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Impulse measurement and analysis using a smartphone accelerometer

Bebeh Wahid Nuryadin[1] **and Ilham Hindawan**[2]

[1] Department of Physics, UIN Sunan Gunung Djati Bandung, Jl. A H Nasution 105, Bandung 40614, Indonesia

[2] Department of Sports Science, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia

E-mail: bebehwahid102@uinsgd.ac.id

Abstract

In this research, we will learn about the concept, measurement and analysis of an impulse using a smartphone accelerometer. The impulse measurements were performed in several experimental conditions such as free-fall objects hitting a sand surface, two cars in collision and straight punching (boxing jab). During the experimental process, the acceleration of objects (such as children's toys and smartphones) is measured using a smartphone accelerometer application. Then, the acceleration versus time data were analysed to determine the impulse characteristic, such as the time interval and area of the impulse, and it was compared with the motion analysis using video (image) analysis. We hope this alternative apparatus is a valuable, low-cost and straightforward experiment for physics laboratories or sports science analysis.

Introduction

Research on the concept, experiment and analysis of dynamic motion is very interesting and has been widely studied [1, 2]. One of the basic concepts of motion that is interesting but not well explored by experiment is impulse. Impulse is an event when an object receives a force on short time intervals, so the momentum of the object changes rapidly (Newton's second law) [3]. The collision experiment is a common example that one could use in learning the concept, experiment and analysis of the impulse-momentum relation. Recent research shows that researchers have been developed impulse (force) measurement apparatus using commercial sensors [4], zero cost experiments [5], and an Arduino board sensor [6] to demonstrate the impulse-momentum relation.

Here we are learning about the concept, measurement and analysis of the impulse using a smartphone accelerometer. The acceleration (force) versus time curve was analysed to determine the impulse characteristics, such as the interval time and area of the impulse, and it was compared to the motion analysis using video (image) analysis.

Experiment overview

Apparatus

In this research, the android-based smartphone (Samsung J1 mini) and the 'Physics Toolbox Sensor Suite Apps' are used to measure the acceleration sensor of the device. The smartphone acceleration sensor is usually called a micro-electro-mechanical system (MEMS) which processes the mechanical system into electrical information. The acceleration sensor consists of a spiral spring that attaches a seismic mass that can move freely in one direction. If acceleration works in the x-direction, it will cause mass M to move in the x-direction. Capacitive, piezoresistive, or piezoelectric methods are commonly used to measure changes in mass position M while measuring the acceleration received [1]. To measure acceleration in 3D directions, three sensor systems must be inserted and positioned orthogonally in a smartphone. So, the a_x, a_y, and a_z accelerations of each spatial direction (x-, y-, and z-axis) can be measured independently.

Procedures

The schematic of the impulse measurement and analysis using a smartphone accelerometer is shown in figure 1. The impulse measurements were found in several collision conditions. In the first experiment we measured the acceleration data of the free fall object (smartphone with a mass at 200 g) hitting the sand surface. In the second experiment we measured the acceleration data of the collision of two cars (with a smartphone). Furthermore, the third experiment was conducted to determine the impact collision by measuring the acceleration data of a straight punch (boxing jab). Then, the acceleration versus time data was analysed using the Newton's second law to determine the time of impulse by [3],

$$F(t) = m \times a(t) \tag{1}$$

the area of the impulse calculated by,

$$J = \Delta P = mv_2 - mv_2 = F(t)\,\Delta t \tag{2}$$

$$J = \int_{t_1}^{t_2} F(t)\mathrm{d}t \tag{3}$$

or, for mass constant the area of the impulse equation became,

$$J = m\int_{t_1}^{t_2} a(t)\mathrm{d}t \tag{4}$$

and compare it with the video image analysis.

Trials and analysis

The easiest way to measure and analyse impulse is by dropping the smartphone on a semi-rigid surface (such as a sand surface), see figure 2. In the experiment, the smartphone will experience free-all motion and then hit the sand surface [1]. With the help of an accelerometer application, this experiment will produce data acceleration with time as shown in figure 3. Free-fall motion is observed on the acceleration curve with time, where the gravitation acceleration is -10 m s^{-2} for almost 0.35 s, with final velocity free fall is,

$$v_{\text{before}} = g \times \Delta t = 10\,\text{m s}^{-2} \times 0.35\,\text{s} = 3.5\,\text{m s}^{-1}.$$

At free-fall motion, the potential energy of the smartphone turns into kinetic energy so the smartphone will have momentum. The smartphone mass is 0.2 kg, the momentum of the smartphone before collision is,

$$P_{\text{initial}} = m \times v_{\text{before}} = 0.2\,\text{kg} \times 3.5\,\text{m s}^{-1} = 0.7\,\text{kg m s}^{-1} \quad (\text{Ns}).$$

