Periodic movement of subject's legs to investigate force-position, force-velocity and force-acceleration relationships: Real time experiment using data logger with force platform and motion sensor

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(Received 2 February 2011, accepted 26 June 2011)

Abstract

Statics and dynamics are topics which feature in colleges and undergraduate physics curriculum. In this real time experimental work, we have explored with students in a laboratory how the force influences subject's periodic motion and investigate the relationship that exists between the position-velocity-acceleration and the force. Force platform and movement sensor were used with data logger interfaced to computer to record and display data and graphs in real time.

Keywords: Impulse-change momentum, force-position, force-velocity, force-acceleration relationship force platform, motion sensor, data logger.

Resumen

La Estática y la Dinámica son temas que figuran en la curricula de la física de pregrado y de licenciatura. En este trabajo experimental en tiempo real, se ha explorado con estudiantes en un laboratorio cómo la fuerza influye en el movimiento periódico y se investigó la relación que existe entre la posición-velocidad-aceleración y la fuerza. Se utilizó una plataforma de fuerza y un sensor de movimiento con un registrador de datos de interfaz a la computadora para registrar y mostrar datos y gráficas en tiempo real.

Palabras clave: Impulso-cambio de ritmo, posición-fuerza, velocidad- fuerza, fuerza-aceleración relación de la plataforma de fuerza, sensor de movimiento, registro de datos.

PACS: 01.50.My, 01.50.Pa, 01.50.Lc, 01.40.-d, 01.50.H- **ISSN 1870-9095**

I. INTRODUCTION

The science of physics such as biomechanics is being in use for decades in medicine and sport to investigate the human motor behavior physiology and to find out ways how to improve the performance of athletes, respectively. Several works related to those matters have been published by researchers elsewhere [1, 2] and [3]. In this experimental work a force platform was used to collect the data measurements of the force as a function of time of standing student vertically doing gentle and rhythmic movement up and down by bending and stretching his knees to form approximately an angle of 40 degrees between highs and lower legs. The position, velocity and acceleration of the top of the student's head which are due to the sequence actions were measured by means of the movement sensor. We have investigated the relationships between the position, velocity and acceleration with the applied force and impulse–momentum change, respectively. We have also verified if the student's cyclic up and down movement approximates the simple harmonic motion.

The force platform, motion sensor and data logger, 750 interface [4] have been used with a computer to record and display data measurements in real time. For analysis and interpretation of different graphs, Datastudio software [4] was used to produce curves which are under investigation. All the experimental and calculated curves are analyzed and the relationship between the applied force, to move the student's thighs and lower legs up and down periodically, and the resulting displacement, velocity and acceleration are examined and discussed with all participant students in the laboratory session.

II. EXPERIMENTAL SETUP

The force platform which was used for the experiment is sturdy glass-filled nylon, approximately 0.4 x 0.4m, weighing around 4Kg, is supported by four force beams which combine to measure the total force. This force platform can be used to measure the static weight of a person standing on it, or the dynamic vertical force involved in moving and jumping. It has the range and strength to measure forces of less than 1N, such as the weight of a tennis ball, and up to 4400N. The other detector which was employed is the movement sensor. This one takes the measurements of the displacement, velocity and acceleration as a function of time of the subject performing movements on the platform. The data logger 750 Interface of PASCO is attached to a computer and connected to the force platform and the sensor motion. The platform is placed on a solid flat ground for measurements, and motion sensor is attached to a metal rod and oriented to the platform center, at a height of approximately 2.10 m.

