
18	Modeling a figure skater’s upper body as a 3 linkage rigid body, find the angular velocity of her torso knowing the velocity of her elbow and rigid body dimensions.

Over the course of a week, students scheduled 30 minute intervals at the lab where at least two research assistants helped students determine the best way to set up their experiment. The students planned marker placement, orientation of their object in the calibrated space, and recorded any other information such as mass or dimensions of their object before starting the trials. Allowing the students to plan marker placement helped them understand the dynamic problem they chose to analyze since they had to decide what kinematic information was important for their analysis. Students usually spent 12 minutes on planning, 7 minutes on recording data and the rest of the time was spent showing the students how their data was post-processed using the Cortex 7.0 system along with the final output of their kinematic data. Any remaining time was allocated to talking about research opportunities on campus as well as further research that the HMB Lab is engaged in.

The students were given an Excel file that contained the real-time position of every marker that they used. There were no diagrams or pictures associated with their experiment, which gave them an opportunity to work with real experimental data. A section of the kinematic output of one experiment can be found in Appendix A. The students produced a report that included a dynamics homework type question along with its analytical solution. The analytical solution was compared with the numerical solution and a percentage error was calculated, which was accompanied with a paragraph of possible sources of errors. An example of a student report can be seen in Appendix B. Following the submission of their report, students were asked to select whether they Strongly Agreed, Agreed, were Neutral, Disagreed or Strongly Disagreed with the statements listed in Table 2.

Table 2. Survey statements that students were asked to indicate whether they Strongly Agreed, Agreed, were Neutral, Disagreed or Strongly Disagreed

Question #	Statement
1	The HMB Project helped me think about realistic scenarios that could be tested using motion analysis technology.
2	The required deliverables were possible to accomplish in the time allotted.
3	There are useful real world applications for the skills gained through the HMB Project.
4	Compared to other homework assignments, the HMB Project was more interesting and engaging.
5	The project got me interested in applications of engineering related to motion analysis technology or biomechanics.
6	This lab got me interested in research.
7	The HMB Project should be repeated in future sections of ME212.

A final question asked students if they had any improvements for the project in the future or if they had any other comments. Student reports were then evaluated based on the following rubric in Table 3. The rubric was not provided to the students prior to the experiment.

Table 3. Rubric used to evaluate student reports.

HMB Project Rubric : GROUP #			
	Points Earned	**Total Possible Points**	**Comments**
Question well posed		2	
Clear givens and reasonable assumptions		3	
Is the solution correct		5	
% error and explanation are reasonable		3	
Presentable solution		1	
Level of complexity of question		2	
Survey completed		2	Thank you for your feedback!
Total		**18**	

Results

Results from the survey are shown in Figure 2. Eighty-three percent of the responding students agreed or strongly agreed that the HMB project helped them think about realistic scenarios that could be tested using motion analysis technology; 81% thought it involved useful real-world skills. Fifty-four percent of students thought the HMB Project was more interesting than other homework assignments, and 52% recommended that the lab be offered in future sections of the class (another 40% were neutral). There was some dissatisfaction with the time allotted for the completion of the project. Forty percent of the students indicated that this project aroused their interest in research, which was a secondary objective of this project.

When asked for improvements to the HMB projects, most students asked for more time to complete the project. A lot of students also requested that the data be more clearly presented or that more guidance be provided on how to analyze the given data. When asked for additional comments, most were positive with the most significant being "I feel my particular ME 212 class has had a better advantage at learning concepts in dynamics by incorporating hands on activities. Thank you for this."

Overall, while a lot of students complained about the difficulty of analyzing the results, the majority of the students were able to get their analytical and numerical solution to match. The students provided sound and technical reasons for the difference between their analytical and numerical solutions which were based off of their assumptions. The students' efforts are evident by their resulting grades shown in Figure 3.

