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Penulis : E. Pratidhina, F. Rizky Yuliani, and W. Sunu Brams Dwandaru

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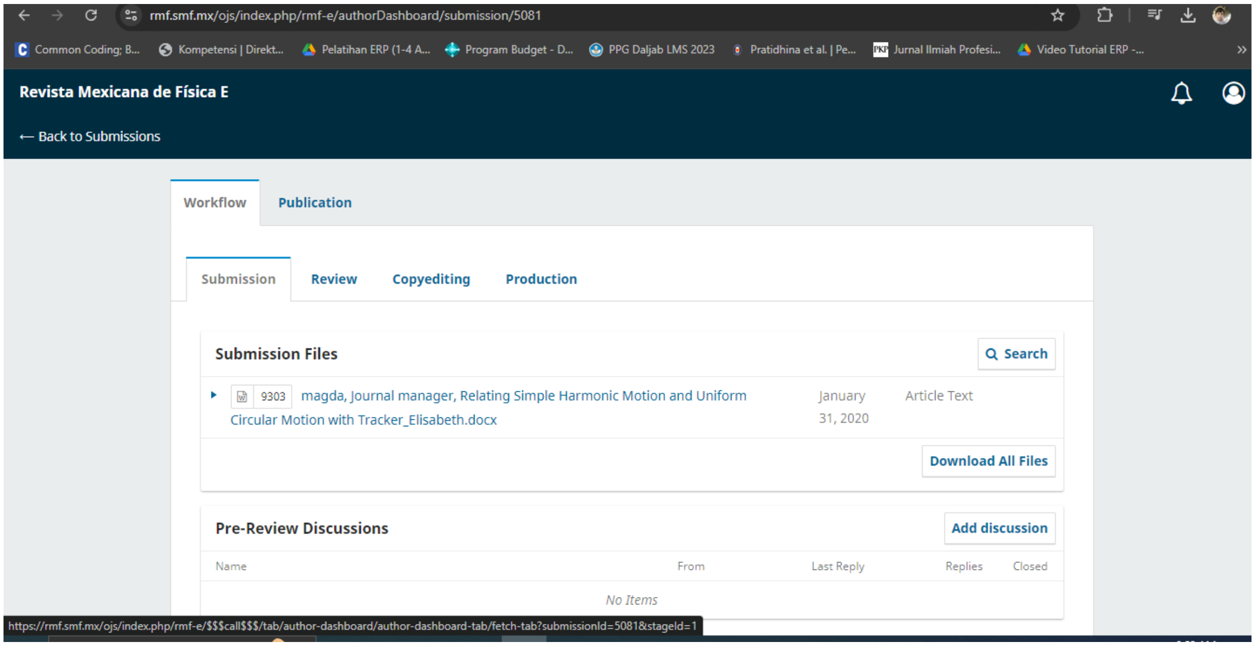
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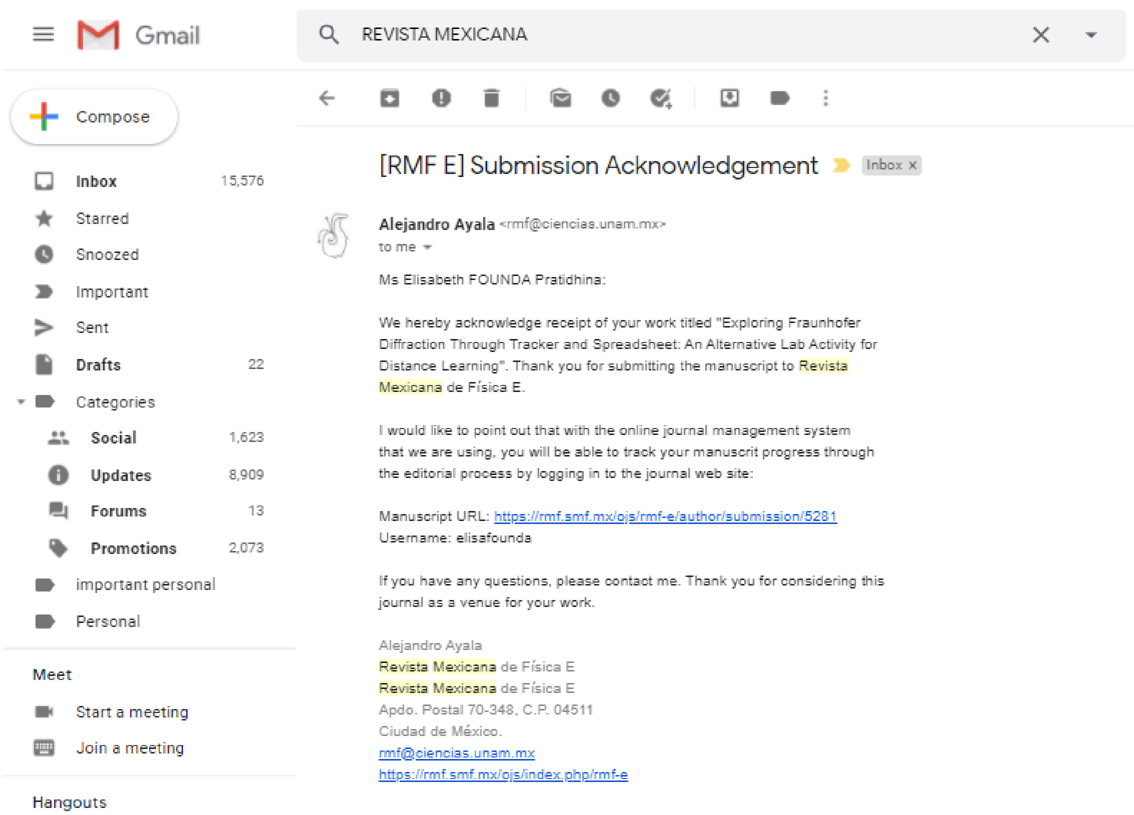
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Relating Simple Harmonic Motion and Uniform Circular Motion with *Tracker*

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ABSTRACT

In this study, we demonstrate an interesting relationship between simple harmonic motion and uniform circular motion trough a simple experiment. The experiment requires a low cost-easily found materials and free software, *Tracker*. To represent uniform circular motion, we use a tape that is stuck on a fan moving with the constant angular speed. Meanwhile, spring and pendulum motion are used to represent simple harmonic motion. Through Video *Tracker* analysis, we have shown that the positions (x and y coordinates) of an object undergoes uniform circular motion fit to the sinusoidal function of time, similar to simple harmonic motion. We also analyze the behavior of velocity and acceleration in simple harmonic motion and uniform circular motion. This simple experiment can be used in high school physics courses to lead students in developing a conceptual understanding of uniform circular motion with a less mathematical approach.

Keyword: simple harmonic motion, uniform circular motion, physics demonstration, *Tracker*

INTRODUCTION

Recently, there is a rapid development of imaging technology. Moreover, technology in mobile phone has been improved significantly. Nowadays, mobile phones provide various features such as camera, internet, sensor, spreadsheet, game, and so on. The development of imaging technology and camera feature on a mobile phone can be used for physics teaching and learning activity. By using imaging technology, *Tracker* has become a useful tool in physics education. *Tracker* is free software developed on the Open Source Physics Java code library which can be used for video analysis and physics modeling. *Tracker* includes features such as object tracking with position, velocity, and acceleration overlays and graphs, calibration points and line profiles for analysis of spectra and interference patterns ("*Tracker* Video Analysis and Modeling Tool," 2019).

Some studies have explored the potential of *Tracker* for pedagogical learning tools (Amoroso & Rinaudo, 2018; Poonyawatpornkul & Wattanakasiwich, 2013; Rodrigues, Marques, & Sime, 2016; Wee, Tan, & Leong, 2015). Poonyawatpornkul & Wattanakasiwich (Poonyawatpornkul & Wattanakasiwich, 2013) use *Tracker* to analyze damped harmonic oscillation; Rodrigues (Rodrigues & P, 2014) use *Tracker* to teach optical phenomena; while Loo Kang Wee (Wee et al., 2015) integrate *Tracker* in physics class when discussing free-fall motion. *Tracker* allows students to identify relationships between physical quantities through observation, compare the real world with mathematical modeling, and be trained to construct a model for a particular physical phenomenon (Aguilar-Marin, Chaves-Bacilio, & Jáuregui-Rosas, 2018).

Circular motion and simple harmonic motion are discussed several times in high school physics and introductory college physics courses. Uniform circular motion and simple harmonic motion have close relationships. Simple harmonic motion is a term used when the periodic motion is a sinusoidal function of time. Most students are able to notice simple harmonic motion in the spring-mass system and the simple pendulum. In fact, the x- and y-coordinates of particle's positions in uniform circular motion are also a sinusoidal function of time, similar to simple harmonic motion. Sometimes students face difficulty to relate uniform circular motion and simple harmonic motion trough geometric and mathematical approaches.

In this work, we show a simple experiment using *Tracker* to compare uniform circular motion and simple harmonic motion. Experiments, representing uniform circular motion and simple harmonic motion, have been conducted with simple materials and tools which can be found easily in daily life. The phenomena were recorded with a mobile phone camera. After that, the videos were analyzed through *Tracker*.

THEORY

Simple Harmonic Motion in Vertical Spring-Mass System

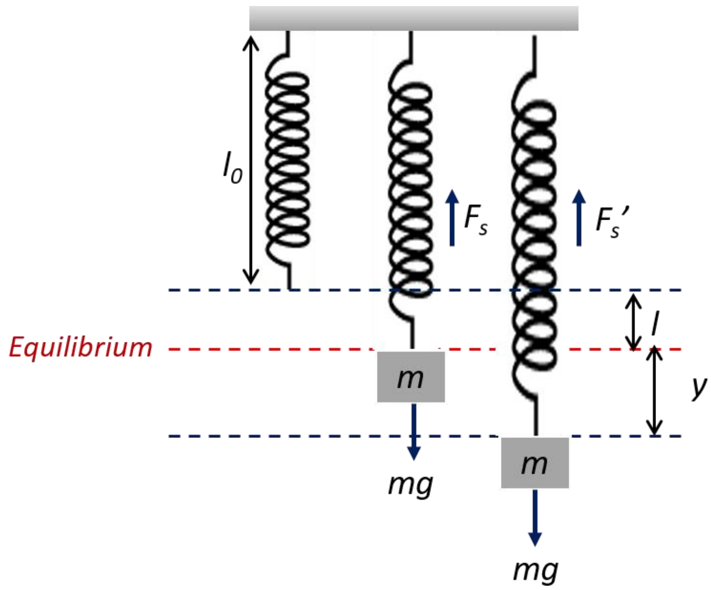

Figure 1. Vertical Spring-Mass System

One of the physical systems representing simple harmonic motion is a vertical spring-mass system. A particle with mass m is attached on vertical spring with an original length of l_o such as shown in Figure 1. At equilibrium point, the spring force is balanced by the gravitational force, or according to Newton's first law, $\boldsymbol{F_s} + \boldsymbol{F_g} = 0$. Thus,

$$-kl + mg = 0$$

Or

$$kl = mg \tag{1}$$

When the spring is stretched down leaving its equilibrium position, there is acceleration, so that $\Sigma\boldsymbol{F} = m\boldsymbol{a}$

$$\boldsymbol{F_s}' + \boldsymbol{F_g} = m\boldsymbol{a}$$

$$-k(l + y) + mg = m\frac{d^2y}{dt^2}$$

Since $kl = mg$,

$$-ky = m\frac{d^2y}{dt^2} \tag{2}$$

Equation (2) can be written as:

$$\frac{d^2y}{dt^2} = -\omega^2 y \tag{3}$$

where, $\omega^2 = \frac{k}{m}$.