III. RECORDING AND ANALYZING DATA MEASUREMENTS

A. Reaction force measurement

The volunteer student to carry out exercise movements is weighing 78kg and having 1.78m of height. He was asked to stand on the platform that was placed on a flat solid ground in the teaching physics laboratory and began to practice few repetitive movements of flexion and extension of lower legs by bending his knees in order to obtain the optimum sampling conditions for the two instruments (force platform and motion sensor). Fig. 1 illustrates the motion involved in the movement of thighs and lower legs by bending the subject's knees. As the force platform measures the force exerted on it by the subject, and according to Newton's third law of motion this also gives the force exerted by the platform on the subject. In addition Newton's second law governs the resulting motion. The mathematical expression of Newton's third law of motion has been demonstrated throughout an interactive discussion with whole students of the teaching laboratory. Newton's 2nd law of motion, $F = m.\ a$; the force $F = R - W$, from these two expressions, $m\ .a = R\text{-}W$, and $R = W + m.a$. Where W is the weight of the subject, R is the reaction force, m is mass of the subject, and a represents acceleration of the subject's center of mass.

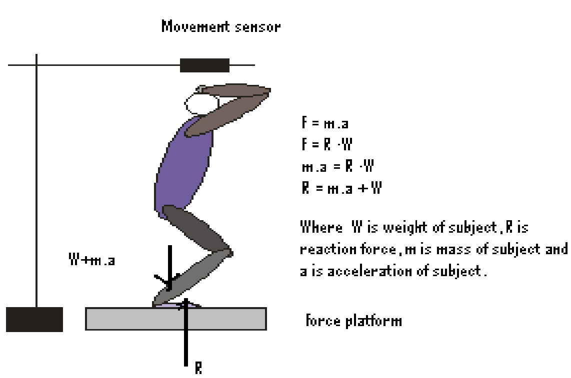

FIGURE 1. Sequences of thighs and lower legs cyclic motions of the subject.

The force of thighs and lower legs of few cyclic motions was measured by the platform and the physical quantities of data of interest pass on to the computer via 750 Interface of PASCO. At regular intervals the computer software, Datastudio, record and displays data as graphs or tables. The curves representing data measurements of reaction force due to cyclic motion of thighs and lower legs as a function of time are shown in Fig. 2. Taking the 1st cycle of the curves as an example, we can explain to students the reaction force and the impulse graphically. The initial point at the left of curve shows the beginning of the subject's bending knees, the peak level is reached at maximum bending knees (around 40 degrees), on the other words at nearly maximum flexion of lower legs, and then student starts to stretch his knees until he returns to the initial position; i.e., extension of lower legs. The area under this curve is defined by the impulse that can be calculated.

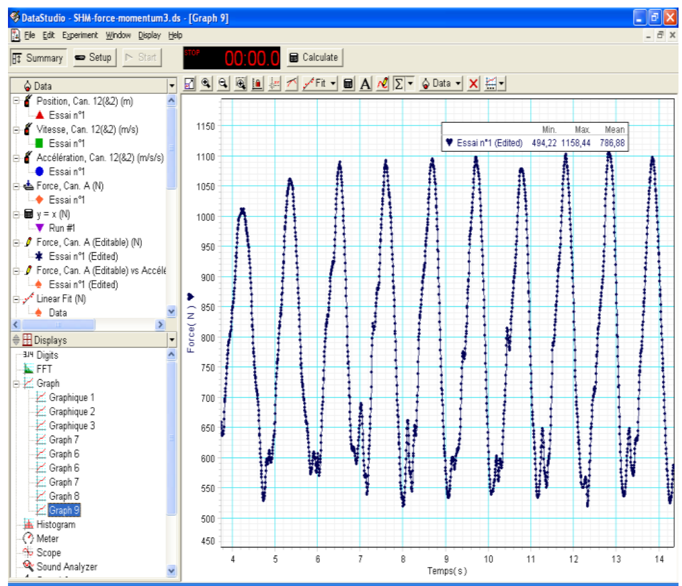

FIGURE 2. Action and reaction force of the subject's thighs and legs cyclic motion.

Newton's 2nd law of motion can be written as $F = m.\frac{\Delta v}{\Delta t}$, where Δ is change or difference between two points in velocity or time. This expression can be expressed as, $F.\Delta t = m.\Delta v$, or impulse $I = \int_{t1}^{t2} f\, dt$ = change in momentum ($\Delta P = m.\Delta v$), or linear quantity of motion. The impulse which is the area under the curve was calculated automatically by data logger software, as shown in Fig. 3. In human movement, force is required first to maintain static equilibrium and second to generate acceleration. The force required to maintain static equilibrium is equal to an object's mass multiplied by gravitational acceleration. Additional force results in acceleration of a mass or change in momentum [2]. These components of acceleration are described as: $F = m.g + m.a = m.g + m\frac{dv}{dt}$.So, the net impulse can be estimated as total impulse – subject's weight.