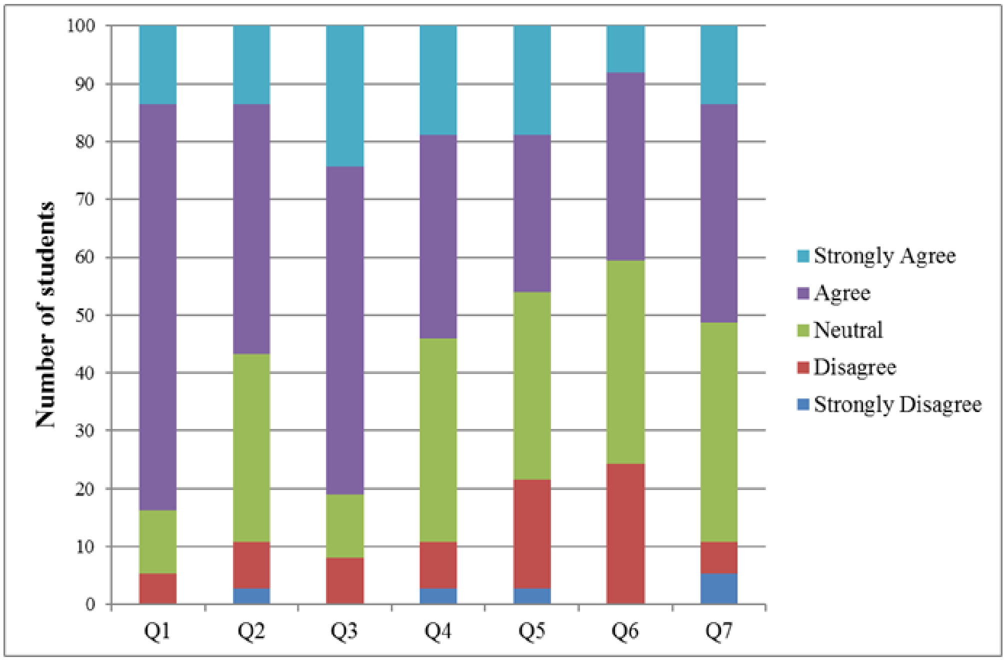


Figure 2. Replies to the seven questions from Table 2.

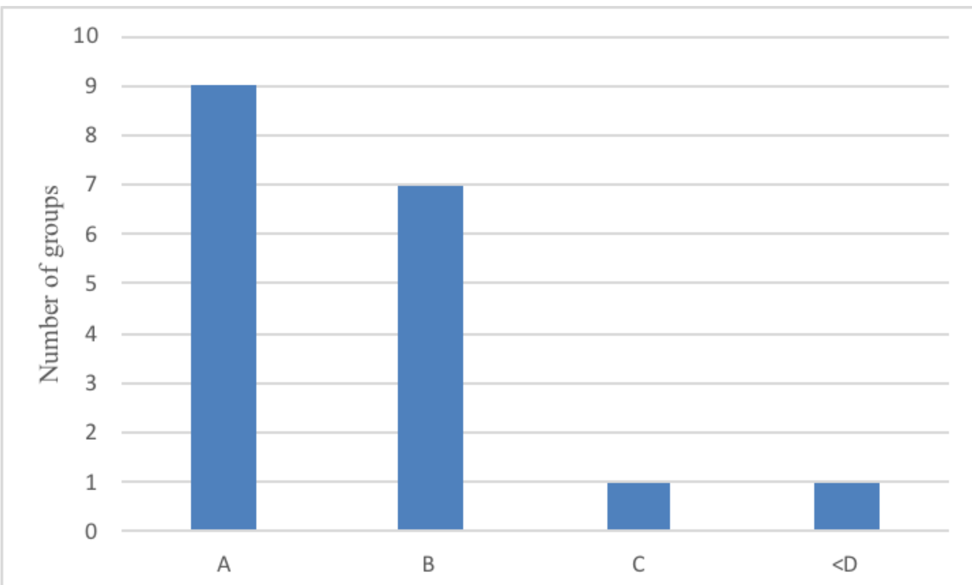


Figure 3. Resulting grades for all 18 groups of students.

Discussion

This project introduced dynamics students to the motion analysis technology available at the HMB Lab. It was designed to push the students to work with unfamiliar technology and raw data to better prepare them for research or summer internships. To motivate the students, we asked them to come up with their own projects and analyze the kinematics of an object that they are interested in. It was not surprising to find that a lot of students used their own hobbies as projects. For instance, one team analyzed the kinematics of one of the members of the team while they were skateboarding. In the survey that same student mentioned that "I enjoyed being able to pick something I enjoy doing (skateboarding), and combining what

I've been learning at school with it." Once again, this showed that motivation to complete a project increases when the students have more freedom to choose what they want to study. The effects of the increase in motivation are also shown through the students' grades. Most students received either an A or B.

As shown in Table 3, the main teaching objective was to make sure the theoretical concepts are being applied correctly by calculating an accurate solution. The understanding of theoretical concepts was also checked by ensuring that the students had chosen appropriate principles for their problems, while also accounting for all the relative assumptions to their solutions. Furthermore, it was important to ensure that the students understood the limitations of the motion capture system and how those limitations applied to their project. This was done by grading them based on their reasoning for the percent error between analytical and numerical solution. Most students proved to have a good understanding of the implementation of theoretical concepts learned in class in their projects. Some students did not provide clear givens or were missing major assumptions to their project. The lowest scores were mostly due to a lack of effort from the students to provide all the information or present their solution as requested.