By solving the second-order differential equation in (3); we yield a solution for the particle's position as follows:

$$y(t) = A\cos(\omega t + \phi) \tag{4}$$

A is called amplitude, whereas ϕ is called initial phase. Both of A and ϕ depend on the initial condition of the particle. As described in equation (4), the particle's periodic motion is a sinusoidal function of time, in which the sinusoidal function is a cosine function. It is the main characteristic of simple harmonic motion. Furthermore, we can determine the velocity and acceleration of the particle by taking the first and second derivative of equation (4), respectively. Thus,

$$v(t) = \frac{dy(t)}{dt} = -A\omega\sin(\omega t + \phi) \tag{5}$$

$$a(t) = \frac{dv(t)}{dt} = -A\,\omega^2\cos(\omega t + \phi) \tag{6}$$

Uniform Circular Motion

A particle moves within uniform circular motion when it moves in a circular path with a constant angular speed. The angular position of a particle is given as:

$$\theta(t) = \phi + \omega t$$

where ω is angular speed, whereas ϕ is the initial angular position or initial phase.

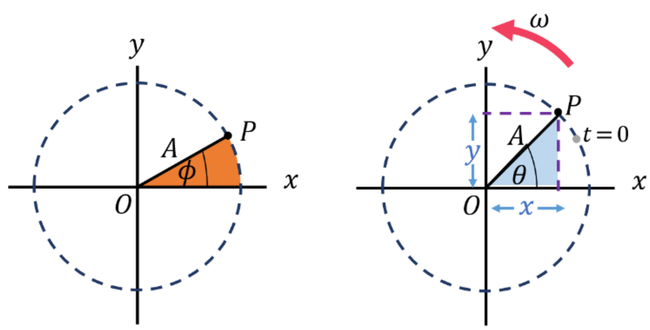

Figure 2. Particle P goes through the uniform circular motion with a constant angular speed of ω. The figure on the left is the initial particle's position. The figure on the right side is the particle's position at time t.

Particle P, in Figure 2, is moving in a uniform circular motion. It moves in a circle with a radius of A and constant angular speed ω. The x-coordinate of particle P is given by:

$$x(t) = A\cos\theta = A\cos(\omega t + \phi) \tag{7}$$

The x-coordinate of particle P is a sinusoidal function of time, analogous to the simple harmonic motion. The x-component of velocity and acceleration are given in equation (8) and (9), respectively.

$$v_x(t) = \frac{d}{dt}x(t) = -A\omega\sin(\omega t + \phi) \tag{8}$$

$$a_x(t) = \frac{d}{dt}v_x(t) = -A\omega^2\cos(\omega t + \phi) \tag{9}$$

The y-coordinates of particle P is also analogous to SHM motion, following the sinusoidal function of time (see equation (10)).

$$y(t) = A\cos\theta = A\sin(\omega t + \phi) \tag{10}$$

$$v_y(t) = \frac{d}{dt}y(t) = -A\omega\cos(\omega t + \phi) \tag{11}$$

$$a_y(t) = \frac{d}{dt}v_y(t) = -A\omega^2\sin(\omega t + \phi) \tag{12}$$

EXPERIMENTAL SETUP

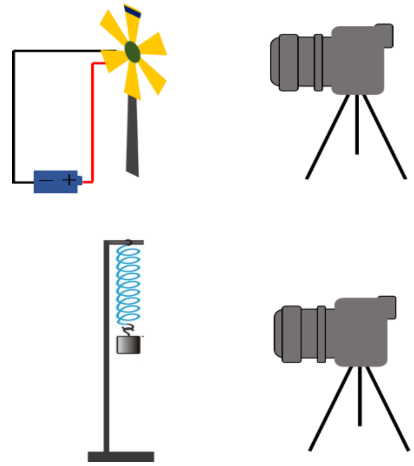

Figure 3. Experimental set-up of (a) uniform circular motion using an electrical fan, (b) simple harmonic motion using spring and slotted weight.

The experimental setup is simple, as shown in Figure 3. The behavior of uniform circular motion is investigated by recording the motion of tape, which is stuck on an electric fan (see Figure 3a). The recorded video is then analyzed with *Tracker* software. Through *Tracker*, we get data about position, velocity, and acceleration as a function of time. Meanwhile, the behavior of simple harmonic motion is represented by the motion of a slotted weight which is attached to a vertical spring (see Figure 3b).

RESULT AND DISCUSSION

The position of an object attached to a fan which moves with constant angular speed has been analyzed through *Tracker* software. As time goes on, the x-coordinate of the object goes down and up following cosine function (see Figure 4a) as predicted in theory. Although it is not perfectly smooth, the x-component of linear velocity tends to follow sine function with an initial phase (ϕ) of π radians. Meanwhile, the x-component of acceleration tends to follow negative cosine function, consistent with equation (7).

As shown in Figure 5, the y-coordinate of the object on uniform circular motion smoothly fits with the sine function in equation (8). On the other hand, the y-component of velocity and acceleration graph are not as smooth as the position graph. However, the y-component of velocity and acceleration still tend to follow cosine and negative sine function, respectively. These results demonstrate that uniform circular motion has symmetry with simple harmonic motion.

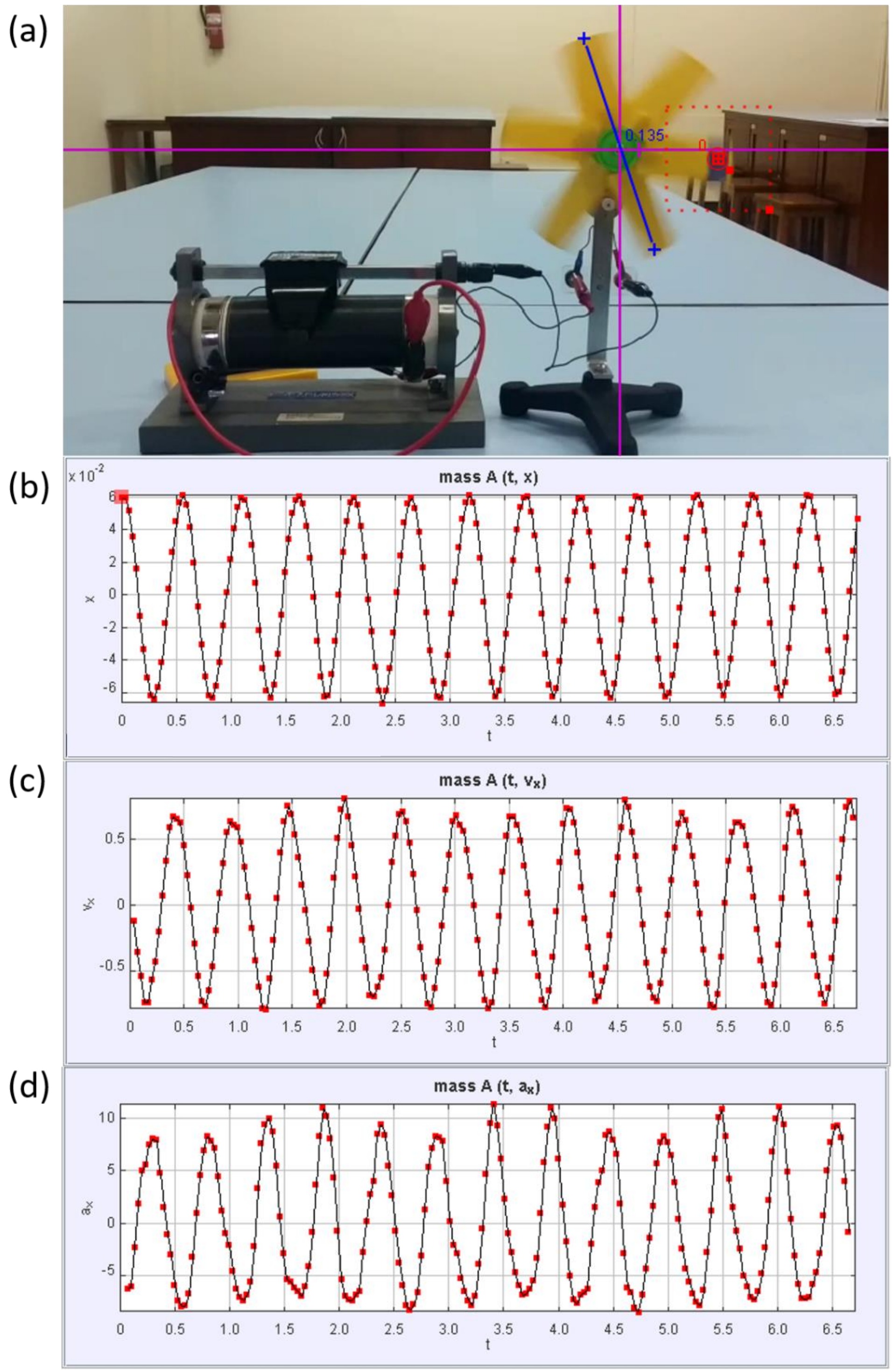

Figure 4. **(a) uniform circular motion experiment using an electric fan (b) x-position versus time graph, (d), x-component linear velocity versus time graph, (e) x-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.**

(a)
(b)
(c)

