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Extending Scope of Atwood's Machine Experiment through Motion sensors

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Abstract - Newton's laws of motion are the basis for most of advanced concepts of physics and engineering. Several misconceptions about various advance concepts in these fields originate in misunderstandings of these basic laws of motion. The setup describes an interactive experiment designed to visually explain these concepts through the basic laboratory setup for Atwood's' machine.The experiment can be improvised to measure the effect of viscosity or resistance to body movement in medium.

Keywords - Atwood's' machine, Newton's Laws, frictional force, excess mass.

I. Introduction

The experiment to study the kinematics of Atwood's machine using microcontroller based laboratory is done by considering the mass and friction of the pulley-system. Given the distance between the sensors the counter provides a way to measure velocity and acceleration with time also plots the corresponding kinematics graphs in real-time with high accuracy The effect of mass and friction of pulley-system on the measured acceleration of the system can be studied accurately, by taking large number of readings in short time. This helps students to improve their conceptual knowledge of kinematics [2.4]. Since the time is measured with the least count of 10µs, the precision in the measurement of acceleration is up to three decimal places is obtained in this set setup, which makes it suitable for studying much faster motion like free fall motion with great precision [1]. This setup can also be used to study free fall motion, motion along inclined plane, and motion of bodies through a viscous medium to study drag and terminal velocity.

The advantage of graphically visualizing the kinematical variables simultaneously was found to be extremely helpful in understanding kinematics of the experiment [3]. This practice enables students to enhance their skills in modern technologies and on the other hand, to acquire a in-depth understanding of the physical process under investigation. We can use multiple parallel arrays of sensors to study motion in three dimensions also. However, we think that the proposed experiment constitutes a useful and relevant educational activity, since it can improve students' skills in modern technologies.

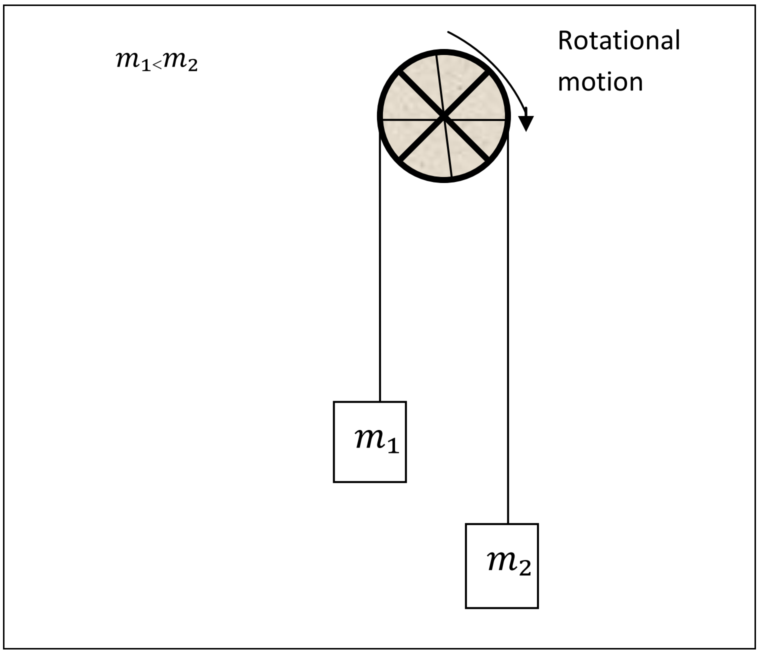

Figure 1: Atwood's machine

Atwood's machine is an illustration of the application of Newton's second law of motion.The acceleration of a system for a single strand of inextensible string and a relatively light pulley system to a good assumption as stated by Newton's 2nd Law of motion is directly proportional to the applied net force F_{net} and inversely proportional to the mass of the system (m_1 + m_2) ,

$$a = \frac{F_{net\ assumed}}{M_{total\ assumed}} = g\frac{m_2 - m_1}{m_1 + m_2}$$

