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# Simultaneous Real time Graphical Representation of Kinematic Variables Using microcontroller based Event counter – an MBL Experiment for Classrooms

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**Abstract:** *This study introduces an MBL (Microcomputer based laboratory) experiment which can be used to study motion along a trajectory. IR Sensors placed in the path of motion collect experimental data which is used in a software program to calculate accurately the displacement, velocity and acceleration as a function of time. There is a real time graphical representation of motion parameters like displacement, velocity and acceleration as a function of time. This was used to explain motion qualitatively as well as quantitatively to the students. The accuracy of the method was established through its ability to correctly measure the values of the acceleration due to gravity 'g'.*

## I. Introduction

Experimental activity plays a crucial role in understanding the concepts of physics. Many researchers have stressed the importance of incorporating laboratory activities for increasing students' interest in physics and to create connections between science knowledge and everyday world experiences [1]. The MBL context gives students more opportunity to explore and learn through investigations. The main educational advantages of a MBL is the possibility to collect physical experimental data in real-time and that data are immediately available for analysis and presentation [2-3]. Because data are quickly taken and displayed, students can easily examine the consequences of a large number of changes in experimental conditions during a short period of time. The MBL context adds capacity and flexibility that, to be exploited requires the lab to be re-conceptualized, giving students more opportunity to explore and learn through investigations. MBL experiments develop and improve graph analysis and interpretive skills of the students [4]. However, simultaneous graphical representation helps students retain the interpretive results in their long term memory due to the graphical nature and the simultaneity of results charting and attention to the salient features of the graphs [5].

We have designed a microcomputer based interface to study motion of an object. In the present study this interface is used to study the experiment on free fall. These experiments are a part of every school and undergraduate physics curriculum. Most of the experiments designed in last two decades to study free fall are based on measurement of time of fall with the help of electronic circuitry capable of measuring time accurately in milliseconds in the laboratory condition [6]. These experiments are based on a maximum of two readings for calculation of acceleration due to gravity g, the position of release is taken as s=0 and the velocity at this position is considered as zero. This introduces error in the value of g due to error in the measurement of initial velocity which is measured at the position of first sensor. The MBL methodology proposed in this study provides time with the least count of 0.01 ms, real time measurements from multiple sensors which are plotted in real time through the sensor – computer interface for immediate presentation. This offers an ideal alternative to traditional lab methods. A large number of readings are taken for accurate results at multiple points in the path of the motion.

The accuracy and validity of the apparatus designed was tested through the experiment to determine the value of the acceleration due to gravity 'g' in free fall experiment. Once the validity is established, the set-up can be used to teach principles of motion and the change in motion parameters throughout the motion. Complex motion and various trajectories can be studied by placing sensors along the trajectory. This can lead to reinforcement of intuitive understanding of motion parameters through graphical real time illustrations where the experiments can be repeated many times easily. The reasons for the effectiveness of MBLs are multimodal reinforcement, real-time linking of concrete and abstract, meaningful context, and elimination of drudgery [7]. When students are in control of a learning experience that they design, are given real-time feedback about that experience, and are freed from the painstaking task of producing a graph, they are in an ideal position to learn what a graph says and means. The computer analysis helps us to understand the variation not only of the displacement of the body, which is experimentally possible to determine, but also of other physical quantities like velocity and acceleration as a function of time [8].

## II. Experiment with freely falling body

A free-falling object is an object that is falling under the sole influence of gravity. Such an object will experience a downward acceleration of 9.8 $m/s^2$. Like any moving object, the motion of an object in free fall can be described by kinematic equations [9].

$$S=S_0 + v_o t + \frac{1}{2}gt^2 \quad (1)$$

$$v_f = v_o + gt \quad (2)$$

$$v_f^2 = v_o^2 + 2gS \quad (3)$$

The vertical position is given by S, with respect to time, t, where $S_0$ is the initial vertical position, $v_0$ is the initial velocity and g is the acceleration due to gravity. Equation (1) yields a quadratic curve for the position vs. time. The relationship between velocity and time can be plotted as a straight line with a slope, g and a y-intercept of $v_0$. The equation (3) is found by eliminating t from the first two equations.