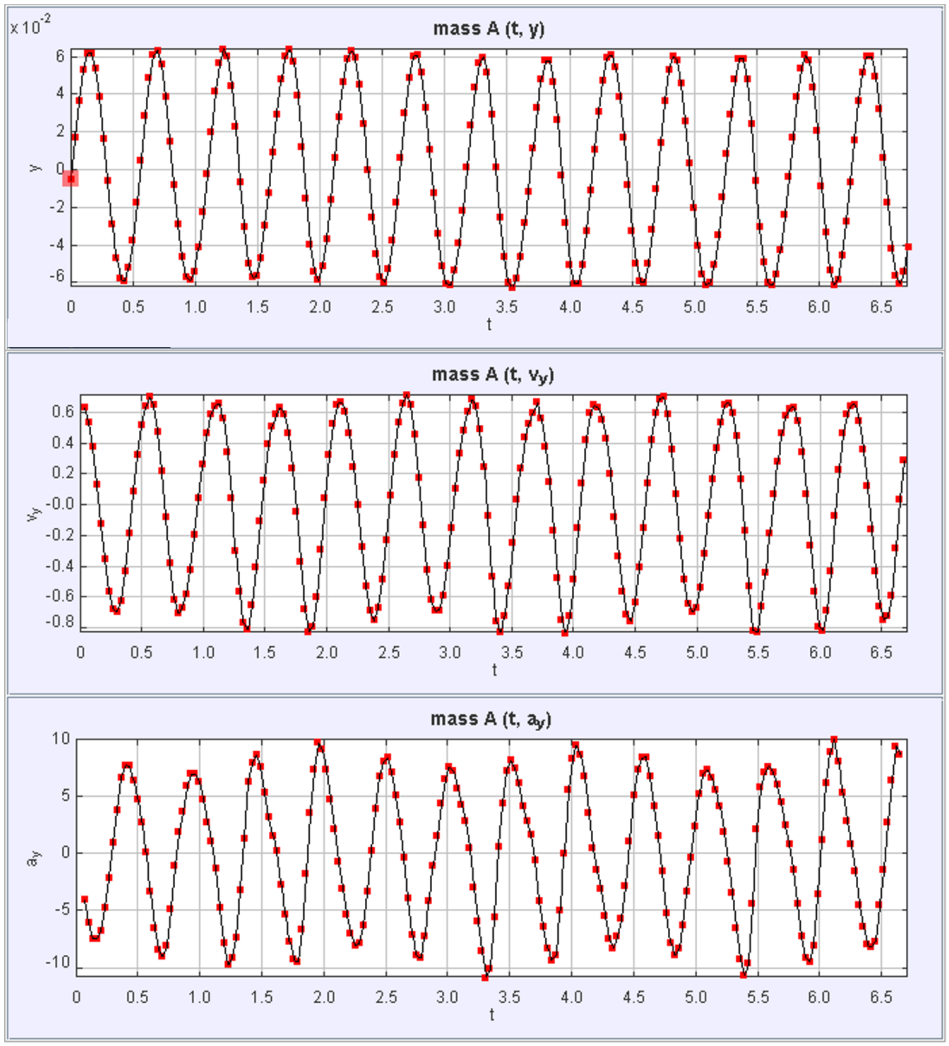

Figure 5. (a) y-position versus time graph, (c), y-component linear velocity versus time graph, (d) y-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.

In addition, we did experiment with a well-known simple harmonic motion system, i.e. mass-spring system and simple pendulum. Figure 6a-c shows the position, velocity, and acceleration of a slotted weight attached on a vertical spring as functions of time. The spring was initially stretched down. As predicted, the position of slotted weight fits sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$, whereas the acceleration fits cosine function or sine function with $\phi = \frac{\pi}{2}$.

The analysis of simple pendulum motion is presented in Figure 7. Consistent with the mass-spring system, the periodic motion of the pendulum is a sinusoidal function of time. The ball was swung to the left initially. The position of the ball perfectly follows the sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$. Meanwhile, the acceleration graph fits the sine function with $\phi = \frac{\pi}{2}$.

We have shown through analysis with *Tracker* that uniform circular motion has symmetry with simple harmonic motion. The linear position, velocity, and acceleration in uniform circular motion fit the sinusoidal function of time, which is the same in simple harmonic motion.

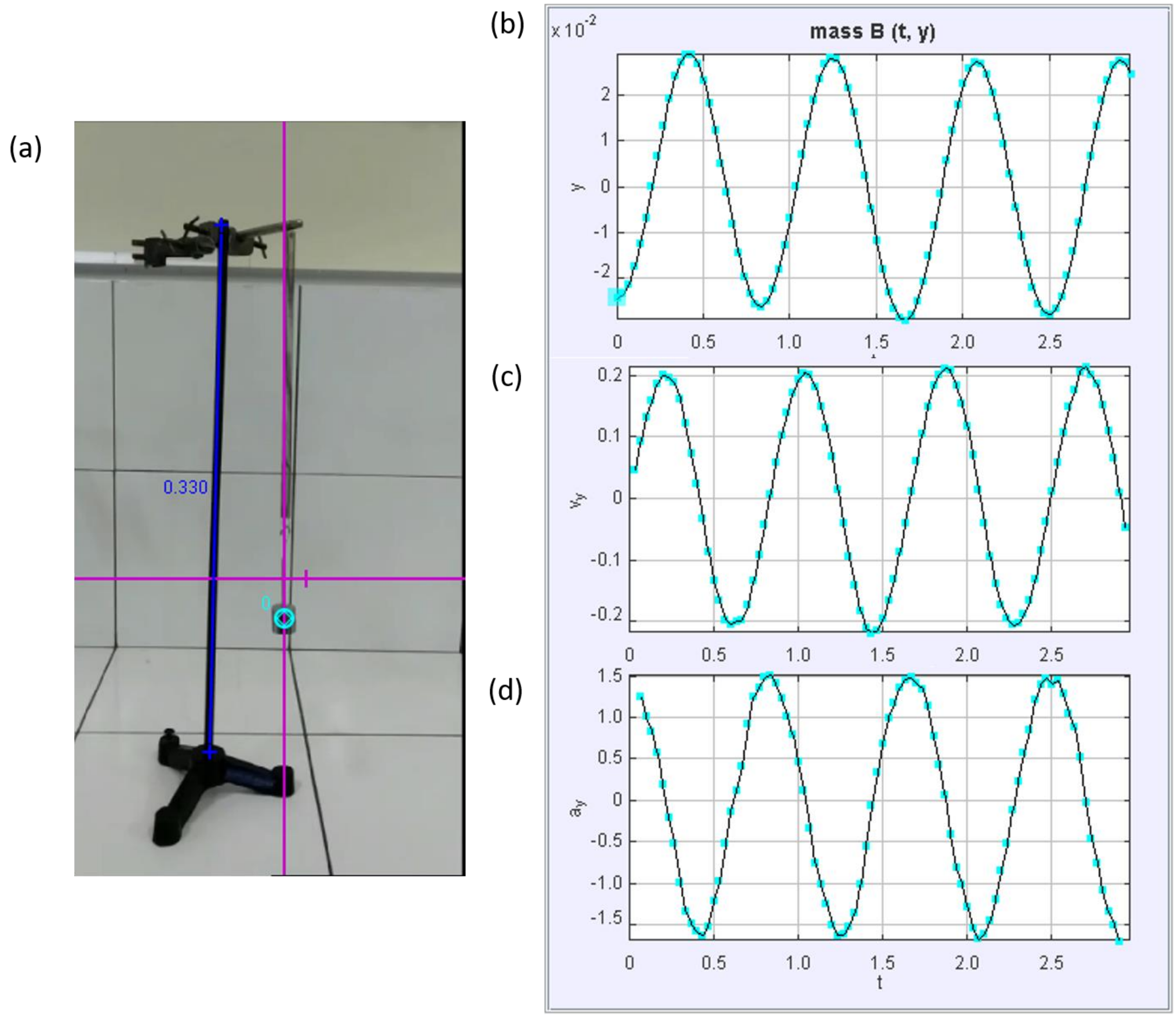

Figure 6. (a) simple harmonic motion experiment using spring and slotted weight, (b) y-position, (c) y-component velocity, (d) y-component acceleration of mass as functions of time in the simple harmonic motion of a spring-mass system. All quantities are presented in SI unit.

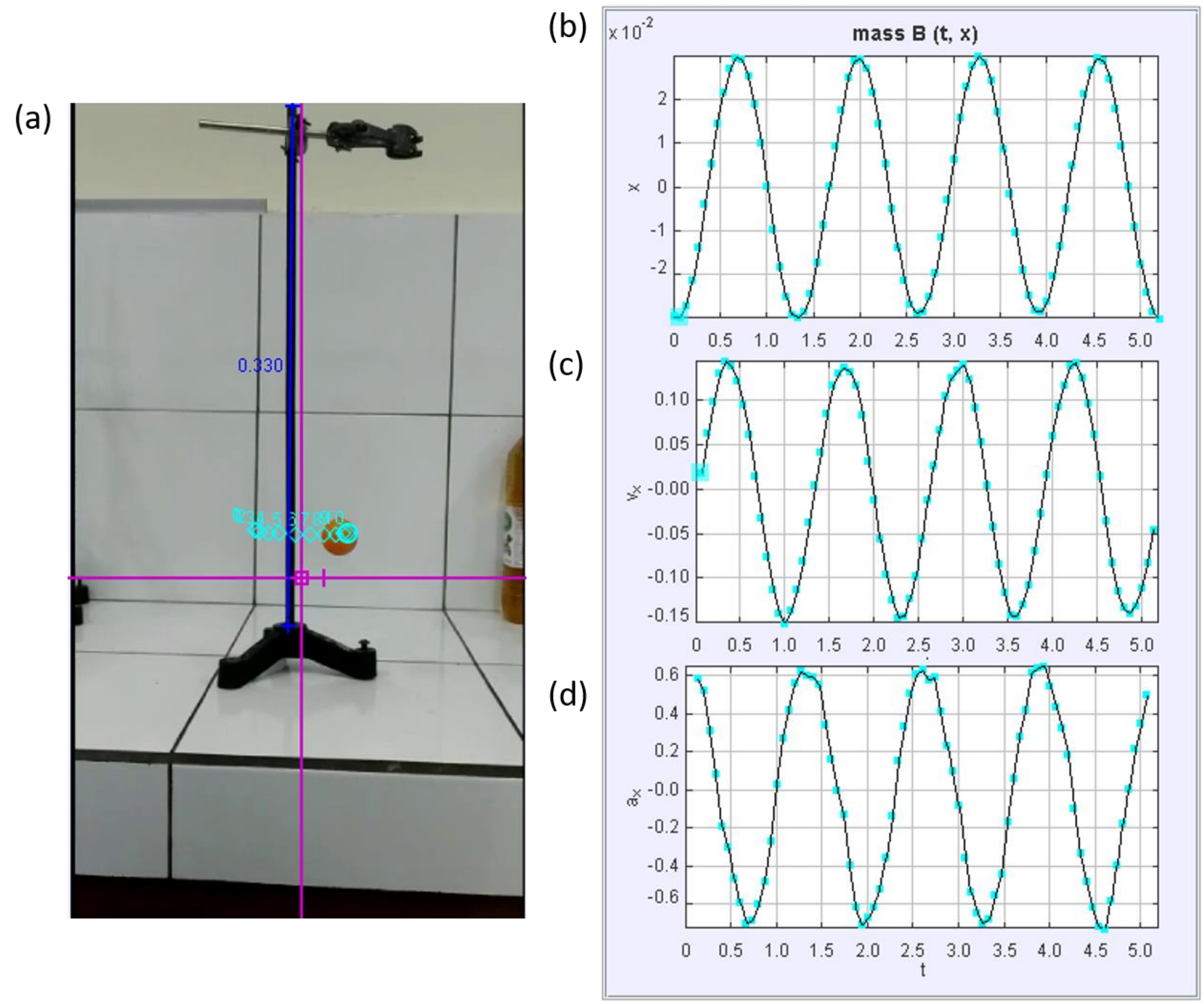

Figure 7. (a) simple pendulum experiment, (b) x-position, (c) x-component velocity, (d) x-component acceleration of mass as functions of time in a simple harmonic motion of simple pendulum system. All quantities are presented in SI unit.

