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# Measurement of Kinetic Friction Coefficient using an Arduino

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**ABSTRACT:** In this paper, a simple experiment is proposed to determine the kinetic friction coefficient between two systems using an Arduino UNO board. The experimental setup consists of an Arduino Uno, an HC-SR04 ultrasonic distance sensor and a rectangular wooden body which moves on top of an inclined rectangular wooden flat surface. Initially, the acceleration of the moving body is determined from the Displacement-Time curve. The magnitude of the kinetic friction coefficient is then calculated from Newton's second law.

**KEYWORDS:** Arduino, physics education, friction, STEM

## I. INTRODUCTION

The Arduino UNO is a low-cost, 8-bit microcontroller board that using various sensors becomes a multi-tool for collecting, processing and visualizing data from the physical world [1]. They are generally affordable and reliable, with low power consumption and small size [2]. Therefore, numerous physics experiments and applications have been implemented and published so far [3-8]. The intervention of microcontrollers in education supports learning achievements in an interdisciplinary educational environment (STEM education) [9]. It develops students' skills and abilities, such as critical thinking, scientific and technological literacy, problem-solving, communication, cooperation and creativity [10].

## II. THEORY

The concept of friction is taught at many levels of education and has many applications in everyday life. In general, if two systems are in contact and stationary relative to one another, then the friction between them is called static friction. If two systems are in contact and moving relative to one another, then the friction between them is called kinetic friction. The magnitude of static friction  $f_s$  is (Fig. 1)

$$f_s \leq \mu_s N \quad (1)$$

where  $\mu_s$  is the coefficient of static friction and  $N$  is the magnitude of the normal force. The maximum force for a given  $N$  comes from the equality in Eq.1. When actual relative motion exists between the two systems then Eq. 1 becomes:

$$f = \mu_k N \quad (2)$$

where  $\mu_k < \mu_s$ .

Maximum static-friction force and kinetic friction force are:

- proportional to normal force
- dependent on type and condition of contact surfaces
- independent of contact area

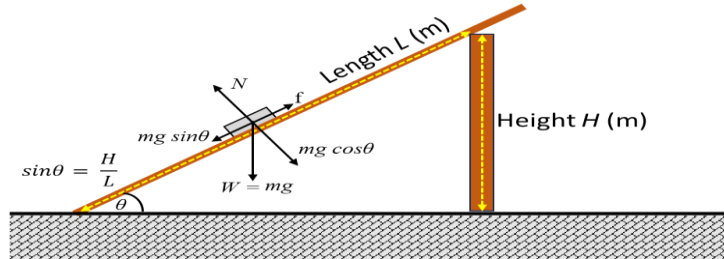


Fig 1. Block of weight  $W=mg$  sliding on a plane with variable inclination angle  $\theta$

With respect to Fig.1 where a block of weight  $W = mg$  slides on the surface of a board, Newton’s 2nd law is written in the form

$$mg\sin\theta - \mu mg\cos\theta = ma \quad (3)$$

If values  $a$  (acceleration) and  $\sin\theta$ ,  $\cos\theta$  are known, the kinetic friction coefficient  $\mu_k$  can be calculated using the equation:

$$\mu_k = \frac{g\sin\theta - a}{g\cos\theta} \quad (4)$$

For a moving object, the equation

$$x = \frac{1}{2}at^2 + v_0 t + x_0 \quad (5)$$

gives the position of the object at any moment. In the simple case, which is studied in the present work, the initial velocity  $v_0$  and initial displacement  $x_0$  equal zero. So, Eq. 5 can be rewritten as

$$x = \frac{1}{2}at^2 \quad (6a)$$

The graphs of Eq. 6 are given in Fig.2. The acceleration  $a$  can be obtained by fitting experimental values of  $x$  and  $t$  to either the nonlinear equation  $x = f(t)$  or the linear equation  $x = g(t^2)$ . However, fitting experimental data to  $x = f(t)$  (Fig.2a) needs solid understanding of non-linear fitting routines (e.g Power law or 2<sup>nd</sup> order polynomial). On the contrary, Fig.2b represents a straight line, which is far easier for younger students to understand and analyze. Utilizing common software like MS-EXCEL {Reference}, Eq. 6b and a graph like Fig.2b, acceleration  $a$  is easily obtained as the slope of the straight line that best fits the experimental data.