Students can easily compute from illustrated graph of force versus time the net impulse, which is equal to 36Ns.

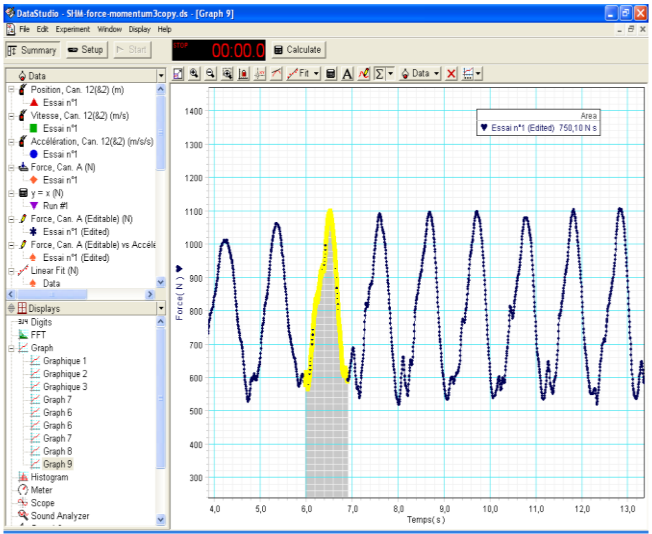

FIGURE 3. The estimated impulse of the subject.

B. Displacement, velocity and acceleration measurements

Motion sensor was set at a height of 2.10m above the force platform .When the student was ready to perform the exercise of motion, Data measurements of reaction force, and displacement, velocity and acceleration were recorded simultaneously in the data logger and graphs of these components as function of time were analyzed by data logger software and displayed in the computer. The subject's cyclic thighs and lower legs displacement, velocity and acceleration as a function of time are shown in Figs. 4, 5 and 6, respectively.

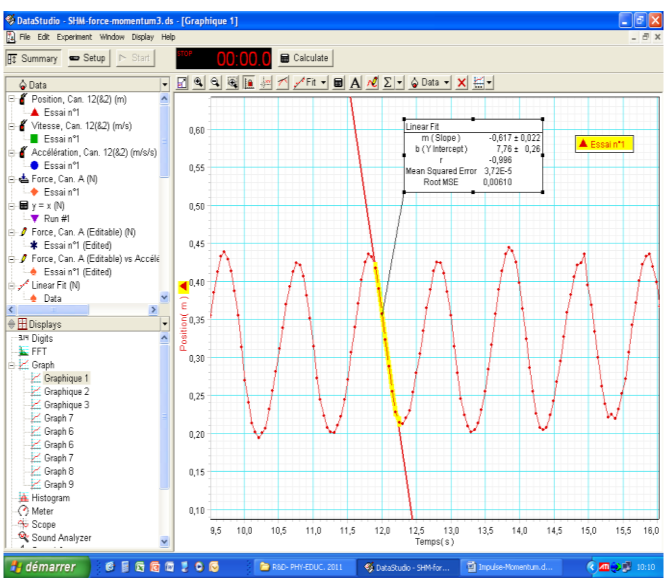

FIGURE 4. Periodic motion of subject's thighs and lower legs motions.