STRATEGIC IMPLEMENTATION IN CLASS

A simple experiment with *Tracker* software is potential to be embedded in a physics classroom to enhance students' conceptual understanding in a uniform circular motion and simple harmonic motion. There are some possible ways to implement this simple experiment in the classroom. For example, the teacher can bring a recorded video about uniform circular motion and simple harmonic motion in class. At the beginning of the class, the videos are distributed to students. With teacher guidance, students are asked to analyze the videos with *Tracker* software. In the scenario, students, individually or in a group, can record the uniform circular motion and simple harmonic motion by themselves with the teacher's help. This scenario will engage students more in the experiments and hopefully, students become more motivated in learning physics.

The teacher can make this activity as projects, laboratory activity, homework or class demonstration. After the activity, the teacher can discuss the relation between simple harmonic motion and uniform circular motion in class through a mathematical approach. The discussion will enrich the students' conceptual knowledge about simple harmonic motion and circular motion.

CONCLUSION

In summary, we have demonstrated the relationship between uniform circular motion and simple harmonic motion by a simple experiment using *Tracker* with non-mathematical approach. The equation of motion of an object which moves in a uniform circular motion is analog to an object which moves in simple harmonic motion such as in spring-mass or pendulum system. The x- and y-coordinates of an object undergoes uniform circular motion, fit to the sinusoidal function of time. The velocity and acceleration also fit the sinusoidal function of time. In other words, we can say that simple harmonic motion can be considered as a projection of uniform circular motion. This demonstration can be embedded in high school physics classes to enhance students' conceptual understanding of simple harmonic motion and uniform circular motion.

REFERENCES

Aguilar-Marin, P., Chaves-Bacilio, M., & Jáuregui-Rosas, S. (2018). Using analog instruments in *Tracker* video-based experiments for understanding electricity and magnetism phenomena in physics education. *European Journal of Physics*, *39*(3), 035204.

Amoroso, A., & Rinaudo, M. (2018). Study of oscillatory motion using smartphones and *Tracker* software Study of oscillatory motion using smartphones and *Tracker* software. *Journal of Physics: Conference Series*.

Poonyawatpornkul, J., & Wattanakasiwich, P. (2013). High-speed video analysis of damped harmonic motion. *Physics Education*, *782*.

Rodrigues, M., Marques, M. B., & Sime, P. (2016). How to build a low cost spectrometer with *Tracker* for teaching light spectra. *Physics Education*, *51*, 014002. https://doi.org/10.1088/0031-9120/51/1/014002

Rodrigues, M., & P, S. C. (2014). Teaching optical phenomena with *Tracker*. *Physics Education*, *49*(6), 671–677.

Tracker Video Analysis and Modeling Tool. (2019). Retrieved from https://physlets.org/*Tracker*/

Wee, L. K., Tan, K. K., & Leong, T. K. (2015). Using *Tracker* to understand ‘ toss up ’ and free fall motion : a case study. *Physics Education*, *50*(4), 436–442. https://doi.org/10.1088/0031-9120/50/4/436

2.	**Bukti konfirmasi review dan hasil review (accepted with minor revision)**	**18 Februari 2020**

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[RMF E] Editor Decision

6 messages

Prof. Alejandro Ayala <rmf@ciencias.unam.mx>
To: Ms Elisabeth FOUNDA Pratidhina <elisa.founda@gmail.com>

Dear Ms Elisabeth FOUNDA Pratidhina:

We are pleased to inform you that your paper titled: "Relating Simple Harmonic Motion and Uniform Circular Motion with Tracker", has been accepted for publication in Revista Mexicana de Física E.

Comments from the referee are enclosed for your information. Please notice that the reviewer suggests that for the final version you correct a typo in Fig. 5.

Sincerely,

Prof. Alejandro Ayala
Chief Editor
Revista Mexicana de Física

Reviewer A:

Subject: Relating Simple Harmonic Motion and Uniform Circular Motion with Tracker

----

Reviewer A:

Subject: Relating Simple Harmonic Motion and Uniform Circular Motion with Tracker

The manuscript is well written, it only has one typo. The authors properly cite past literature with similar findings to theirs, so comparing their findings to these studies in particular would be most helpful to the reader. The manuscript is concise and easy to understand. Effectively presents a demonstrative interesting relationship between uniform circular motion and simple harmonic motion trough simple experiment using the free software Tracker. I found especially valuable how they have shown that uniform circular motion has symmetry with simple harmonic motion through VideoTracker analysis, where they have shown that the positions of an object undergoes uniform circular motion fit to sinusoidal function of time, as same as, the one shown in a simple harmonic motion. Comparing the analytical and experimental method the results are consistent. Also, are very helpful experiments for students and teachers of engineering faculty. The article could be published with a improvement:

Minor typographical improvement:

In the Figure 5 in the incise (c) should be replaced “compenent” by “component”.

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Elisabeth Founda <elisa.founda@gmail.com> Tue, Feb 18, 2020 at 8:48 PM
To: "Prof. Alejandro Ayala" <rmf@ciencias.unam.mx>

Dear. Prof. Alejandro Ayala

Thank you for the response

We will revise the manuscript soon

Thank you

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Elisabeth Founda <elisa.founda@gmail.com>
To: "Prof. Alejandro Ayala" <rmf@ciencias.unam.mx>

Tue, Feb 18, 2020 at 9:56 PM

Dear. Prof. Alejandro Ayala

We have read the reviewer comments and revised our manuscript.
We make some changes on the sentences and correct the typo.
In addition, we also revised the authors' affiliation in the manuscript
The revised manuscript is attached in this email

Thank you

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With sincere regards,

Elisabeth Pratidhina Founda Noviani

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Revista Mexicana de Fisica <rmf@ciencias.unam.mx>
to me

Sat, Feb 22, 2020, 3:36 AM

Dear Ms Elisabeth FOUNDA Pratidhina:

We acknowledge receipt the file.

We will now begin the technical editing process that includes layout and style correction. This process is carried out for all received papers in strict chronological order according to the reception date of the aforementioned files. The technical editor will contact and send you the galley proof. This process can take a bit more than a couple of weeks, this means that the status of your work in our platform during this time will be "in editing".

We thank you in advance for your understanding.

Sincerely,
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Revista Mexicana de Física.

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Elisabeth Pratidhina[1, 2]*, Ferina Rizky Yuliani[2], Wipsar Sunu Brams Dwandaru[1]

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THEORY

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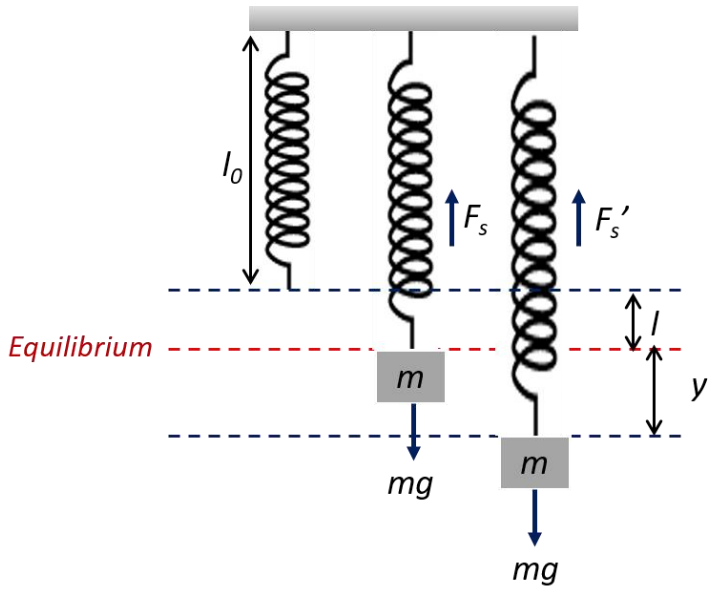

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Or

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$$v(t) = \frac{dy(t)}{dt} = -A\omega\sin(\omega t + \phi) \tag{5}$$

$$a(t) = \frac{dv(t)}{dt} = -A\,\omega^2\cos(\omega t + \phi) \tag{6}$$

Uniform Circular Motion

A particle moves within uniform circular motion when it moves in a circular path with a constant angular speed. The angular position of a particle is given as:

$$\theta(t) = \phi + \omega t$$

where ω is angular speed, whereas ϕ is the initial angular position or initial phase.

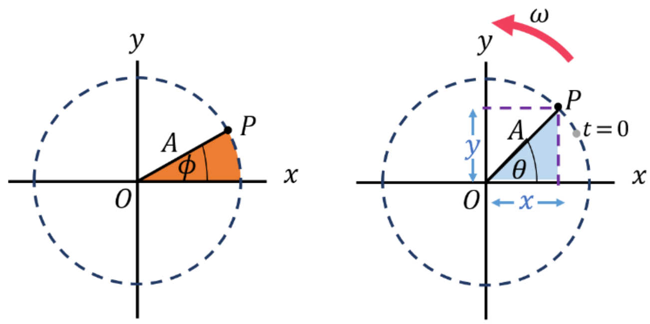

Figure 2. Particle *P* goes through the uniform circular motion with a constant angular speed of ω. The figure on the left is the initial particle's position. The figure on the right side is the particle's position at time t.

Particle P, in Figure 2, is moving in a uniform circular motion. It moves in a circle with a radius of A and constant angular speed ω. The x-coordinate of particle P is given by:

$$x(t) = A\cos\theta = A\cos(\omega t + \phi) \tag{7}$$

The x-coordinate of particle P is a sinusoidal function of time, analogous to the simple harmonic motion. The x-component of velocity and acceleration are given in equation (8) and (9), respectively.

$$v_x(t) = \frac{d}{dt}x(t) = -A\omega\sin(\omega t + \phi) \tag{8}$$

$$a_x(t) = \frac{d}{dt}v_x(t) = -A\omega^2\cos(\omega t + \phi) \tag{9}$$

The y-coordinates of particle P is also analogous to SHM motion, following the sinusoidal function of time (see equation (10)).

$$y(t) = A\cos\theta = A\sin(\omega t + \phi) \tag{10}$$

$$v_y(t) = \frac{d}{dt}y(t) = -A\omega\cos(\omega t + \phi) \tag{11}$$

$$a_y(t) = \frac{d}{dt}v_y(t) = -A\omega^2\sin(\omega t + \phi) \tag{12}$$

EXPERIMENTAL SETUP

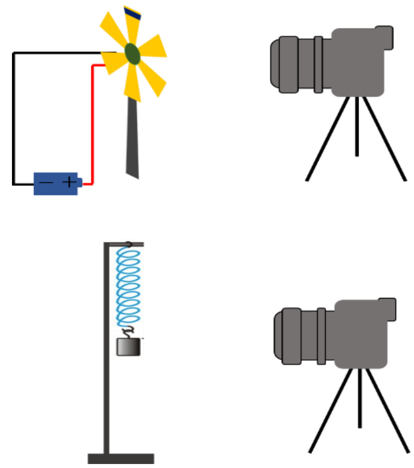

Figure 3. Experimental set-up of (a) uniform circular motion using an electrical fan, (b) simple harmonic motion using spring and slotted weight.

The experimental setup is simple, as shown in Figure 3. The behavior of uniform circular motion is investigated by recording the motion of tape, which is stuck on an electric fan (see Figure 3a). The recorded video is then analyzed with *Tracker* software. Through *Tracker*, we get data about position, velocity, and acceleration as a function of time. Meanwhile, the behavior of simple harmonic motion is represented by the motion of a slotted weight which is attached to a vertical spring (see Figure 3b).

