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The falling chain analysis using kitchen scales

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Abstract

This research aims to develop a falling chain experiment apparatus using kitchen scales and digital cameras (smartphones). Digital cameras were used to observe and record changes in the mass of falling chains measured using kitchen scales. Video recordings from observations of falling chain masses were analysed using Tracker 5.1.1 software. The observations show that the change in chain mass measured by kitchen scales has three main patterns of motion. The first pattern is a linear measurement, where an increase in the mass of a falling chain is measured three times higher than its actual mass. Then, the second is damped oscillation motion when the needle scale oscillates with an amplitude that continues to decrease with time. The damped oscillation movement caused by the use of springs (and air friction) as the primary system of mass measurement, so the kitchen scales need time to show the exact mass measurements (stable pattern). This experiment hopefully makes it easier for the student to understand some of the concepts of physics, especially the concepts of force, object mass, time, kinematics, momentum (impulse), and damped oscillations, through experiments at home, school, or university.

Keywords: falling chain, kitchen scales, smartphone camera, the concept of mass, kinematics, tracker motion analysis

1. Introduction

The development of physics learning media, which aim to help and facilitate the process of abstraction and experiment of physics concepts, has been a concern of many researchers and educators [1]. One of the exciting topics in physics learning through experimentation is the kinematics and dynamics of object motion [1, 2]. Kapucu *et al* developed a speed measurement device (toy car) using a light sensor on a smartphone [3]. Ann-Marie Pendrill and her research group developed children's playground-based kinematics learning media, which aims to bring the topic of physics experiments closer to students [4]. Besides, Nuryadin *et al* developed kinematics learning media using various smartphone sensors to measure the speed of objects, vectors of velocity, and impulse events [2, 5]. However, the development trend in the methodical system in learning physics in future needs to combine several comprehensive experiments in kinematics, such as a falling chain experiment. The falling chain experiment will teach students some of the

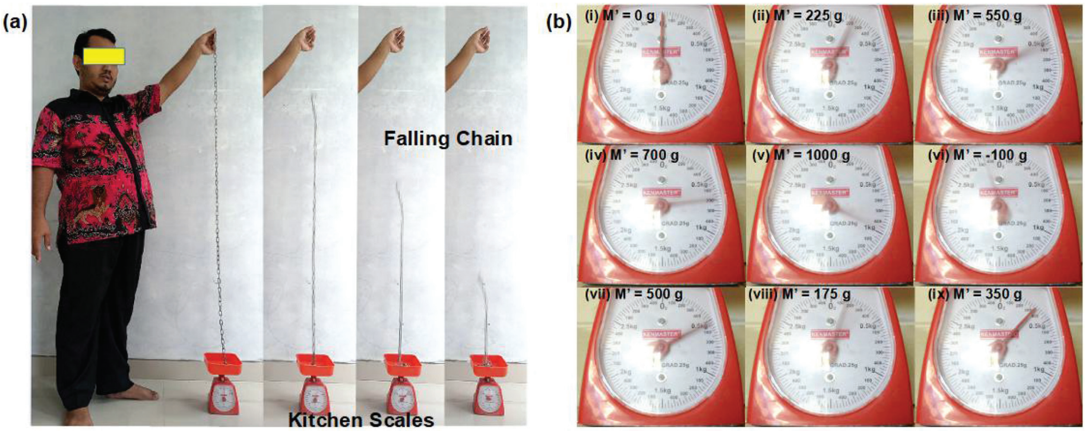

Figure 1. (a) Schematic of the falling chain analysis using kitchen scales and Tracker motion analysis, and (b) measured of chain mass on kitchen scales with linear position (i)–(v), damped oscillation (v)–(ix), and stable position at (x).

main concepts of physics, such as the concepts of force, object mass, time, kinematics, momentum (impulse), and damped oscillations [6–9].

Therefore, this study aims to develop a falling chain experiment apparatus using kitchen scales and digital cameras (smartphones), with the analysis process using Tracker 5.1.1 software. Through this experiment, students will study some of the main concepts of physics, such as the concepts of force, object mass, time, kinematics, momentum (impulse), and damped oscillations; through experiments at home, school, or university.