Since 'g' is constant, its value at any instant will be the same as the *average acceleration* over any time interval. If we have a set of data showing the position of an object over small time intervals, we can find average velocity using equation

$$\bar{v} = \frac{\Delta S}{\Delta t} = \frac{S_2 - S_1}{t_2 - t_1} \quad (4)$$

where $s_2$ and $s_1$ are the positions of the object at the beginning and the end of the time interval $\Delta t = t_2 - t_1$. We also make use of the fact that, for constant acceleration, the *instantaneous* velocity at the midpoint of the time interval is equal to the *average* velocity over the time interval. That is,

$$v_{midpoint} = v\left(\frac{t_1 + t_2}{2}\right) = \bar{v}$$

Thus the position-time data allows us to calculate the velocity at selected times, which in turn can be used to calculate the acceleration. The average acceleration is defined as

$$\bar{a} = \frac{\Delta v}{\Delta t}.$$

An advantage of this solution is that one can easily adopt it to study any mechanical motion including scillation. Also, one can evaluate those physical quantities which are difficult to measure experimentally.

Real time data from freely falling body have been recorded using the event counter. In this experiment a small solid rubber ball, with small iron pin embedded in it, is dropped using a magnetic coil to ensure exact line of fall. The sensor pairs are arranged vertically using a plumb line and the sensors are numbered from 8 to 1, from up to down. The magnetic coil was positioned above the $8^{th}$ sensor at certain distance in such a way that when ball is dropped, it passes through each pair of sensors. The origin is placed at the position of sensor pair 1 and defined upward direction as positive. As soon as the ball crosses the $8^{th}$ IR sensor pair, the microcontroller starts internal counter and this point is the (8, 0) coordinate of this experiment. The system stores the elapse time as the ball passes the second sensor pair and calculates the time between $8^{th}$ and $7^{th}$ pair. This time, along with the distance between the sensor pair generates a second data point. In this manner time taken by the ball to pass through each consecutive sensor pairs is stored in the system as it falls through the aligned sensors. With distances between corresponding sensors pairs and measured time intervals, the system generates eight data points for displacement-time graph. Using these data points the software generates three graphs viz. displacement v/s time, velocity v/s time, and acceleration v/s time. The average velocity between two consecutive sensors pairs is calculated using the relation $V_{avg} = \Delta S/\Delta t$. 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. From the data for velocity-time graph, average acceleration due to gravity 'g' is calculated using the relation $g = \Delta v/\Delta t$. Since the velocity is downward and the object is speeding up, the vertical acceleration is also downward (in the negative direction). The data for time, velocity and acceleration with the position of each sensor can be exported to MS excel.

## III. Microcontroller Based Event Counter

We have designed a microcontroller based interface to study motion of an object. For this purpose we have designed a circuit with LCP2148 microcontroller, TSOP1738 sensors, astable multivibrator and interfaced with computer. The circuit measures time intervals between successive sensors when object passes through the array of sensors. In the present study this interface is used to study the experiment on free fall. The MBL methodology proposed in this study provides time with the least count of 10 µs, real time measurements from multiple sensors which are plotted in real time through the sensor – computer interface for immediate presentation. This offers an ideal alternative / complement to traditional lab methods. A large number of readings are taken for accurate results at multiple points in the path of the motion.

The event counter circuit is built with 32-bit microcontroller LPC2148 (Phillips), Astable multivibrator using IC 555, Infrared (IR) transmitter- receiver array, 2 input 'OR' gate IC's, 16 × 2 character LCD, , DIP switch, 3.3 volt Zener diode, LEDs, Resistors, general purpose NPN transistors, Magnetic coil, 12 volts DC power supply. The block diagram is shown in Fig. 1. The heart of the circuit is LPC 2148 microcontroller based on 32-bit ARM7TDMI-S CPU with real-time emulation and with embedded on-chip static RAM and high speed flash memory of 512 KB. The ARM7TDMI-S is a general purpose 32-bit microprocessor, which offers high-performance and very low power consumption [10-12].