RESULT AND DISCUSSION

The position of an object attached to a fan which moves with constant angular speed has been analyzed through *Tracker* software. As time goes on, the x-coordinate of the object goes down and up following cosine function (see Figure 4a) as predicted in theory. Although it is not perfectly smooth, the x-component of linear velocity tends to follow sine function with an initial phase (ϕ) of π radians. Meanwhile, the x-component of acceleration tends to follow negative cosine function, consistent with equation (7).

As shown in Figure 5, the y-coordinate of the object on uniform circular motion smoothly fits with the sine function in equation (8). On the other hand, the y-component of velocity and acceleration graph are not as smooth as the position graph. However, the y-component of velocity and acceleration still tend to follow cosine and negative sine function, respectively. These results demonstrate that uniform circular motion has symmetry with simple harmonic motion.

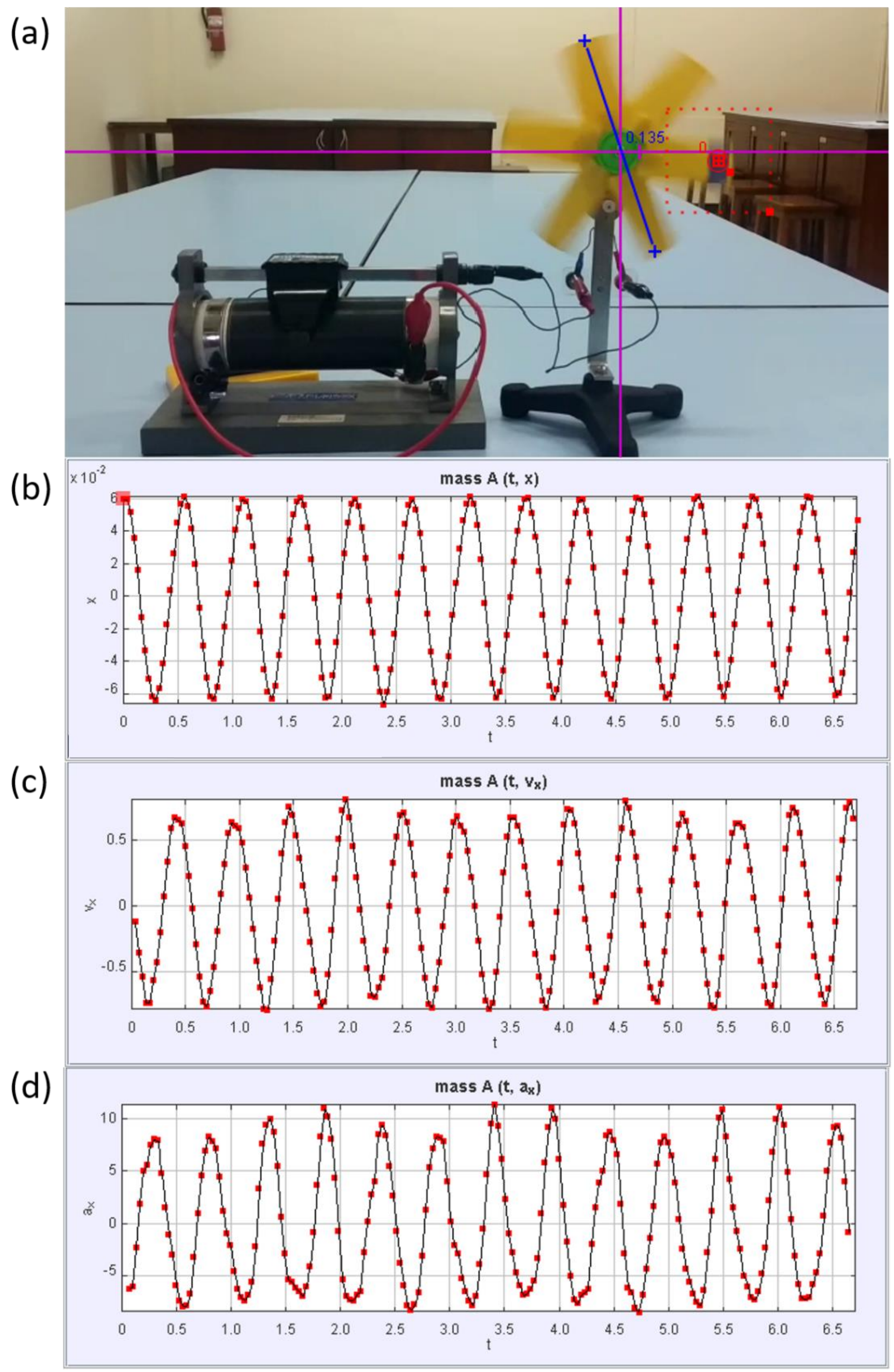

Figure 4. (a) uniform circular motion experiment using an electric fan (b) x-position versus time graph, (d), x-component linear velocity versus time graph, (e) x-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.

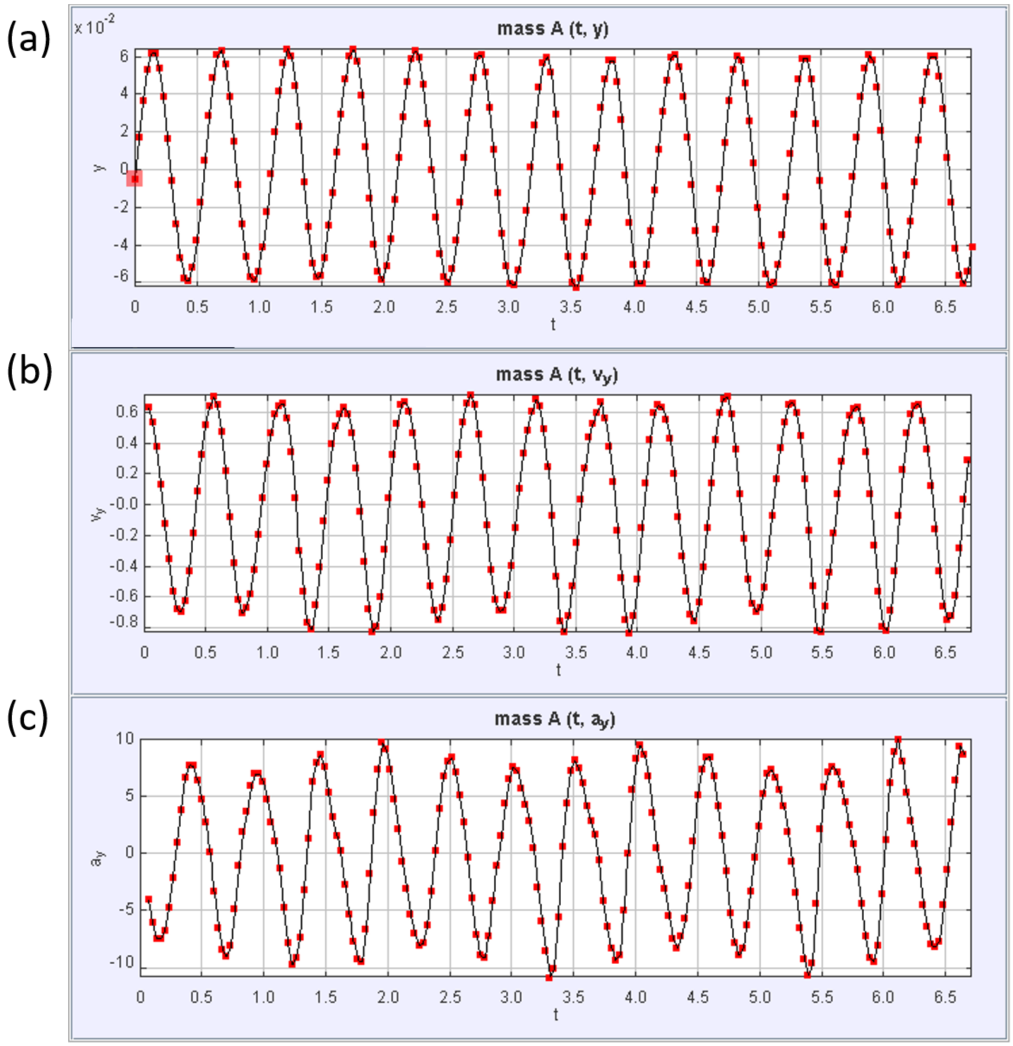

Figure 5. (a) y-position versus time graph, (c), y-component linear velocity versus time graph, (d) y-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.

In addition, we did experiment with a well-known simple harmonic motion system, i.e. mass-spring system and simple pendulum. Figure 6a-c shows the position, velocity, and acceleration of a slotted weight attached on a vertical spring as functions of time. The spring was initially stretched down. As predicted, the position of slotted weight fits sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$, whereas the acceleration fits cosine function or sine function with $\phi = \frac{\pi}{2}$.

The analysis of simple pendulum motion is presented in Figure 7. Consistent with the mass-spring system, the periodic motion of the pendulum is a sinusoidal function of time. The ball was swung to the left initially. The position of the ball perfectly follows the sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$. Meanwhile, the acceleration graph fits the sine function with $\phi = \frac{\pi}{2}$.

We have shown through analysis with *Tracker* that uniform circular motion has symmetry with simple harmonic motion. The linear position, velocity, and acceleration in uniform circular motion fit the sinusoidal function of time, which is the same in simple harmonic motion.