2. Experimental overview

The density of masses of uniform chain elements is $dm = M/L\,dx$, where dx, M, and L are elements of length, mass, and the total length of the chain. When a chain element falls on the surface of the scale, the scale will feel the resultant force (F_{dx}) due to the gravity (F_{mg}) and the momentum change force (F_{mv}), which is equal to [6, 8]:

$$F_{dx} = F_{mg} + F_{mv} \tag{1}$$

$$F_{dx} = dmg + \frac{dp}{dt} \tag{2}$$

$$F_{dx} = \frac{M}{L}gdx + \frac{d}{dt}(mv) \tag{3}$$

$$F_{dx} \cong \frac{M}{L}gdx + \frac{d}{dt}\left(\frac{M}{L}xv\right) \tag{4}$$

$$F_{dx} \cong \frac{M}{L}gdx + \frac{M}{L}v\frac{dx}{dt} \tag{5}$$

$$F_{dx} \cong \frac{M}{L}gdx + \frac{M}{L}v^2. \tag{6}$$

Also, when a falling chain element moves along a fall, there is a change in potential energy (ΔE_p) to kinetic energy (ΔE_p), then:

$$\Delta E_p = \Delta E_k \tag{7}$$

$$mgdx = \frac{1}{2}mv^2, \text{ or } \quad v^2 = 2gdx. \tag{8}$$

Thus, the resultant force perceived by the kitchen scales is,

$$F_{dx} \cong 3\frac{M}{L}gdx. \tag{9}$$

The apparatus of the falling chain experiment consists of several iron chains with different lengths (50 cm (125 g), 100 cm (225 g) and 150 cm (350 g)), commercial kitchen scales (measuring range 0–3 kg, smallest unit value at 25 g) and digital cameras (smartphone) for

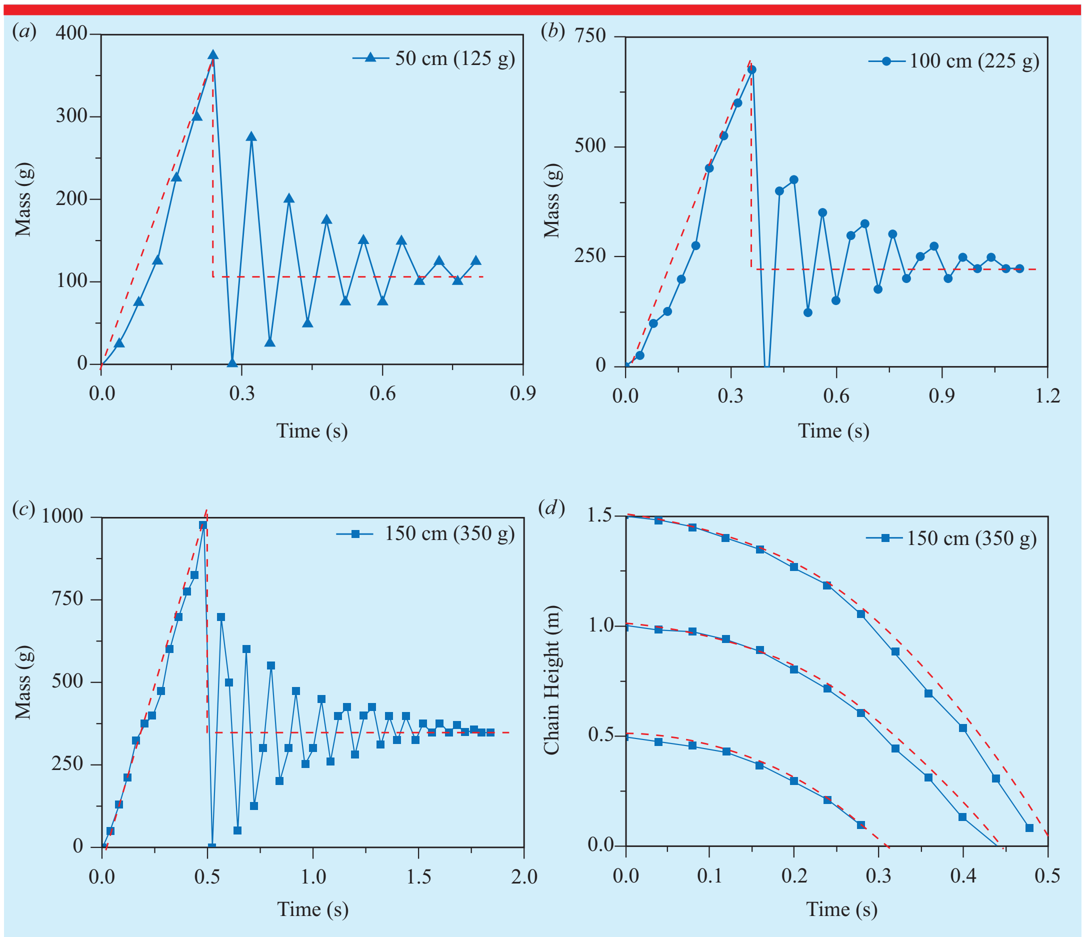

Figure 2. The chain mass vs. time measurement on kitchen scales using video recording, with a length of chain at (a) 150 cm (350 g), (b) 100 cm (225 g), and (c) 50 cm (125 g). Moreover, it also measures the height versus time of the end-tip of the falling chain and free-fall simulation (d).