This project will be continued in future dynamics classes while also taking into consideration students' suggestions. More time will be allotted for students to familiarize themselves with the data and complete the project. Nevertheless, considering that all students were able to analyze their results and produce accurate solutions, the format of the data will not be changed. While the students complained that they wanted a more concise format, a major part of this activity is exposing students to real life data analysis and allowing them to experience the difference between analytical and numerical solutions. Future research could address the value of the cognitive gains of students compared to other dynamics classes that do not participate in the HMB Project.

Acknowledgments

This work was supported by the W.M. Keck Foundation. Opinions, interpretations, conclusions and recommendations are those of the authors.

References:

[1] Kolmos, Anette, and Erik de Graaff. "Problem-based and project-based learning in engineering education." *Cambridge handbook of engineering education research* (2014): 141-161.

[2] Reffeor, W. (2002, June), *Incorporating Design In An Introduction To Dynamics Course* Paper presented at 2002 Annual Conference, Montreal, Canada. https://peer.asee.org/10263

[3] Self, B.P. and Wood, J. (2004) Teaching undergraduate kinetics using a LEGO Mindstorms race car competition. Proceedings, American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, Utah.

[4] Hagglund, R. R., & Cobb, E. C., & Jolley, W. O., & Rencis, J. (2003, June), *A Fun And Challenging Engineering Dynamics Project Using A Lego Construction Set* Paper presented at 2003 Annual Conference, Nashville, Tennessee. https://peer.asee.org/12496

[5] Sloboda, A. R. (2015, June), *A Roller Coaster Project as Part of an Undergraduate Dynamics Course in Mechanical Engineering* Paper presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 10.18260/p.23445

[6] Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. Journal of Educational Psychology, 88 (4), 715-730.

[7] Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. Sports Medicine (Auckland, N.Z.), 38(12), 1025–1043.

[8] Calvert T. (2016) Approaches to the Representation of Human Movement: Notation, Animation and Motion Capture. In: Laumond JP., Abe N. (eds) Dance Notations and Robot Motion. Springer Tracts in Advanced Robotics, vol 111. Springer.

[9] Long T.J., Harris F. G., "Pediatric gait and motion analysis: Current limitations and emerging opportunities for quantitative assessment," Technology and Disability, vol. 22, no. 4, pp. 199-206, 2010.

[10] Self, B.P., Montoya, D.J., Mavrommati, K. (2017) Incorporating a Motion Analysis Research Laboratory into a Dynamics Course using Model Eliciting Activities. *SEFI Annual Conference*, Azores, Portugal.