One of the main assumptions of theoretical analysis of Atwood's machine is that the pulley-system has no significant mass and that its motion has no effect on the measured acceleration of the system. But the pulley moves together with the hanging masses and is thus also part of "the system. For this "extra mass," let's introduce a term m′ to the total mass of the system, thus the total mass is:

$$M_{\substack{\text{total}\\ \text{actual}}} = m_1 + m_2 + m'$$

A small amount of friction in pulley may drag the pulley. The presence of any frictional force between pulley and the string will reduce the net force. Thus the net force becomes

$$F_{\substack{\text{net}\\ \text{actual}}} = F_{\substack{\text{net}\\ \text{assumed}}} - f'$$
$$= (m_1 g - m_2 g) - f'$$

The experimentally measured acceleration must include all effects of excess mass and friction. Let's say that the measured acceleration for each run is actually given by

$$a = \frac{F_{\substack{\text{net}\\ \text{aasumed}}} - f'}{M_{\substack{\text{total}\\ \text{assumed}}} + m'}$$

Rearranging this equation, $F_{\text{net assumed}} - (M_{\text{total assumed}})\,a = m'a + f'$ where m' and f' are the unknowns. The graph of $F_{\text{net assumed}} - (M_{\text{total assumed}})a$ versus $m'a + f'$ is straight line with m' as slope and f' as y intercept [6].

II. Finding acceleration due to gravity by Atwood machine

Two unequal masses, connected by a mass less thread, are draped over a pulley, as shown in the Figure 1. When the larger mass is released by the electromagnet after pressing start button on the screen, it accelerates downward and the smaller one accelerates upward. The arrangement is made in such a way that the larger mass passes through the IR transmitter and receiver system arranged for the experiment with distance between sensors slightly changed. The MBL based instrumental experiment setup is described in the authors paper [5].Real time data from falling mass have been recorded using the motion detector. In this experiment a mass m_1 on one side of string with a pin attached to it is allowed to fall through an array of transmitter and receiver using a magnetic coil to ensure exact line of fall. The sensor pairs are arranged vertically a magnetic coil is used to release the mass. The pin attached to the mass passes through the each pair of sensors. As soon as the pin crosses the first IR sensor pair, the microcontroller starts internal counter and this point is the first coordinate of this experiment. The system stores the elapse time as the pin passes the second sensor pair and calculates the time between each consecutive pair. This time, along with the distance between the sensor pair generates a second data point. The distances between the sensors pairs and measured time intervals, the system generates data points for displacement-time graph, velocity v/s time, and acceleration v/s time. As the motion of falling objects is the example of motion with constant acceleration, this average velocity is assigned to "mid time" of the interval between two sensors pairs. In this manner seven data points for velocity-time graph are generated.

Since the velocity is in downward direction and the object is speeding up, the acceleration is also downward and negative. The data for speed and acceleration with time interval between two successive sensors with the position of each sensor can be exported to MS excel.

The data was collected in the excel file to calculate the value of 'g'. Multiple observations were made using four different set of masses.

Table 1
Data obtained from the counter for distance, velocity and acceleration for Atwood

machine for m_1= 109.173 gm and m_2 = 50 gm.

Position of sensor	Time(s)	S (m)	t_{mid}	Velocity m/s	Acceleration m/s^2
8	0				
			0.07014	-0.75207	
7	0.14028	-0.4219			-3.45943
			0.16534	-1.0814	
6	0.1904	-0.3164			-3.60126
			0.21061	-1.24443	
5	0.23082	-0.2622			-3.63646
			0.249955	-1.38751	
4	0.26909	-0.2119			-3.64268
			0.28645	-1.52045	
3	0.30381	-0.1588			-3.69403
			0.31984	-1.64379	
2	0.33587	-0.106			-3.62524
			0.351025	-1.75685	
1	0.36618	-0.0533			

Table 2

Data obtained from the motion detector for acceleration for Atwood machine

Trial	m_1 (g)	m_2 (g)	Theoretical Acceleration m/s²	Experimental Acceleration m/s²	$F_{net-asumed}$ $(m_1-m_2)g$	$M_{total}a$ $(m_1+m_2)a$	Acceleration a m/s^2	$F_{net-assumed}- M_{totalassumed}a$
1	200	50	-5.868	-5.84404	1.47	1.461011	5.844045	0.008989
2	109.17	50	-3.64318	-3.60985	0.579895	0.57459	3.609847	0.005305
3	56.8	50	-0.62397	-0.62034	0.06664	0.066253	0.620344	0.000387
4	54.813	50	-0.44994	-0.44875	0.047167	0.047035	0.448753	0.000132