Meanwhile, when the smartphone hit the sand surface, the momentum of the smartphone decreases rapidly caused by a reaction force from the sand surface which is large enough to produce a much greater acceleration than free fall acceleration. The impulse was observed in the acceleration data curve, where there was a rapid change

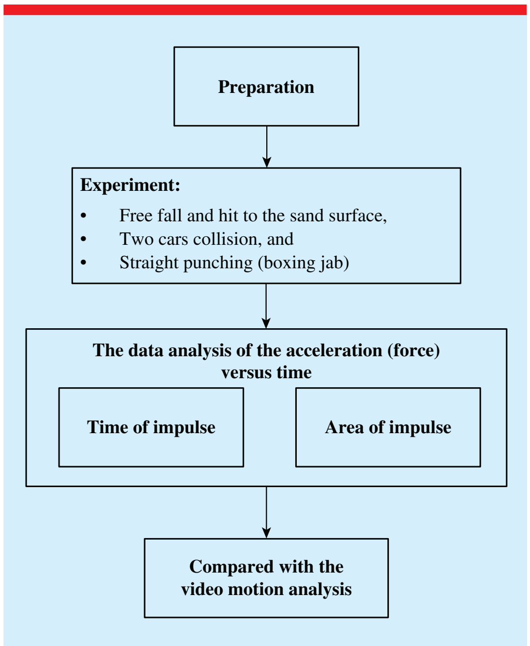

Figure 1. The schematic of the impulse measurement and analysis using a smartphone accelerometer.

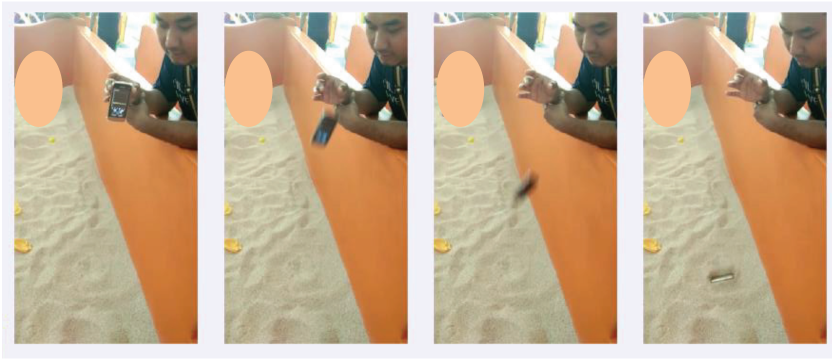

Figure 2. Image analysis of the smartphone free-fall and hitting the sand surface.

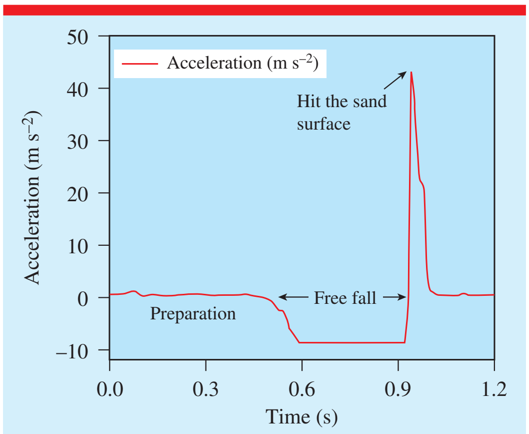

Figure 3. Acceleration measurement of the smartphone in free-fall and hitting the sand surface.

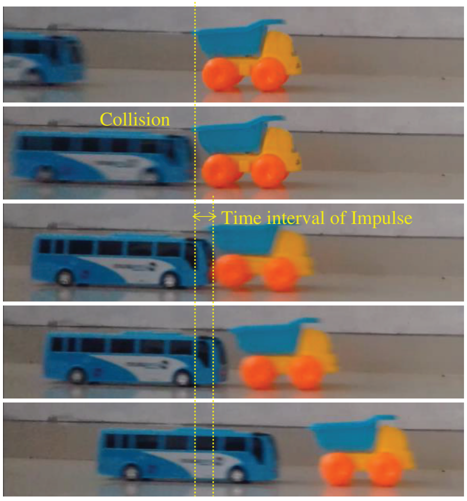

Figure 4. Video (image) analysis of the two car collision experiment.