Appendix A

The figure below shows an excerpt of one of the data sets produced in this project. All students received a similar spreadsheet of kinematic data.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	PathFileTy	4	(X/Y/Z)	H:\Class Data\ME 212\2017Oct24-01\DataFiles\Trimmed_2017Oct24_Group17_Trial_1_Processed\Trimmed_2017Oct24_Grou											
2	DataRate	CameraRa	NumFram	NumMark	Units	OrigDataR	OrigDataS	OrigNumFrames							
3	200	200	389	5	mm	200	1	389							
4	Frame#	Time	Shoulder			Elbow			Wrist			Hand			Baseball
5			X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3	X4	Y4	Z4	X5
6															
7	1	0	-1830.14	111.939	1451.25	-1810.73	212.833	1156.29	-2095.14	223.668	1131.65	-2146.89	207.803	1173.94	-2211.6
8	2	0.005	-1830.14	111.939	1451.25	-1810.46	212.755	1156.32	-2095.06	223.791	1131.22	-2147.36	207.564	1173.93	-2211.6
9	3	0.01	-1830.4	111.891	1451.15	-1810.66	212.524	1156.42	-2095.06	223.791	1131.22	-2147.14	207.67	1173.98	-2211.4
10	4	0.015	-1830.44	111.954	1451.14	-1810.66	212.524	1156.42	-2095.06	223.791	1131.22	-2147.33	207.12	1173.65	-2211.6
11	5	0.02	-1830.14	111.939	1451.25	-1810.58	212.453	1156.29	-2094.94	223.012	1130.41	-2147.08	207.189	1173.9	-2211.4
12	6	0.025	-1830.24	111.692	1451.16	-1810.58	212.453	1156.29	-2095.06	223.791	1131.22	-2147.33	207.12	1173.65	-2211.6
13	7	0.03	-1830.4	111.891	1451.15	-1810.58	212.453	1156.29	-2095.06	223.791	1131.22	-2147.08	207.189	1173.9	-2211.6
14	8	0.035	-1830.05	111.805	1451.47	-1810.66	212.524	1156.42	-2095.06	223.791	1131.22	-2147.13	207.609	1174.24	-2211.6
15	9	0.04	-1830.13	111.522	1451.37	-1810.45	212.318	1156.4	-2095.06	223.791	1131.22	-2147.08	207.189	1173.9	-2211.6
16	10	0.045	-1829.87	111.57	1451.47	-1810.66	212.524	1156.42	-2095.14	223.668	1131.65	-2147.2	206.829	1174.52	-2211.6
17	11	0.05	-1829.87	111.57	1451.47	-1810.64	212.48	1156.67	-2095.14	223.668	1131.65	-2147.15	207.132	1174.28	-2211.5
18	12	0.055	-1830.16	110.931	1451.45	-1810.63	212.337	1156.74	-2095.2	223.571	1132	-2147.27	206.899	1174.94	-2211.5
19	13	0.06	-1829.87	111.54	1451.69	-1810.64	212.48	1156.67	-2095.2	223.571	1132	-2147.22	207.18	1174.69	-2211.5
20	14	0.065	-1829.72	111.362	1451.56	-1810.73	212.422	1156.88	-2095.2	223.571	1132	-2147.27	206.899	1174.94	-2211.5
21	15	0.07	-1829.98	111.059	1451.75	-1810.54	212.339	1157.11	-2095.19	223.094	1131.84	-2147.27	206.899	1174.94	-2211.3
22	16	0.075	-1829.8	111.442	1451.77	-1810.44	212.466	1157.47	-2095.19	223.094	1131.84	-2147.27	206.899	1174.94	-2211.3
23	17	0.08	-1830.16	110.931	1451.45	-1809.61	212.411	1157.75	-2094.74	223.784	1132.06	-2147.28	206.344	1174.85	-2210.8
24	18	0.085	-1830.16	110.931	1451.45	-1809.61	212.411	1157.75	-2094.74	223.784	1132.06	-2147.28	206.344	1174.85	-2211.
25	19	0.09	-1829.9	110.979	1451.55	-1809.62	212.438	1157.59	-2094.38	223.704	1132.06	-2146.88	206.955	1174.64	-2211.0

Trimmed_2017Oct2... Sum :0

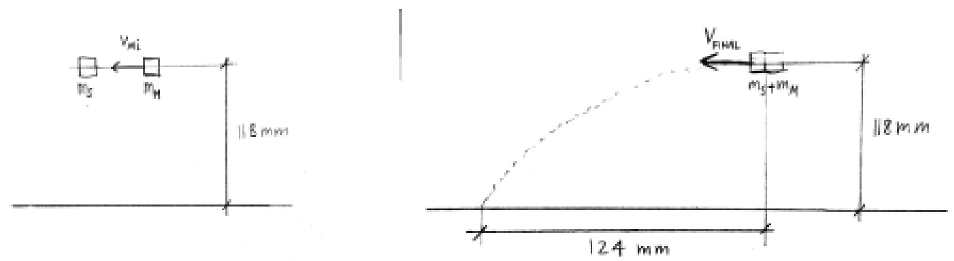
Figure A.1. Excerpt of kinematic data providing XYZ real time position relative to time and frame number of the cameras.

Appendix B

Below is a sample paper of one of the groups of students participating in this project. This group received an A for their project.

Problem:
Two drones are free to move in a vertical plane and are on a collision course. Drone 'S' has a mass of 20g and is *stationary* while drone 'M' has a mass of 28g and an initial velocity of v_{MI}. Then BAM they collide! Miraculously, their blades bind creating a perfectly plastic collision. After impact the drones fall 0.118 meters to the ground and travel 0.124 meters horizontally.

Find: v_{FINAL} (velocity of drones after impact), v_{MI} (the initial velocity of the moving drone).