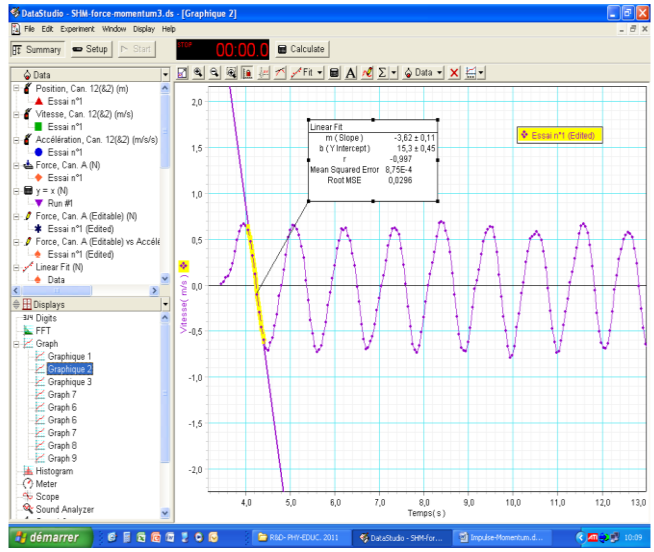

FIGURE 5. Velocity of subject's cyclic motion.

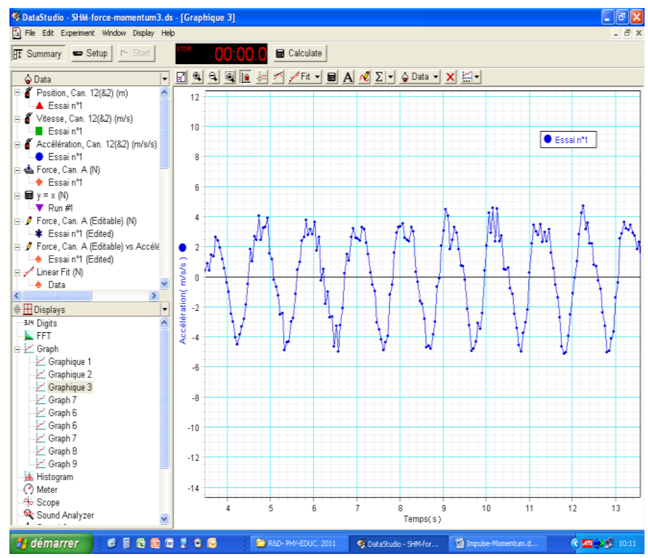

FIGURE 6. Acceleration of subject's cyclic motion.

The sampling for the displacement, velocity and acceleration of motion sensor was set at 20Hz. It was observed from the displacement curve of the subject's thighs and lower legs that the motion approximates the Simple Harmonic Motion of a pendulum. The expected sine curve fit of the motion is given by data logger software as illustrated in Fig. 7. Where the dot line is the experimental curve and full line represents the expected curve. In fact the movement of thighs and lower legs is described by models that solve differential equations obtained from the dynamic model of the coupled pendulum representing the motion of thighs and lower legs [5 and 6]. The detailed differential equations describing the dynamical models of thighs and lower legs motion are not within the scope of this paper.

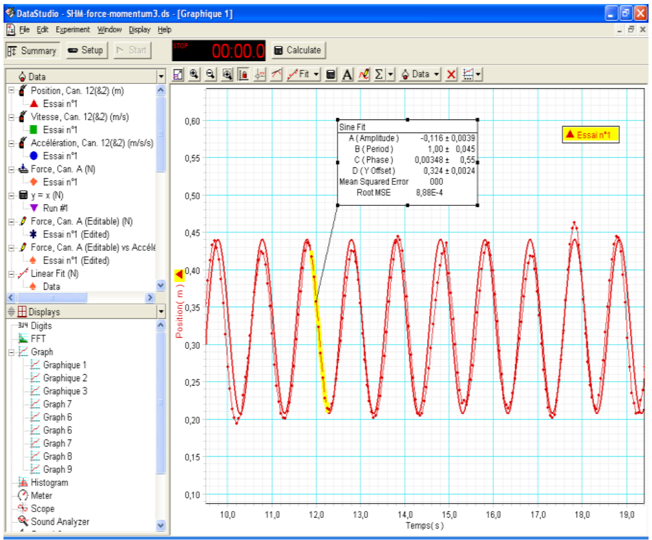

FIGURE 7. Experimental and expected curves of subject's thighs and lower legs motion.