Combination of all above components as per the circuit diagram makes the fully functional system. Here after 'system' refers whole circuit including LPC2148 and all other components. The circuit is interfaced with computer with serial port (or USB to serial convertor).

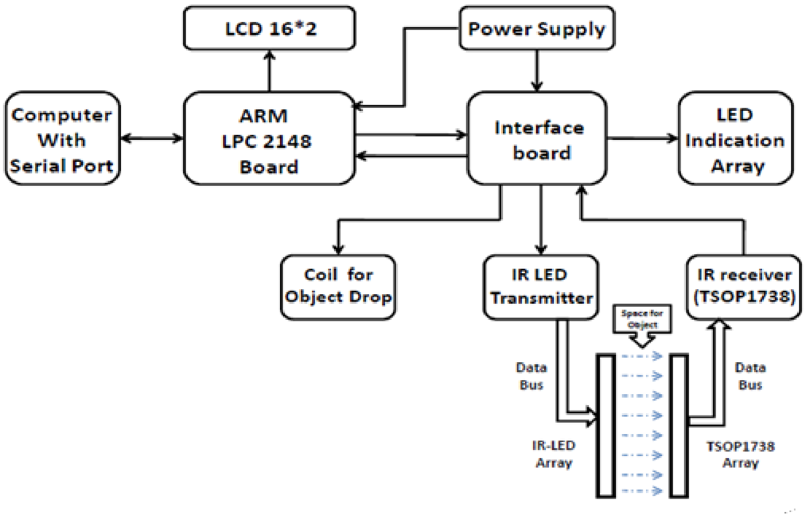


**Fig.1 Block diagram of event counter circuit.**

For detection of moving object we have used standard IR transmitters and IR receivers. In this circuit TSOP1738 IR receiver module is used. For this module the incident light must have data format which is square wave with frequency 38 KHz [13,14]. IR transmitter with 38 KHz frequency has been designed using 555 Timer IC in astable multivibrator mode as shown in Fig. 2. The output of astable multivibrator is square wave with ~63.20% duty cycle [15]. The output of the astable multivibrator is directly connected to the eight numbers of 3 mm Infrared LED's in parallel to create eight different IR sources. All IR transmitters could be fixed on board along the trajectory of motion with separation as desired. On the other side, eight numbers of IR receivers are arranged exactly in front of the IR transmitter pair wise. An array of IR transmitter-receiver pair is arranged in such way that emitted light from IR LED should fall on the IR receiver. The output of TSOP1738 sensor is interfaced with ARM LPC2148 microcontroller by using two resisters (10KΩ and 300Ω) and one capacitor (4.7µf) in parallel with output and ground. One more 3.3 volt Zener Diode connected in parallel with capacitor to regulate output voltage up to 3.3v Volt which protects microcontroller from unwanted voltage spice. Eight outputs from all receivers are connected to the microcontroller directly. All sensor's output are 'OR' by using OR logic gate IC7432.