Assumptions:
Collision is perfectly plastic (e = 0)
Air resistance is negligible
At impact, both drones turn off. (no additional aerodynamic forces after impact)
Initial velocities have no y component

Solution:
Given: m_S = 20g, m_M = 28g, v_{SI} = 0, Δh = 0.118m, Δx = 0.124m, e = 0

Find: v_{FINAL}, v_{MI}

Solve:
$\Delta y = \frac{1}{2}at^2$
$0.118 = 0.5 * 9.8 * (t^2)$
t=0.155 s
$v_{FINAL} = \Delta x/t$
$v_{FINAL} = 0.124 / 0.155$
$\mathbf{v_{FINAL} = 0.8}$ **m/s**

$m_m v_m + m_s v_s = v_{FINAL} * (m_s + m_m)$
$(0.028 * v_1) + (0.02 * 0) = 0.8 * (0.02 + 0.028)$
$v_m = 0.8 * (0.02 + 0.028) / 0.028$
$\mathbf{v_m = 1.371}$ **m/s**
% Error v_m= (1.371 - 1.342) / 1.371 = 2.11% error
% Error Δx= (0.124 - 0.234) / 0.124 = 88.7% error (due to thrust after impact)

Error Analysis:
When we executed this problem in the lab the initial velocities, masses, and collision height were the same as stated in the problem. Unlike the problem statement, the blades did not shut off after impact, which created an acceleration after the impact of the two quadcopters. This effect can be seen in the velocity graph shown in Figure 1. After impact, the velocity of the quadcopters continues to increase. The increase in velocity led to a horizontal displacement greater than 0.118 meters. The actual horizontal displacement was 0.234 meters.

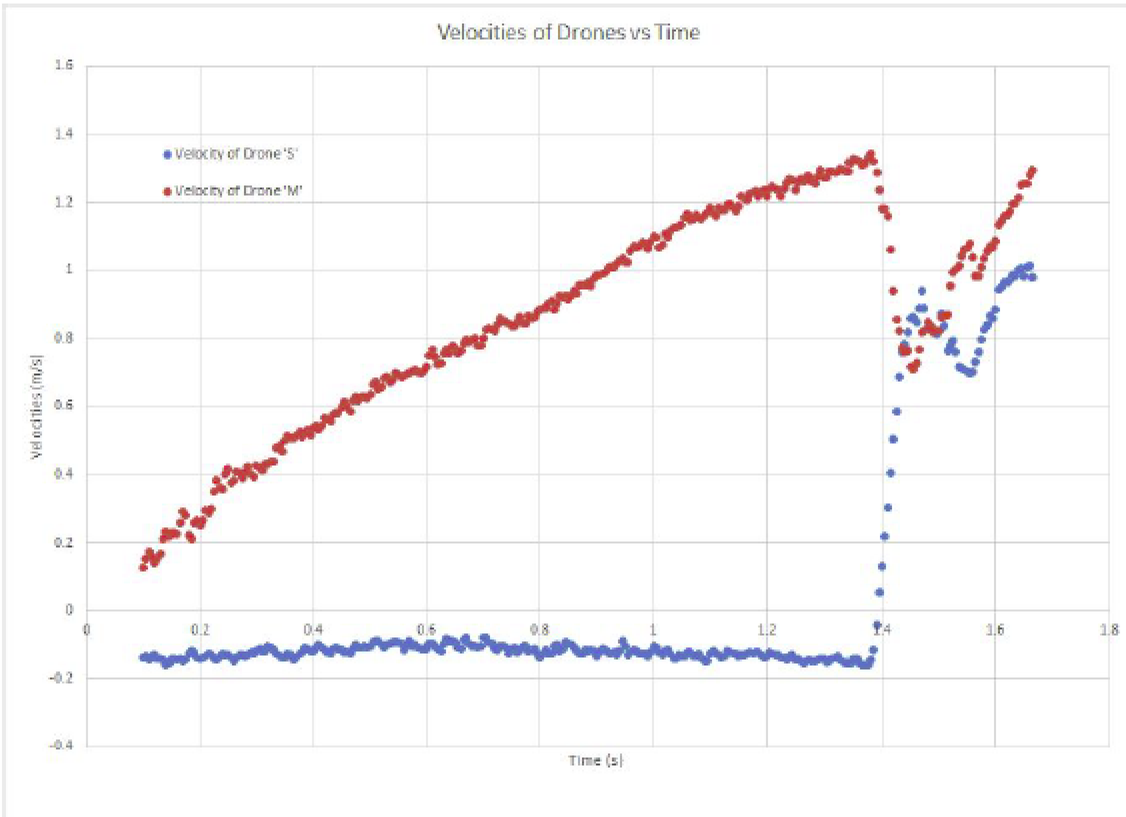


Figure 1: Velocity of drones vs. Time

Raw Data Calculations:

Table 1: X positions and Velocities vs Time (near Impact)

Time	X2(stationary)	X1(moving)	V(stationary)	V(Moving)
1.255	-1056.12878	-1291.42419	-0.141691	1.257717556
1.26	-1056.41833	-1286.11743	-0.147212556	1.268420444
1.265	-1057.94751	-1279.27173	-0.155847111	1.262155444
1.27	-1057.86279	-1273.40051	-0.149058667	1.277890333