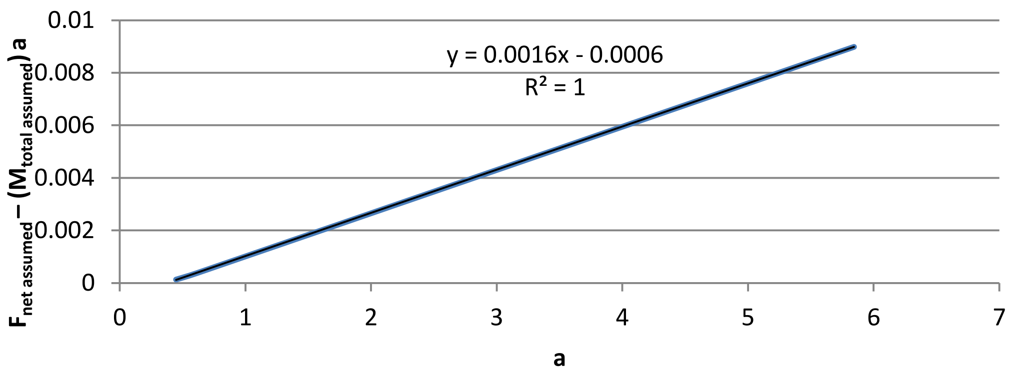

Figure 2: The graph of $F_{net\ assumed} – (M_{total\ assumed})a$ versus acceleration

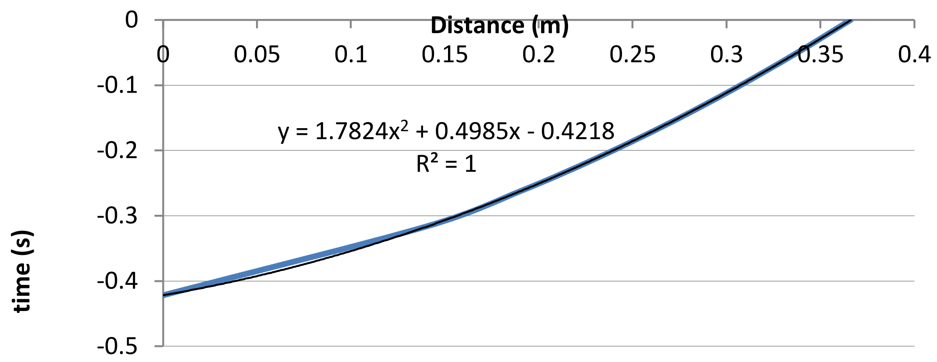

Figure 3: Displacement vs. time graph for Atwood machine

The graph of $F_{net\ assumed} - (M_{total\ assumed})a$ versus acceleration shows that the slope graph is 0.001 which means the excess mass of pully-system is 0.001 kg and the friction is negligibly small.

III. Advantages of Proposed method

Object is released electronically thus maintaining height of release and the path of fall, this allows us to take multiple readings as the distance between sensors and the point of release is kept same throughout.

1) The experiment can be performed repeatedly once the setup is ready. The change in motion parameters can be visualized and studied.

2) We can increase the number of sensors and distance between the sensors to reduce the experimental error.

3) The response time is 1000 times higher than LDR.

4) The time resolution is 10 μs.

5) The system can measure excess mass as well as friction between the thread and the pulley.

IV. Discussion and conclusion

We have performed experiment on the Atwood's machine, to validate the accuracy of the MBL system we have designed. The advantage of graphically visualizing the displacement, velocity and acceleration graphs instantaneously was found to be extremely helpful by students to understand kinematics of the experiment. Performing the experiments repeatedly in short time students could intuitively understand the concept of slope (differentiation) and area under the curve (integration). An overview of current literatures shows us that the methodology adopted by us has distinct advantage of fast, accurate and simultaneous graphical representation of motionvariables. The benefit of this approach is that it can be adopted to study any mechanical motion including oscillation.

V. References

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