Students have verified the expected value of velocity and acceleration from graphs of displacement and velocity as a function of time. Data logger software was used to estimate the linear best fit function of displacement and velocity, the obtained slopes that represent the velocity and acceleration are m_v = -0.617 ± 0.022ms^{-1} and m_a = -3.62 ± 0.11ms^{-2}, respectively. The magnitude of velocity and acceleration match quite well the experimental results obtained in Figs.5 and 6, respectively. The magnitude of acceleration experienced by the subject's head is greater than the expected center-of-mass (CM) associated with the predicted acceleration [7].

C. Force-displacement, force-velocity, force-acceleration

Curves of force-displacement, displacement -velocity, force-velocity and force-acceleration of subject's thighs and lower legs periodic movement are shown in Figs. 8, 9, 10 and 11, respectively. The relationships that exist between these curves were examined by students. They noticed that the force and displacement are directly proportional a graph of *F* versus *x* is a straight line with a slope representing the stiffness (*K*) of the elastic body, its value equals 2330 ± 16, as shown in Fig. 8. This high value is dependent upon the subject's thigh and lower leg muscles which is being studied. A high stiffness constant will require a large amount of force to cause a little displacement.

Students have interpreted the relationship of reaction force-velocity by displacement and velocity thesis. As the displacement is proportional to reaction force, they have made a connection between uniform circular motion and S. H.M. They have considered that the subject is experiencing uniform motion. Thus the displacement is expressed by the sine function and the velocity is expressed by the cosine function. This means that the velocity is advanced in phase by 90 degrees (π/2) relative to the displacement and has an amplitude ω. A_y. Where, ω is angular frequency and *A* is amplitude. On the other words, the velocity is a maximum when the displacement is zero. The graph of sine function (displacement) versus cosine function (velocity) we obtain circular paths for several periodic motions, as illustrated in Fig. 9. These circular curves are similar to the circular curves of force related to the velocity, Fig. 10.

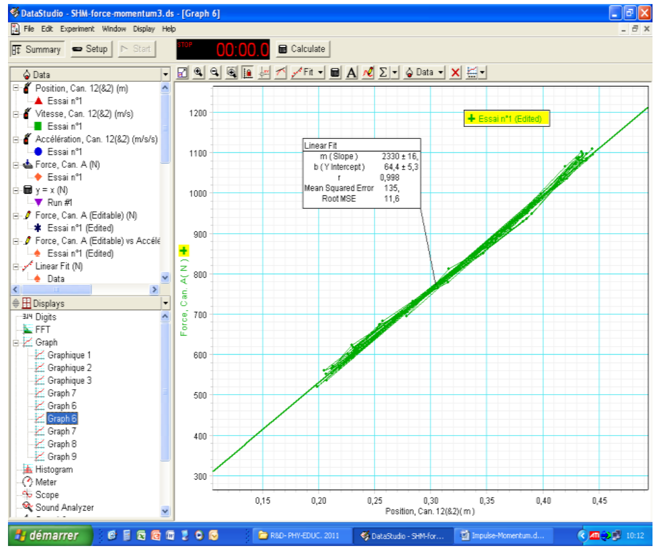

FIGURE 8. Force of subject's motion as a function of displacement.

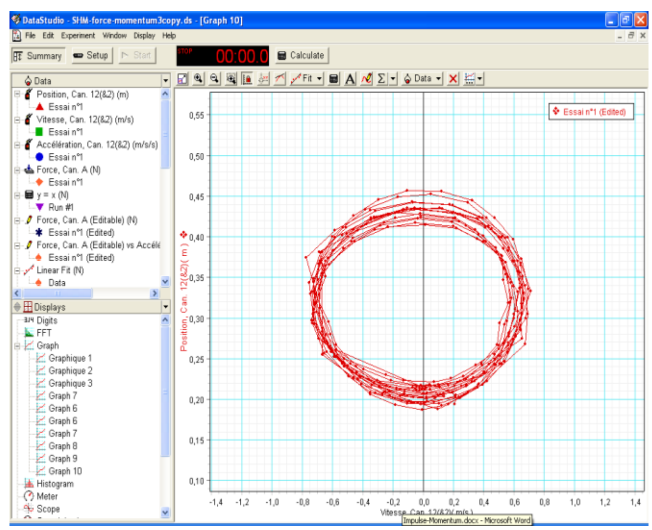

FIGURE 9. Vertical displacement of subject's motion versus its vertical velocity.