observing and recording masses from falling chains. All of the apparatus are arranged as in figure 1(a), where the iron chain was hanging above the kitchen scale, and the camera is set a position to video record the measured mass changes on the kitchen scale. The video was processed using Tracker software 5.1.1, by observing the position of the scale needle (mass) of the kitchen scale, as shown in figure 1(b). The chain mass measurement is carried out from the beginning of the fall until the total chain mass is perfectly measured. In general, there are three different patterns of motion in the falling chain, namely: linear pattern (i)–(v), damped oscillation pattern (v)–(ix), and stable pattern ((x), etc). It also conducted measurements and compares the height on the tip of the chain versus time to the falling chain experiment and free-fall simulation. All data processing, charts, and curve analysis in falling chain experiments were carried out using commercial (free) data processing software.

3. Results and discussions

The results of experiments (black triangles) and simulations (dashed lines) on the mass measurements of falling chains measured using kitchen scales at several different chain lengths (50–150 cm) are shown in figures 2(a)–(c). The observations show that the change in chain mass measured by kitchen scales has three main patterns of motion. The first pattern is a linear measurement, where an increase in measured chain mass is three times higher than the actual falling chain mass. The observations showed that the maximum measured chain mass for 50 cm (125 g), 100 cm (225 g), and 150 cm (325 g) are 375 g, 675 g, and 975 g, respectively. The results of the measurement of the falling chain in the linear phase are consistent with the theoretical approach explained by equation (8). The result shows that the change in mass (force) of the falling chain measured by the kitchen scale, in general, is due to the gravitational force and the force formed due to changes in momentum (impulse) of the falling chain. However, according to result and observe measurement, it will show deviations compared to the simulation process, especially at the beginning of the measurement. The deviation in measurements and physical models caused by friction between the chain granules used or air friction. Then, the second pattern is the damped oscillation pattern, when the needle of kitchen scale oscillates with the amplitude decreasing with time. The damped oscillation movement needle scales, caused by the use of springs (and air friction) as the primary system of mass measurement, where a load of mass (gravitational force) and the change in momentum (impulse) turn into a spring force so that harmonic oscillations occur in the kitchen scale. However, due to air friction, the total force due to the spring force (oscillation motion) and friction will cause the formation of damped oscillations, so the kitchen scales need time to show the exact mass measurements [10]. The observations show that the total time for the linear phase and the damped oscillation phase for each different chain length has increased. This total time is due to the damping constants in the kitchen scales related to the chain length (chain mass) and the spring constant. Then, the stable phase pattern begins when the needle scale is unmoving or static and will show the actual mass of the chain. Then, measurements of height versus time in the end-tip of the falling chain experiment (black triangle) and free fall simulation (dashed line) shown in figure 2(d). The measurement and simulation results show that the movement from the end tip of the falling chain moves faster than the free-fall simulation. The results and analysis are consistent with observations made by Hamm *et al*, which explain that the deviation between the experimental results and simulations chain falls is caused by air friction, friction between chain components, or the physical model in equation (8) is too simple [8].

4. Conclusions

The apparatus development of the falling chain experiment using kitchen scales and digital cameras (smartphones), and analyzes using Tracker 5.1.1 software has successfully been studied. The observations show that the change in chain mass measured by kitchen scales has three main patterns of motion. The first pattern is a linear measurement, where an increase in the mass of a falling chain is measured to be (approximately) three times higher than its actual mass. The result shows that the change in mass (force) of the falling chain measured by the kitchen scale, in general, is due to the gravitational force and the force formed due to changes in momentum (impulse) of the falling chain. Then, the second is a damped oscillation motion when the needle scale oscillates with an amplitude that continues to decrease with time. The damped oscillation movement caused by the use of springs (and air friction) as the primary system of mass measurement, so the kitchen scales need the time to show the exact mass measurements (stable pattern).

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