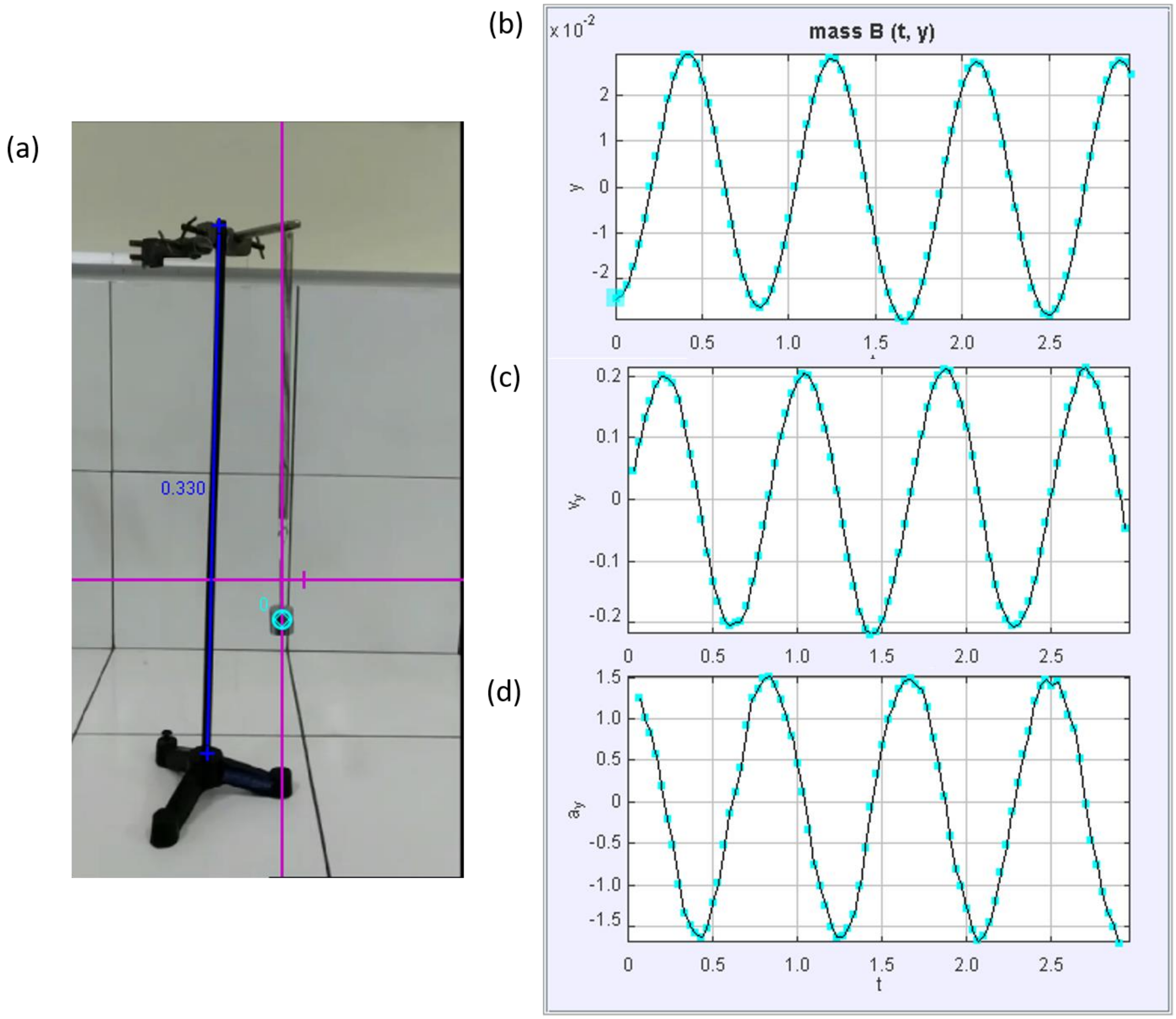

Figure 6. (a) simple harmonic motion experiment using spring and slotted weight, (b) y-position, (c) y-component velocity, (d) y-component acceleration of mass as functions of time in the simple harmonic motion of a spring-mass system. All quantities are presented in SI unit.

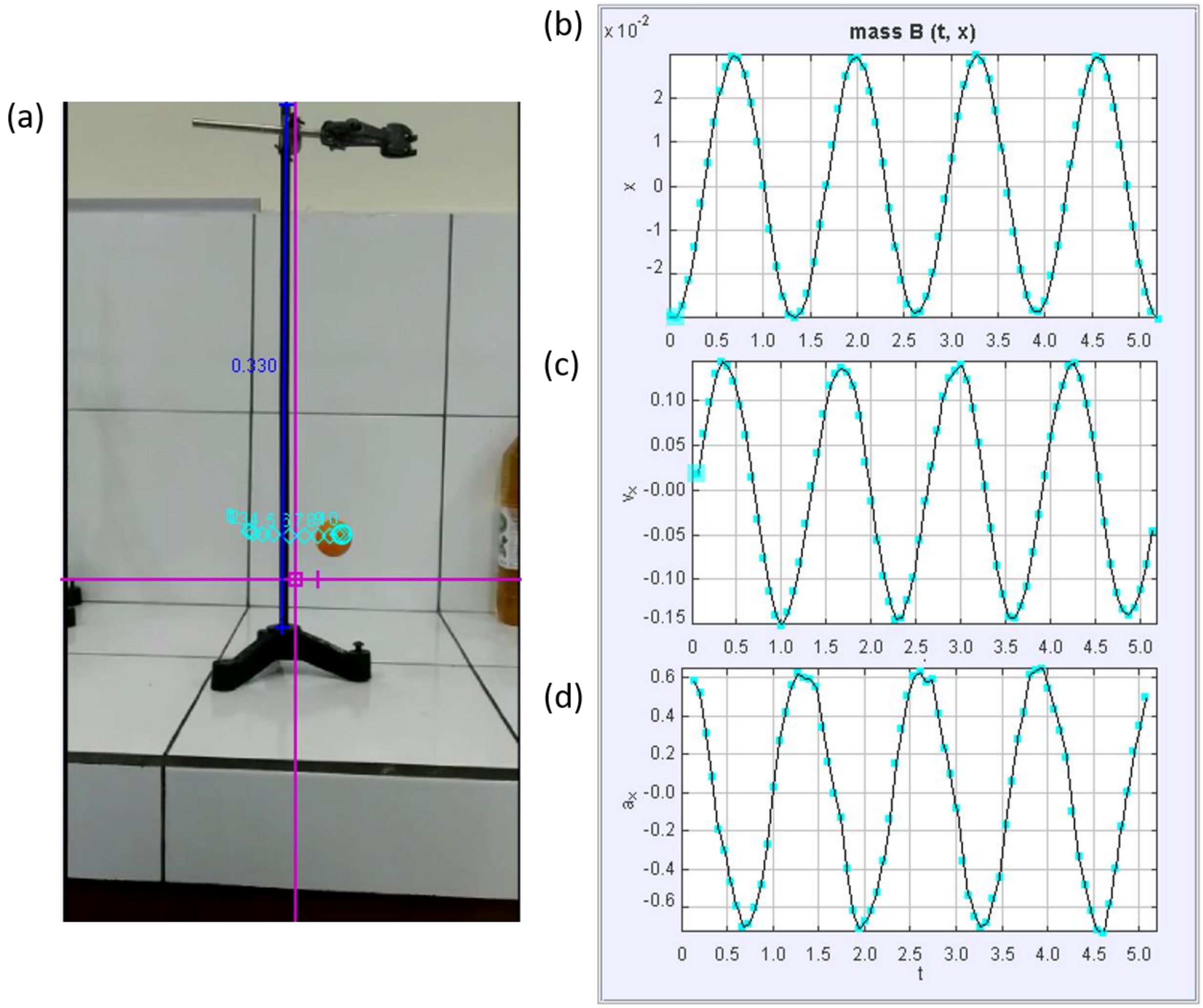

Figure 7. (a) simple pendulum experiment, (b) x-position, (c) x-component velocity, (d) x-component acceleration of mass as functions of time in a simple harmonic motion of simple pendulum system. All quantities are presented in SI unit.

STRATEGIC IMPLEMENTATION IN CLASS

A simple experiment with *Tracker* software is potential to be embedded in a physics classroom to enhance students' conceptual understanding in a uniform circular motion and simple harmonic motion. There are some possible ways to implement this simple experiment in the classroom. For example, the teacher can bring a recorded video about uniform circular motion and simple harmonic motion in class. At the beginning of the class, the videos are distributed to students. With teacher guidance, students are asked to analyze the videos with *Tracker* software. In the scenario, students, individually or in a group, can record the uniform circular motion and simple harmonic motion by themselves with the teacher's help. This scenario will engage students more in the experiments and hopefully, students become more motivated in learning physics.

The teacher can make this activity as projects, laboratory activity, homework or class demonstration. After the activity, the teacher can discuss the relation between simple harmonic motion and uniform circular motion in class through a mathematical approach. The discussion will enrich the students' conceptual knowledge about simple harmonic motion and circular motion.

CONCLUSION

In summary, we have demonstrated the relationship between uniform circular motion and simple harmonic motion by a simple experiment using *Tracker* with non-mathematical approach. The equation of motion of an object which moves in a uniform circular motion is analog to an object which moves in simple harmonic motion such as in spring-mass or pendulum system. The x- and y-coordinates of an object undergoes uniform circular motion, fit to the sinusoidal function of time. The velocity and acceleration also fit the sinusoidal function of time. In other words, we can say that simple harmonic motion can be considered as a projection of uniform circular motion. This demonstration can be embedded in high school physics classes to enhance students' conceptual understanding of simple harmonic motion and uniform circular motion.

REFERENCES

Aguilar-Marin, P., Chaves-Bacilio, M., & Jáuregui-Rosas, S. (2018). Using analog instruments in *Tracker* video-based experiments for understanding electricity and magnetism phenomena in physics education. *European Journal of Physics*, *39*(3), 035204.

Amoroso, A., & Rinaudo, M. (2018). Study of oscillatory motion using smartphones and *Tracker* software Study of oscillatory motion using smartphones and *Tracker* software. *Journal of Physics: Conference Series*.

Poonyawatpornkul, J., & Wattanakasiwich, P. (2013). High-speed video analysis of damped harmonic motion. *Physics Education*, *782*.

Rodrigues, M., Marques, M. B., & Sime, P. (2016). How to build a low cost spectrometer with *Tracker* for teaching light spectra. *Physics Education*, *51*, 014002. https://doi.org/10.1088/0031-9120/51/1/014002

Rodrigues, M., & P, S. C. (2014). Teaching optical phenomena with *Tracker*. *Physics Education*, *49*(6), 671–677.

Tracker Video Analysis and Modeling Tool. (2019). Retrieved from https://physlets.org/*Tracker*/

Wee, L. K., Tan, K. K., & Leong, T. K. (2015). Using *Tracker* to understand ‘ toss up ’ and free fall motion : a case study. *Physics Education*, *50*(4), 436–442. https://doi.org/10.1088/0031-9120/50/4/436

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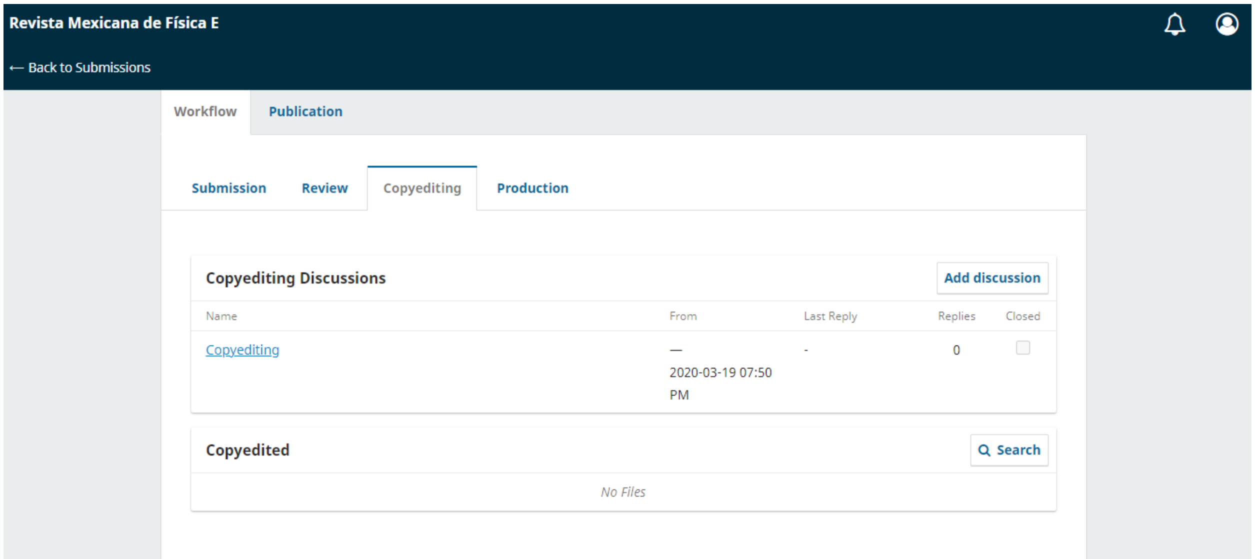
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E. Pratidhina *et al.*, *Relating simple harmonic motion and uniform circular motion with Tracker*