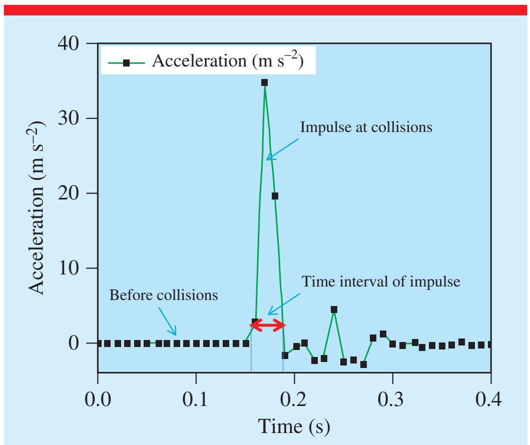

Figure 5. Acceleration measurement of the two car collision for second car (blue-yellow).

in acceleration from -10 to 45 m s^{-2}. The magnitude of the impulse due to collisions with the surface of the sand is 45 m s^{-2} for 0.08 s. Using equation (4), we can calculate the impulse (J) received by smartphones,

$$J = F \times \Delta t = m \times a \times \Delta t = 0.2\,\text{kg} \times 45\,\text{m}\,\text{s}^{-2} \times 0.08\,\text{s} = 0.72\,\text{kg}\,\text{m}\,\text{s}^{-1} \quad (\text{Ns}).$$

So, this collision experiment shows that the impulse (J) is proportional to the change in momentum, by

$$\Delta P = |P_{\text{final}} - P_{\text{initial}}| = |0 - 7.0\,\text{kg}\,\text{m}\,\text{s}^{-1}| = 7.0\,\text{kg}\,\text{m}\,\text{s}^{-1}.$$

Figure 4 shows video (image) analysis for the the two car collision experiment. At initial, the first car (blue) moves with constant speed

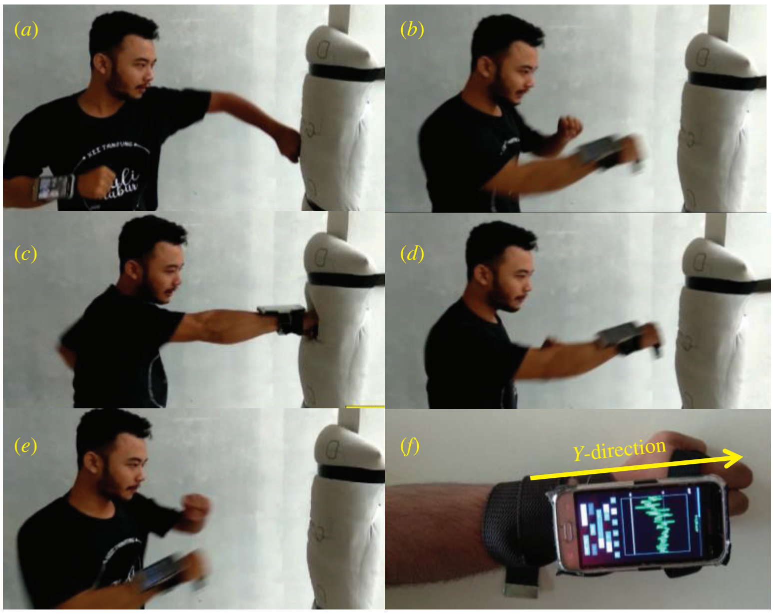

Figure 6. Video (image) analysis of a straight punch on a pillow with (a) initial position, (b) force (forward), (c) impulse, (d) force (reverse), and (e) back to initial position; (f) smartphone attached to right arm.

and the second car (yellow–blue) is motionless. Then, collisions occur between the two cars, so the second car recieves an impulse and moves. The video analysis shows that there is a collision contact time called the time interval of impulse. The acceleration versus time analysis is shown in figure 5, its shows that the time interval of the impulse and the acceleration at the impulse are 0.03 s and 35 m s^{-2}, respectively. By utilizing equation (2) and/or (4), the calculation shows that the second car speed after a collision (v_{after}) is,

$$v_{\text{after}} = a_{\text{collision}} \times \Delta t = 35\,\text{m}\,\text{s}^{-2} \times 0.03\,\text{s} = 1.05\,\text{m}\,\text{s}^{-1}.$$

The total mass of the second car and smartphone is 0.4 kg. The impulse of the collision is proportional with a change in momentum of the second car (and smartphone), and calculated by:

$$J = \Delta P = m \times v_{\text{after}} - m \times v_{\text{before}} = 0.4\,\text{kg} \times 1.05\,\text{m}\,\text{s}^{-1} - 0 = 0.42\,\text{kg}\,\text{m}\,\text{s}^{-1}(\text{Ns}).$$

A simple example of the concept of impulse application in sports science is the straight punch (boxing jab), with focus on the hand movement acceleration [7]. Figures 6(a)–(e) describes the straight punching steps which consist of initial position, forward force, impulse (surface contact), and hand pulling force (reverse), and then moving back to the initial position. The data acceleration of the straight punch was found with a smartphone attached to the right arm using a rope/tape, as shown in figure 6(e). The acceleration versus time data in the *Y*-direction is shown in figure 7, with the inset for a repeat of the straight punch. The acceleration data and video (image) analysis compared for all punching steps shows zero acceleration in the initial position, positive acceleration in the forward force, high acceleration with a fast time interval is the impulse, and negative acceleration is the hand pulling force (reverse) for the move back to the starting position. On the other side, the result shows that the forward force is higher than the hand pulling force so that the forward force produces great momentum, and the hand pulling force is only for repositioning the hand back to the initial position.