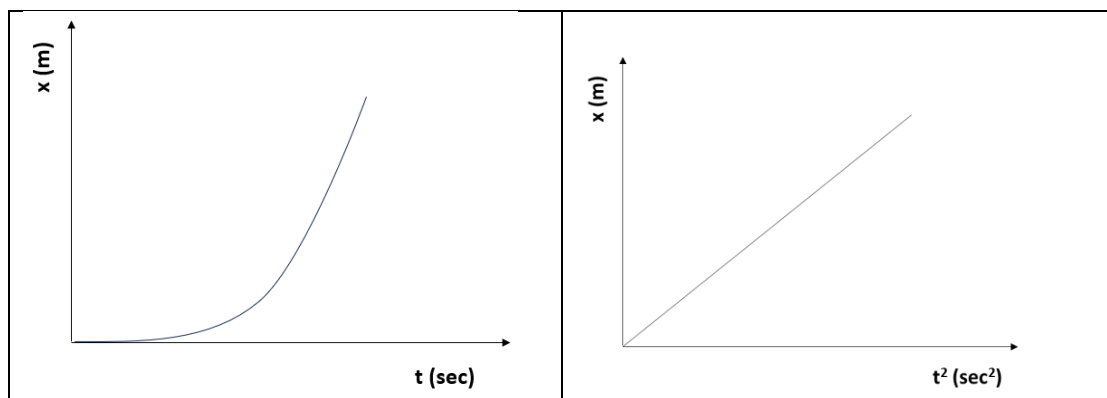
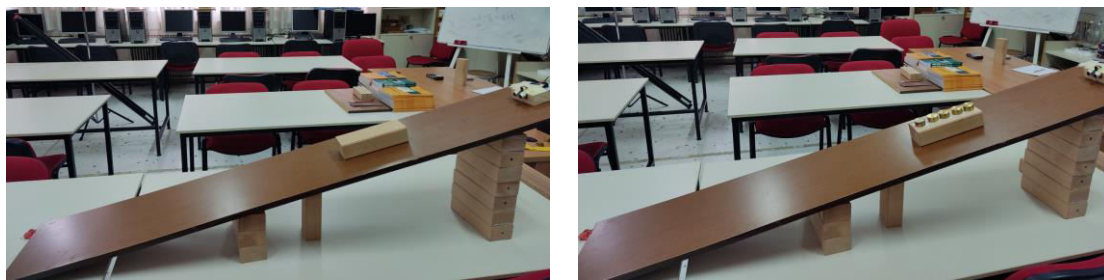


Fig. 2. (a) Plot of Eq.6 in the nonlinear form  $x = f(t)$ . (b) Plot of Eq.6 in the form  $x=g(t^2)$  which is linear when acceleration  $a$  is constant.

### III. THE EXPERIMENTAL SETUP

The experimental setup for this experiment is rather simple. Specifically, an Arduino Uno Rev3 was used with a prototyping shield and a mini breadboard for Arduino. A HC-SR04 ultrasonic distance sensor was mounted on the breadboard while, a rectangular wooden block was left to move on top of a smooth wooden plane. A picture of the experimental setup is given in Figure 3, while a schematic of the Arduino shield and the HC-SR04 sensor (red circle in Fig. 3) is shown in an enlarged view in Figure 4. The corresponding code uploaded to Arduino is listed in Appendix. The body is left free on the inclined plane as shown in Figure 3. The sensor measures the distance travelled ( $x$ ) and the corresponding time ( $t$ ). The  $x-t^2$  graph and equation obtained using these recorded time and position values are shown in figure 5 for a typical run.



(a)

(b)

Fig. 3. The experimental set-up. The moving wooden block has mass  $m_1 = 500\text{gr}$  (a) and  $m_2 = 1000\text{gr}$  (b) for the two runs reported in the present work