In the case of the relationship between force and acceleration due to subject's periodic motion, students have noticed that the reaction force graph versus the change in acceleration resulted in best linear fit, Fig. 11. The acceleration graph agrees with the force graph, and the relation between the force and the acceleration remains constant and equal to the mass of the moving object [8], that is $F = m.a$. The slope of the straight line represents the subject's mass.

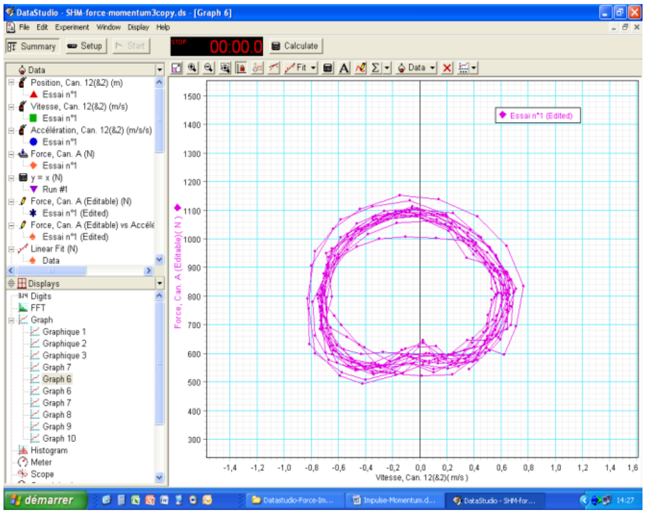

FIGURE 10. Vertical force of subject's motion versus its vertical velocity.

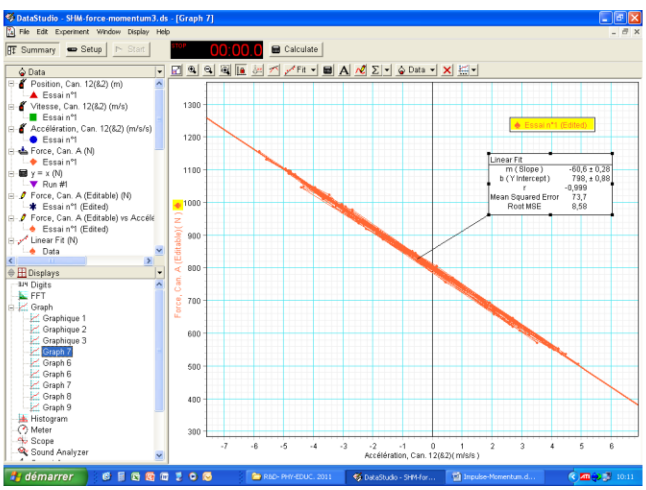

FIGURE 11. Force subject's motion as a function of acceleration.

IV CONCLUSION

As mentioned in published work that force platform is used mostly in sport sciences to investigate the athletes' performances and in biomechanics to study human movements [9]. In fundamental physics, force platform can be used by physics educators to teach and demonstrate the laws of motion, momentum, energy and work of objects. We have investigated with our students the relationships that exist between force- displacement, force-velocity and force-acceleration of subject's periodic motion using force platform and movement sensor with data logger to record, analyze and plot graphs in real time. Students are getting direct feedback from the interpretation of data measurements graphically. As the subject's motion was approximating the Simple Harmonic Motion, students are able to estimate the stiffness of elasticity (K) of the subject's thigh and lower leg muscles. The system is used by physics instructors of our department to demonstrate Newton's laws, impulse-momentum relationship and work-energy method of dropped objects or jumped subjects on the platform.

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