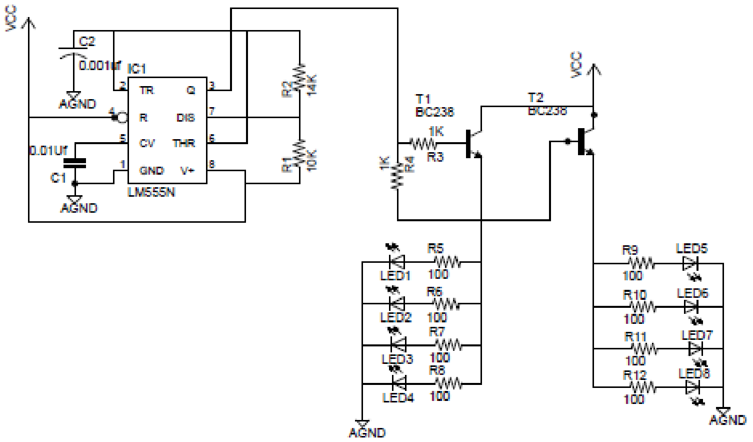


**Figure 2. Astable multivibrator with 1 IR Transmitters**

When IR light fall on the TSOP, it gives ‘0’ output. But, when light is blocked by object, receiver changes the output state from ‘0’ to ’1’. The output state of receiver changes with respect to object position. When object cut the IR ray then output of 8-input ‘OR’ gate is ‘HIGH’ and serves as interrupt for LPC2148. This sequence happens every time when object cut the IR ray. To monitor and record every output change and generate an interrupt we need one ‘OR’ gate having eight inputs - One output. Cascading of eight inputs - one output OR gate is done with 8 number of two input - one output OR gate IC 7432. The high priority external interrupt initialize the 16 bit timers to calculate time between two successive receivers. When this occurs, current counter value in the timer variable is sent through serial port to PC with corresponding sensor number. The time measurement least count is around 10 µs and it can be improved by using high frequency (40 MHz) crystal in PLL mode.

The software is designed using C to collect sensor data to compute speed and acceleration using distance between the sensors and plots them on the screen as the function of time. The sensor alignment should be perfect and all sensors need to be checked for sending data. The software checks these conditions as well. The screenshot of software window is shown in Fig. 3.

When IR sensor array and IR LED array properly mounted and distance between successive sensors is measured, we can switch on the ‘system’. There is an indicator LED in the system which confirms if the IR sensors and receivers are aligned perfectly by giving welcome message on the LCD screen. An indicator LED array is provided on board, where each LED represents unique sensor pair, to check if selected number of sensors is working or not using. When the pair is not working, the corresponding LED does not glow. The distance between successive sensors is entered in the software allows and software takes that distances when we click on **“Set Distance”** button. Once the sensor alignment is perfect we can select the sensor as per requirement using “**Up**” and “**Down**” buttons on the screen. When number of sensors is fixed then reset the system using reset switch and press “**Set**” button. Then circuit will check if selected number of sensors are working or not using LED array where each LED represent unique sensor pair. One by one all LED ON and again OFF in reverse order. If all sensors are properly aligned, the LCD shows the message 'Ready **to Use**'.