By assuming hand mass is 5.33% of the average of human body mass [8], the time interval and maximum acceleration are 4 kg, 0.1 s and 40 m s^{-2}, respectively. The magnitude of the impulse transferred to the pillow is approximately:

$$J = F \times \Delta t = m \times a \times \Delta t = 4\,\text{kg} \times 40\,\text{m}\,\text{s}^{-2} \times 0.1\,\text{s} = 16\,\text{kg}\,\text{m}\,\text{s}^{-1} \quad (\text{Ns}).$$

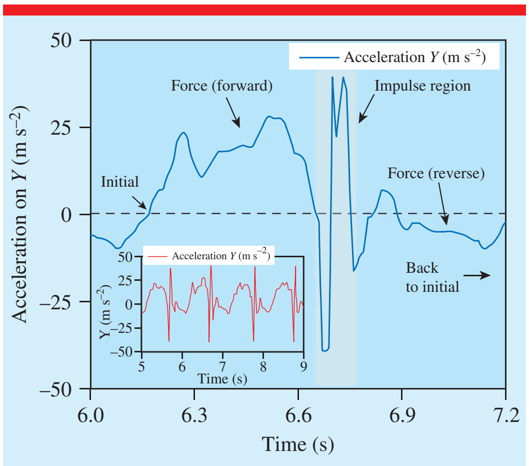

Figure 7. Acceleration (force) versus time data of the straight punch on a pillow in a body-like shape.

The perceived magnitude of the impulse is quite large, for some conditions, this large impulse could damage the body's tissues [7].

Conclusion

The impulse measurement and analysis using a smartphone accelerometer has been investigated and studied. The impulses of the collision experiment were measured using a smartphone accelerometer. Then, the acceleration data was analysed to determine the impulse characteristics, such as the time interval and area of the impulse, and it was compared with the simple video (image) analysis. This collision experiment shows that the impulse magnitude is proportional to the change in momentum. Furthermore, the simple straight punch (boxing jab) analysis shows that the impulse magnitude transferred to the pillow is 16 kg m s^{-1} (Ns), this large impulse could damage the body's tissues.

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ORCID iDs

Bebeh Wahid Nuryadin https://orcid.org/0000-0002-6653-4174

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References

[1] Vogt P and Kuhn J 2012 Analyzing free fall with a smartphone acceleration sensor *Phys. Teach.* **50** 182–3
[2] Pili U 2018 A dynamic-based measurement of a spring constant with a smartphone light sensor *Phys. Educ.* **53** 033002
[3] Serway R A and Jewett J W 2004 *Physics for Scientists and Engineers* 6th edn, vol 1 (Pacific Grove, CA: Thomson Brooks/Cole)
[4] Horton P 2004 Elastic experiment is licensed to thrill *Phys. Educ.* **39** 326–8
[5] Ganci S and Oneto D L 2017 A zero cost experiment on the 'impulse-momentum theorem *Phys. Educ.* **52** 13002
[6] Espindola P R, Cena C R, Alves D C B, Bozano D F and Goncalves A M B 2018 Impulse measurement using an Arduíno *Phys. Educ.* **53** 035005
[7] Nakano G, Iino Y, Imura A and Kojima T 2014 Transfer of momentum from different arm segments to a light movable target during a straight punch thrown by expert boxers *J. Sports Sci.* **32** 517–23
[8] Plagenhoef S 1983 Anatomical data for analyzing human motion *Res. Q. Exerc. Sport* **54** 169–78

Bebeh Wahid Nuryadin has a doctoral degree in physics, specializing in nanomaterials and semiconductors. He is currently an assistant professor at UIN Sunan Gunung Djati Bandung, Indonesia. His research areas include synthesis and functionalization of nanomaterials, new-types ceramic semiconductors and solar-based renewable energy. Moreover, he tries to develop a Mobile Science Laboratory for Madrasah/ School Improvement (MOSLM Lab's), especially using smartphones and open source applications.

Ilham Hindawan has a bachelor's degree from Universitas Singaperbangsa Karawang (UNSIKA). He is currently a master's students at Sport Science, Institut Teknologi Bandung (ITB). His research areas include sport science, health and recreation. Moreover, he has tried to develop a maritim life (ocean)-based sport science, healty life, recreational spot for Indonesian peoples.