Q1: between → between the
Q2: low cost-easily found materials → low cost, easily-found materials,
Q3: software, *Tracker* → software Tracker
Q4: Video *Tracker* analysis → video analysis with Tracker
Q5: phone → phones
Q6: camera, internet, sensor, spreadsheet, game, → cameras, internet, a variety of sensors, spreadsheets, games,
Q7: camera feature on a mobile phone → the inclusion of cameras on mobile phones
Q8: activity → activities
Q9: *Tracker* → Tracker
Q10: *Tracker* is free → Tracker is a free
Q11: *Tracker* → Tracker
Q12: *Tracker* → Tracker
Q13: Poonyawatpornkul and Wattanakasiwich
Q14: *Tracker* → Tracker
Q15: Rodrigues and Simeão Carvalho
Q16: *Tracker* → Tracker
Q17: delete "while"
Q18: Wee *et al.*
Q19: *Tracker* → Tracker
Q20: class → lessons
Q21: *Tracker* → Tracker
Q22: particle's positions → particles' positions
Q23: *Tracker* → Tracker
Q24: *Tracker* → Tracker
Q25: m → m
Q26: by → with
Q27: insert comma after ma
Q28: include equation number
Q29: replace period with comma at the end of equation
Q30: remove indent
Q31: remove comma
Q32: (3); → Eq. (3),
Q33: insert comma at the end of equation
Q34: A in called amplitude, whereas ϕ is called initial phase.→ where A is the amplitude and ϕ is the initial phase.
Q35: (acceleration should be the second derivative of the position or the first derivative of the velocity)
Q36: remove comma
Q37: remove comma
Q38: remove ":"

Q39: Eq. → Eqs.
Q40: replace period with comma and insert comma and period after Eqs. (9) and (10), respectively
Q41: replace period with comma
Q42: *Tracker* software → Tracker
Q43: *Tracker* → Tracker
Q44: unit → units
Q45: unit → units
Q46: *Tracker* software → Tracker
Q47: y → y
Q48: did → performed an
Q49: *i.e.* → i.e.,
Q50: unit → units
Q51: unit → units
Q52: *Tracker* → Tracker
Q53: *Tracker* software is potential to be embedded in a physics classroom→ Tracker could potentially be included in physics classrooms
Q54: *Tracker* software → Tracker
Q55: *Tracker* → Tracker

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Q56: P. Aguilar-Marín, M. Chavez-Bacilio, and S. Jáuregui-Rosas, Using analog instruments in Tracker video-based experiments to understand the phenomena of electricity and magnetism in physics education, *Eur. J. Phys.* **39** (2018) 035204, https://doi.org/10.1088/1361-6404/aaa8f8.
Q57: A. Amoroso and M. Rinaudo, Study of oscillatory motion using smartphones and tracker software, *J. Phys. Conf. Ser.* **1076** (2018) 012013, https://doi.org/10.1088/1742-6596/1076/1/012013.
Q58: J. Poonyawatpornkul and P. Wattanakasiwich, High-speed video analysis of damped harmonic motion, *Phys. Educ.* **48** (2013) 782, https://doi.org/10.1088/0031-9120/48/6/782.
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Q60: M. Rodrigues and P. Simeão Carvalho, Teaching optical phenomena with Tracker, *Phys. Educ.* **49** (2014) 671, https://doi.org/10.1088/0031-9120/49/6/671.
Q61: D. Brown, "Tracker: Video Analysis and Modeling Tool", Physlets.org, https://physlets.org/tracker/.
Q62: L. K. Wee, K. K. Tan, T. K. Leong, and C. Tan, Using Tracker to understand 'toss up' and free fall motion: a case study, *Phys. Educ.* **50** (2015) 436, https://doi.org/10.1088/0031-9120/50/4/436.

Relating simple harmonic motion and uniform circular motion with Tracker

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Q1 In this study, we demonstrate an interesting relationship between simple harmonic motion and uniform circular motion trough a simple experiment. The experiment requires a low cost-easily found materials and free software, *Tracker*. To represent uniform circular motion, we use a tape that is stuck on a fan moving with the constant angular speed. Meanwhile, spring and pendulum motion are used to represent simple harmonic motion. Through Video *Tracker* analysis, we have shown that the positions (x and y coordinates) of an object undergoes uniform circular motion fit to the sinusoidal function of time, similar to simple harmonic motion. We also analyze the behavior of velocity and acceleration in simple harmonic motion and uniform circular motion. This simple experiment can be used in high school physics courses to lead students in developing a conceptual understanding of uniform circular motion with a less mathematical approach.

Keywords: Simple harmonic motion; uniform circular motion; physics demonstration; Tracker

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1. Introduction

Recently, there is a rapid development of imaging technol-
Q5 ogy. Moreover, technology in mobile phone has been improved significantly. Nowadays, mobile phones provide various features such as camera, internet, sensor, spreadsheet, game, and so on. The development of imaging technology and camera feature on a mobile phone can be used for physics teaching and learning activity. By using imaging technology, *Tracker* has become a useful tool in physics educa-
Q10 tion. *Tracker* is free software developed on the Open Source Physics Java code library which can be used for video analysis and physics modeling. *Tracker* includes features such as object tracking with position, velocity, and acceleration overlays and graphs, calibration points and line profiles for analysis of spectra and interference patterns [6].

Some studies have explored the potential of *Tracker* for pedagogical learning tools [2-4,7]. Poonyawatpornkul Wattanakasiwich [3] use *Tracker* to analyze damped har-
Q15 monic oscillation; Rodrigues [5] use *Tracker* to teach optical phenomena; while Loo Kang Wee [7] integrate *Tracker*
Q20 in physics class when discussing free-fall motion. *Tracker* allows students to identify relationships between physical quantities through observation, compare the real world with mathematical modeling, and be trained to construct a model for a particular physical phenomenon [1].

Circular motion and simple harmonic motion are discussed several times in high school physics and introductory college physics courses. Uniform circular motion and simple harmonic motion have close relationships. Simple harmonic motion is a term used when the periodic motion is a sinusoidal function of time. Most students are able to notice simple harmonic motion in the spring-mass system and the simple pendulum. In fact, the $x-$ and $y-$coordinates of particle's positions in uniform circular motion are also a sinusoidal function of time, similar to simple harmonic motion. Sometimes students face difficulty to relate uniform circular motion and simple harmonic motion trough geometric and mathematical approaches.

In this work, we show a simple experiment using *Tracker* to compare uniform circular motion and simple harmonic motion. Experiments, representing uniform circular motion and simple harmonic motion, have been conducted with simple materials and tools which can be found easily in daily life. The phenomena were recorded with a mobile phone camera. After that, the videos were analyzed through *Tracker*.

2. Theory

2.1. Simple harmonic motion in vertical spring-mass system

One of the physical systems representing simple harmonic motion is a vertical spring-mass system. A particle with mass
m is attached on vertical spring with an original length of l_o Q25
such as shown in Fig. 1. At equilibrium point, the spring force is balanced by the gravitational force, or according to Newton's first law, $\boldsymbol{F}_s + \boldsymbol{F}_g = 0$. Thus,

$$-kl + mg = 0,$$

or

$$kl = mg. \tag{1}$$

When the spring is stretched down leaving its equilibrium position, there is acceleration, so that $\sum \boldsymbol{F} = m\boldsymbol{a}$

$$\boldsymbol{F}_s + \boldsymbol{F}_g = \boldsymbol{m}a,$$

$$-k(l+y) + mg = m\frac{d^2y}{dt^2}.$$

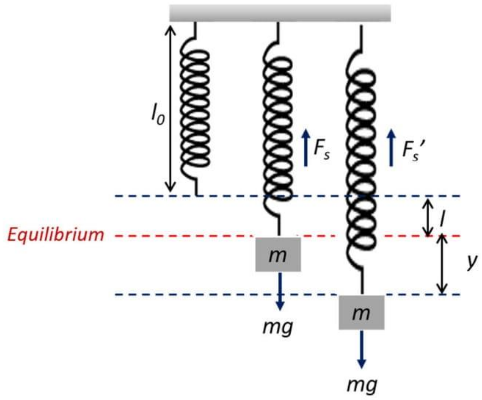

FIGURE 1. Vertical Spring-Mass System.

Since $kl = mg$,

$$-ky = m\frac{d^2y}{dt^2}. \tag{2}$$

Q30 Equation (2) can be written as:

$$\frac{d^2y}{dt^2} = \omega^2 y, \tag{3}$$

where, $\omega^2 = k/m$.

By solving the second-order differential equation in (3); we yield a solution for the particle's position as follows:

$$y(t) = A\cos(\omega t + \phi) \tag{4}$$

A is called amplitude, whereas ϕ is called initial phase. Both of A and ϕ depend on the initial condition of the particle. As described in Eq. (4), the particle's periodic motion is a sinusoidal function of time, in which the sinusoidal function is a cosine function. It is the main characteristic of simple harmonic motion. Furthermore, we can determine the velocity and acceleration of the particle by taking the first and second derivative of Eq. (4), respectively. Thus,

$$v(t) = \frac{dy(t)}{dt} = -A\omega\sin(\omega t + \phi), \tag{5}$$

Q35

$$a(t) = \frac{dy(t)}{dt} = -A\omega^2\sin(\omega t + \phi). \tag{6}$$

2.2. Uniform circular motion

A particle moves within uniform circular motion when it moves in a circular path with a constant angular speed. The angular position of a particle is given as:

$$\theta(t) = \phi + \omega t, \tag{7}$$

where ω is angular speed, whereas ϕ is the initial angular position or initial phase.

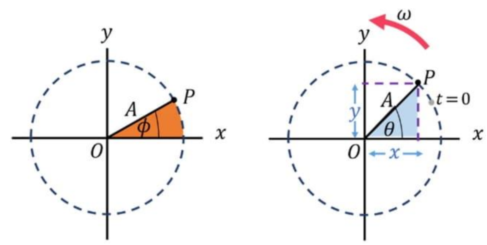

FIGURE 2. Particle P goes through the uniform circular motion with a constant angular speed of ω. The figure on the left is the initial particle's position. The figure on the right side is the particle's position at time t.