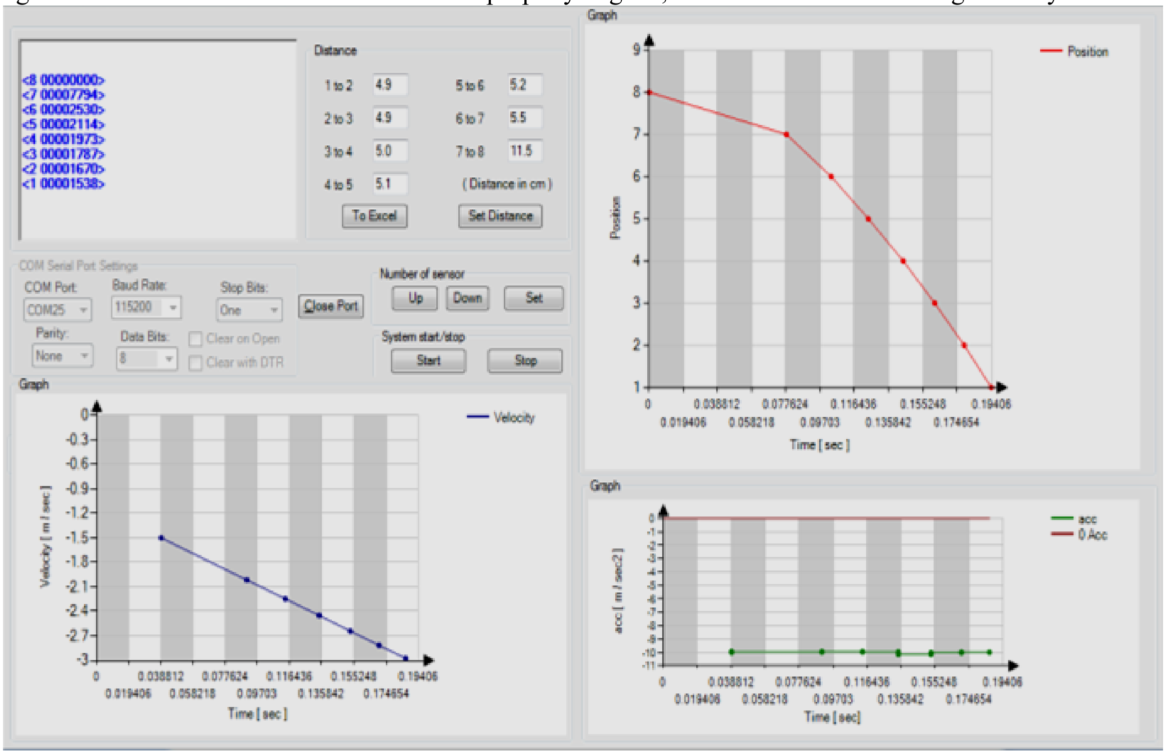


**Fig. 3 Screenshot of the software**

Observations are recorded when an object passes in between the array of sensor pairs. The system stores the counter's count as the object passes the second sensor pair and calculates the time between first and second sensor pair. This time with the distance between the first and second sensor pair generates second data point. In this manner time taken by the object o pass through each consecutive sensor pairs is stored in the system as it passes through the aligned sensors and with distance between corresponding sensors pairs stored in the system generates eight data points for displacement-time graph. Using these data points the software generates three graphs viz. Displacement v/s time, Velocity v/s time, and Acceleration v/s time. The average velocity between two consecutive sensors pairs is calculated using the relation $V_{avg} = \Delta S/\Delta t$. The object can be moved either in forward or backward direction across the sensors. The time between two sensors is measured with resolution of 0.00001 seconds (10 µs) which ensures the final result is accurate to three significant figures [16].

## IV. Results and Discussion

The experiment is repeated at least 25-30 times for each height of magnetic coil above 8$^{th}$ sensor. Table 1 shows the results obtained in one of such sets for rubber ball dropped from the height of 17 cm above first sensor pair.

**Table 1. The data obtained from the software for total fall distance 0.6 m.**

| Sensor | T | S (m) | $t_{mid}$ | v (m/s) | a (m/s$^2$) |
|---|---|---|---|---|---|
| **8** | 0 | 0.421 | - | - | - |
| | | - | 0.02745 | -2.09472 | - |
| **7** | 0.0549 | 0.306 | | | -9.77344 |
| | | - | 0.06593 | -2.4708 | - |
| **6** | 0.07716 | 0.251 | | | -9.78681 |
| | | - | 0.086925 | -2.67627 | - |
| **5** | 0.09659 | 0.199 | | | -9.80234 |
| | | - | 0.10554 | -2.85874 | - |
| **4** | 0.11443 | 0.148 | | | -9.76672 |
| | | - | 0.12273 | -3.02663 | - |
| **3** | 0.13095 | 0.098 | | | -9.77019 |
| | | - | 0.138825 | -3.18389 | - |
| **2** | 0.14634 | 0.049 | | | -9.80306 |
| | | - | 0.15407 | -3.33333 | - |
| **1** | 0.16104 | 0 | | | |

The displacement-time graph is a parabola as shown in the Fig 4. The data points were fit to the second order polynomial to calculate the value of 'g'. The average velocity-time graph is shown in Fig. 5.