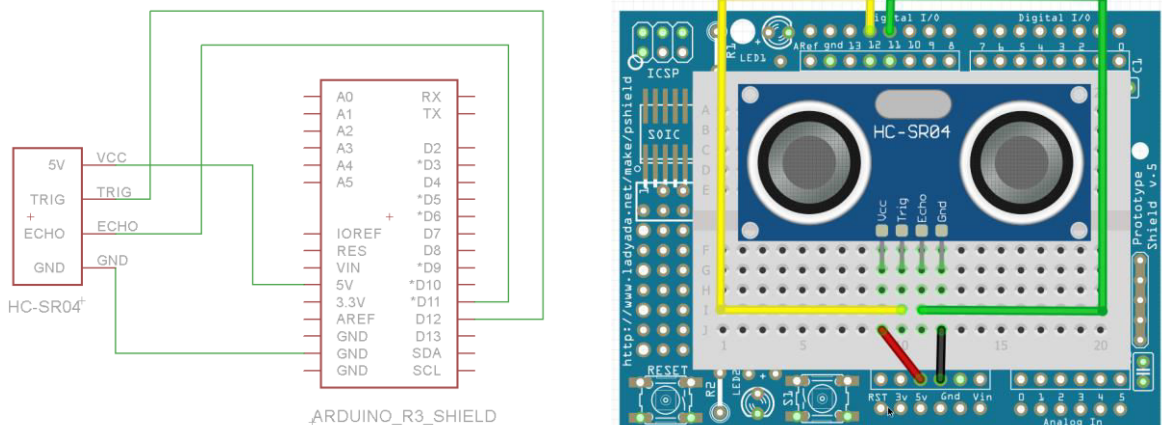


Fig. 4. The circuit board on the Arduino shield used (Schematic created in Fritzing).

### IV. EXPERIMENTAL RESULTS

Experimental data for two runs are shown in Fig.5. Apart from the mass of the wooden block, every other parameter is same in both experiments. In order to ensure that the surface in contact will be identical small metallic masses have been added on top of the moving wooden block to double its mass. In this way, the dimensions of the block remain practically unaltered, and the kinetic friction coefficient is expected to remain the same in both experiments.

Coefficient  $\mu_k$  is obtained from Eq. 4, where the inclination angle  $\theta$  was set at  $\theta = 13.9^\circ$ . It is interesting to note that both plots in Fig 5, are linear beyond the initial 3 points and have the same slope. Therefore, assuming that the gravitational acceleration was  $g = 9.80 \text{ m s}^{-2}$ , the same acceleration value  $a = 0.500 \pm 0.005 \text{ ms}^{-2}$  is obtained leading to a common friction coefficient  $\mu_k = 0.195$ .

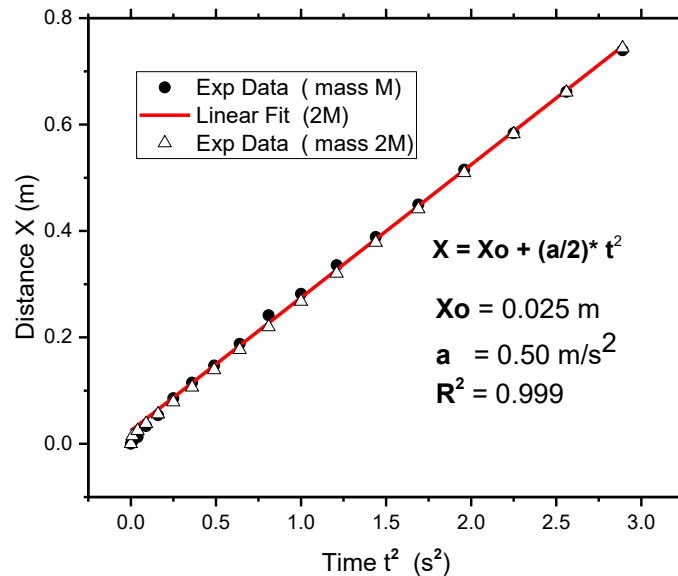


Fig. 5. Experimental  $x-t^2$  data and linear fit for two blocks with  $m_1 = 500\text{gr}$  and  $m_2 = 1000\text{gr}$ . Surface areas in contact, inclination angle  $\theta$  and materials (blocks and incline) are identical.

## V. CONCLUSIONS

This study measured the kinetic friction coefficient of a moving block on top of an inclined flat surface. The experimental set up is based on an Arduino microcontroller and an ultrasonic distance sensor. Data analysis of the corresponding plots confirmed the theoretical context. Additionally, students can use the same software and experimental procedure to measure the kinetic friction coefficient of various surfaces (plastic, wool, glass, paper) or different inclination angles.

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