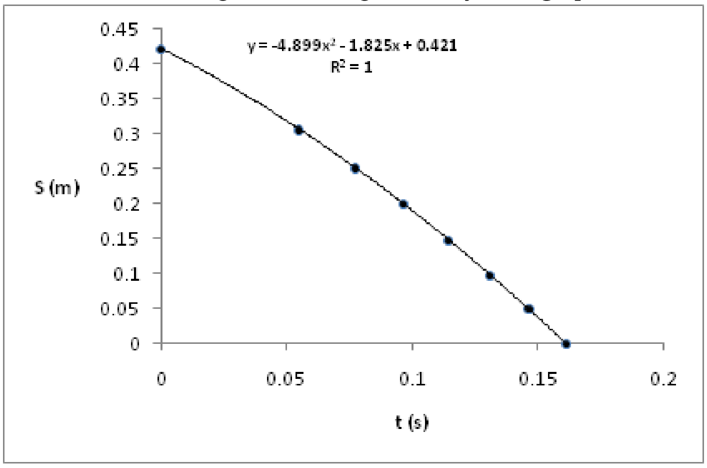


**Fig.4 Distance S verses time t graph**

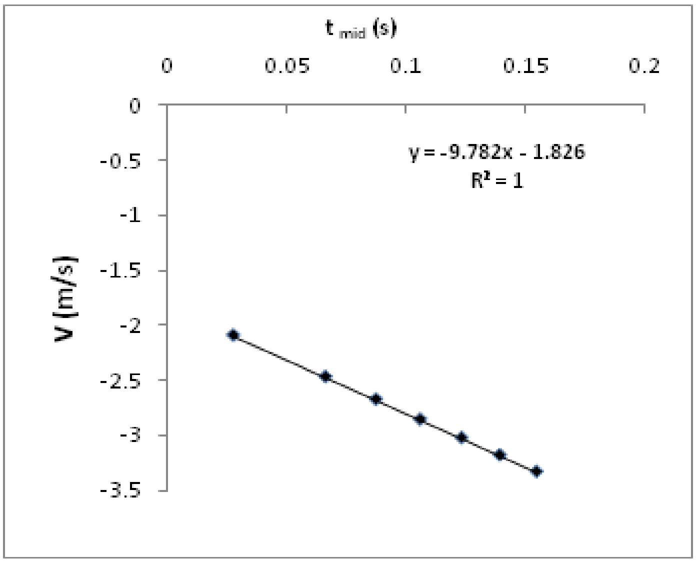


**Fig. 5 Velocity time graph**

The value of g as calculated from fig 2 is 9.782 m/s$^2$, which is very close to the value of 'g' in Pune, India. Observations for different heights H of point of release from the first sensor pair are given in Table 2.

**Table 2: Accelerations for different fall heights from 8$^{th}$ sensor**

**(V**alue of 'g' in Pune, India: - Latitude18.6186°N, Longitude73.8037° E is 9.78076 m/s²**)**

| H (m) | $v_o$ (m/s) | g (m/s$^2$) |
|---|---|---|
| 0.17 | 1.824 | 9.789 |
| 0.25 | 2.192 | 9.787 |
| 0.37 | 2.694 | 9.785 |
| 0.51 | 3.145 | 9.788 |

In this experiment, the object is released electronically, thus maintaining height of release and the path of fall. This allows taking multiple readings as the distance between the point of release and subsequent sensors remains same throughout the set. A large number of readings can be taken in short time once the experimental arrangement is done. An error was observed to be small because the time is not measured from point of release but from passage across the first sensor where the body has a nonzero velocity by the time. The change in motion parameters like displacement, velocity and acceleration can visualized and studied. The interfaced circuit has facility to increase the number of sensors and distance between the sensors to reduce the experimental error. The experiment can be done in normal ambient light. The system can detect small objects which is not possible with LDR. It has better response time than LDR. The time resolution is 10 microseconds and distance resolution is around 01mm. Real-time graphical representation help in better understanding of kinematics graphs. The distance between Transmitter and Receiver can extendable up to few meters. Since analog to digital conversion not required the system is faster.

## V. Discussion and conclusion:

We have performed the experiment on free fall to validate the accuracy of the MBL system we have designed. The system accurately measures the kinematic motion and predicts the resultant value of 'g'. The experimental errors are very minimal and the apparatus enables multiple readings in a very short time. The advantage of graphically visualizing the displacement, velocity and acceleration of the object in real-time was found to be extremely helpful by students to understand kinematics of the experiment. Over a large number of experiments the 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 graphical representation of kinematic quantities. This methodology does not depend on the kinematic equation $S= ut +1/2\ gt^2$. Hence the error in the value of initial velocity at the position of first sensor is not present. The experimental setup can also be used to study motion of bodies through a viscous medium to study drag and terminal velocity or to find viscosity of liquids.

The accurate performance and validity of the experimental setup is proven by the ease of experimentation, availability of simultaneous charting of results and ability to take multiple readings on very short duration. We believe that such a setup will be very helpful to the students

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