Particle P, in Fig. 2, is moving in a uniform circular motion. It moves in a circle with a radius of A and constant angular speed ω. The $x-$coordinate of particle P is given by:

$$x(t) = A\cos\theta = A\cos(\omega t + \phi). \tag{8}$$

The $x-$coordinate of particle P is a sinusoidal function of time, analogous to the simple harmonic motion. The $x-$component of velocity and acceleration are given in Eq. (8) and (9), respectively. Q40

$$v_x(t) = \frac{d}{dt}x(t) = -A\omega t\sin(\omega t + \phi) \tag{9}$$

$$a_x(t) = \frac{d}{dt}v_x(t) = -A\omega^2 t\cos(\omega t + \phi) \tag{10}$$

The $y-$coordinates of particle P is also analogous to SHM motion, following the sinusoidal function of time (see Eq. (10)).

$$y(t) = A\cos\theta = A\sin(\omega t + \phi), \tag{11}$$

$$v_x(t) = \frac{d}{dt}y(t) = -A\omega\cos(\omega t + \phi), \tag{12}$$

$$a_y(t) = \frac{d}{dt}v_y(t) = -A\omega^2 t\sin(\omega t + \phi). \tag{13}$$

3. Experimental setup

The experimental setup is simple, as shown in Fig. 3. The behavior of uniform circular motion is investigated by recording the motion of tape, which is stuck on an electric fan (see Fig. 3a). The recorded video is then analyzed with *Tracker* software. Through *Tracker*, we get data about position, velocity, and acceleration as a function of time. Meanwhile, the behavior of simple harmonic motion is represented by the motion of a slotted weight which is attached to a vertical spring (see Fig. 3b).

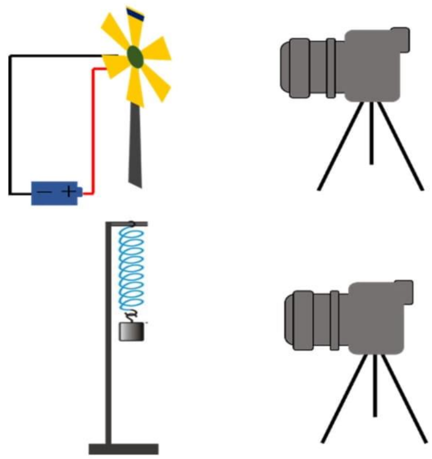

FIGURE 3. Experimental set-up of (a) uniform circular motion using an electrical fan, (b) simple harmonic motion using spring and slotted weight.

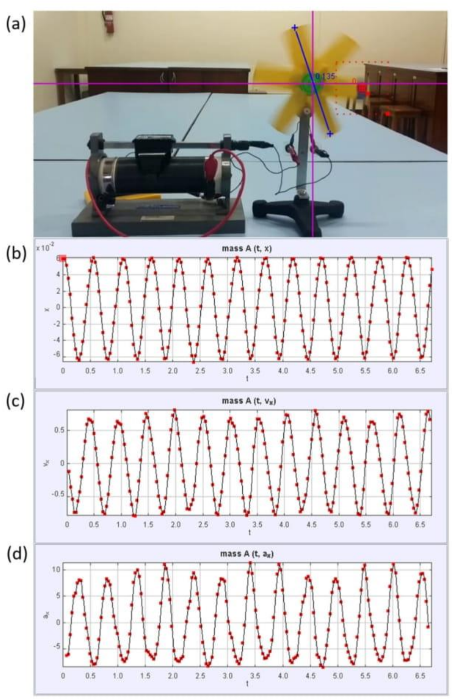

FIGURE 4. (a) Uniform circular motion experiment using an electric fan, (b) $x-$position versus time graph, (c) $x-$component linear velocity versus time graph, (d) $x-$component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.
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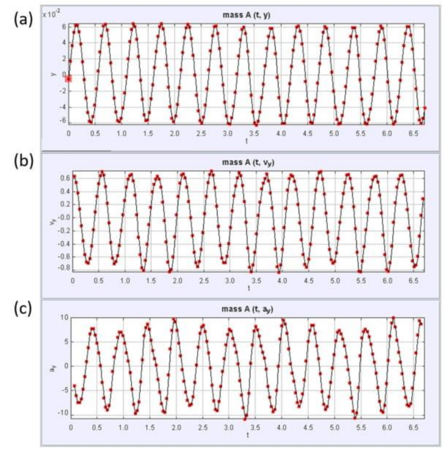

FIGURE 5. (a) $y-$position versus time graph, (b) $y-$component linear velocity versus time graph, (c) $y-$component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI unit.

4. Result and discussion

The position of an object attached to a fan which moves with constant angular speed has been analyzed through *Tracker* software. As time goes on, the $x-$coordinate of the object goes down and up following cosine function (see Fig. 4a) as predicted in theory. Although it is not perfectly smooth, the $x-$component of linear velocity tends to follow sine function with an initial phase (ϕ) of π radians. Meanwhile, the $x-$component of acceleration tends to follow negative cosine function, consistent with Eq. (7).

As shown in Fig. 5, the y-coordinate of the object on uniform circular motion smoothly fits with the sine function in Eq. (8). On the other hand, the $y-$component of velocity and acceleration graph are not as smooth as the position graph. However, the y-component of velocity and acceleration still tend to follow cosine and negative sine function, respectively. These results demonstrate that uniform circular motion has symmetry with simple harmonic motion.

In addition, we did experiment with a well-known simple harmonic motion system, *i.e.* mass-spring system and simple pendulum. Figure 6a-c) shows the position, velocity, and acceleration of a slotted weight attached on a vertical spring as functions of time. The spring was initially stretched down. As predicted, the position of slotted weight fits sine function with $\phi = -\pi$ radians. The velocity fits cosine function with $\phi = -\pi/2$, whereas the acceleration fits cosine function or sine function with $\phi = \pi/2$.

The analysis of simple pendulum motion is presented in Fig. 7. Consistent with the mass-spring system, the periodic motion of the pendulum is a sinusoidal function of time. The

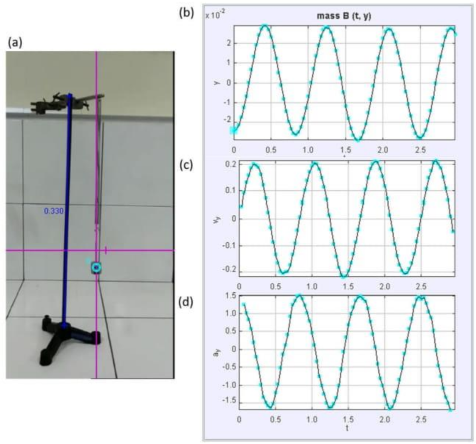

FIGURE 6. (a) simple harmonic motion experiment using spring and slotted weight, (b) $y-$position, (c) $y-$component velocity, (d) $y-$component acceleration of mass as functions of time in the simple harmonic motion of a spring-mass system. All quantities are
Q50 presented in SI unit.

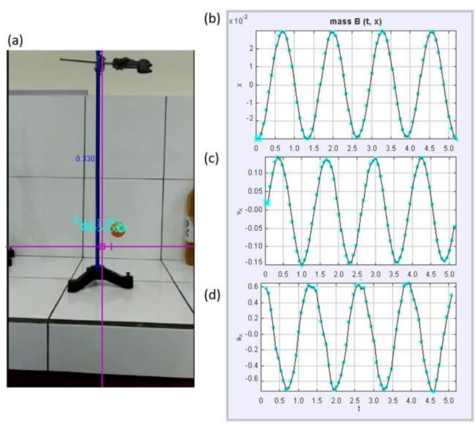

FIGURE 7. (a) simple pendulum experiment, (b) $x-$position, (c) $x-$component velocity, (d) $x-$component acceleration of mass as functions of time in a simple harmonic motion of simple pendulum system. All quantities are presented in SI unit.

ball was swung to the left initially. The position of the ball perfectly follows the sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\pi/2$. Meanwhile, the acceleration graph fits the sine function with $\phi = \pi/2$.

We have shown through analysis with *Tracker* that uniform circular motion has symmetry with simple harmonic motion. The linear position, velocity, and acceleration in uniform circular motion fit the sinusoidal function of time, which is the same in simple harmonic motion.

5. Strategic implementation in class

A simple experiment with *Tracker* software is potential to be embedded in a physics classroom to enhance students' conceptual understanding in a uniform circular motion and simple harmonic motion. There are some possible ways to implement this simple experiment in the classroom. For example, the teacher can bring a recorded video about uniform circular motion and simple harmonic motion in class. At the beginning of the class, the videos are distributed to students. With teacher guidance, students are asked to analyze the videos with *Tracker* software. In the scenario, students, individually or in a group, can record the uniform circular motion and simple harmonic motion by themselves with the teacher's help. This scenario will engage students more in the experiments and hopefully, students become more motivated in learning physics.

The teacher can make this activity as projects, laboratory activity, homework or class demonstration. After the activity, the teacher can discuss the relation between simple harmonic motion and uniform circular motion in class through a mathematical approach. The discussion will enrich the students' conceptual knowledge about simple harmonic motion and circular motion.

6. Conclusion

In summary, we have demonstrated the relationship between uniform circular motion and simple harmonic motion by a simple experiment using *Tracker* with non-mathematical ap- Q55
proach. The equation of motion of an object which moves in a uniform circular motion is analog to an object which moves in simple harmonic motion such as in spring-mass or pendulum system. The $x-$ and $y-$coordinates of an object undergoes uniform circular motion, fit to the sinusoidal function of time. The velocity and acceleration also fit the sinusoidal function of time. In other words, we can say that simple harmonic motion can be considered as a projection of uniform circular motion. This demonstration can be embedded in high school physics classes to enhance students' conceptual understanding of simple harmonic motion and uniform circular motion.

1. P. Aguilar-Marin, M. Chaves-Bacilio, and S. Jáuregui-Rosas, *Eur. J. Phys.* **39** (2018) 035204.
2. A. Amoroso and M. Rinaudo, *J. Phys.: Conference Series* (2018).
3. J. Poonyawatpornkul and P. Wattanakasiwich, *Phys. Ed.* (2013) 782.
4. M. Rodrigues, M. B. Marques, and P. Sime, *Phys. Educ.* **51** (2016) 014002. https://doi.org/10.1088/0031-9120/51/1/014002
5. M. Rodrigues, and S. C. P. *Phys. Ed.* **49** (2014) 671-677.
6. *Tracker* Video Analysis and Modeling Tool. (2019). Retrieved from https://physlets.org/Tracker/
7. L. K. Wee, K. K. Tan, and T. K. Leong, *Phys. Ed.*, **50** (2015) 436-442. https://doi.org/10.1088/0031-9120/50/4/436

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Elisabeth Founda <elisa.founda@gmail.com> Mar 23, 2020, 8:49 PM

to Jordi

Dear Editor of Revista Mexicana de Fisica E,

I have reviewed the copy edit file. I have made revision according to Editor's suggestion and answer the Editor's inquiries.

I also made some revision. I found some typos in the equation. In addition, I have adjusted the equations numbers.

I send my revision though this email.The revision has also been uploaded in the web.

Thank you

Authors' Comments:

1. **Equation numbers need to be adjusted. (This version has been adjusted)**
2. **Citation numbers need to be adjusted. (This version has been adjusted)**
3. **My own revisions or adjustments are indicated by yellow-highlight**
4. **PACS has been added**
5. **This version has been revised according to the editor's suggestions. The revision is indicated by orange-color font.**

Relating Simple Harmonic Motion and Uniform Circular Motion with *Tracker*

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[1]Graduate School of Educational Science, Yogyakarta State University

[2]Department of Physics Education, Widya Mandala Catholic University Surabaya

***Corresponding Email: elisa.founda@gmail.com**

ABSTRACT

In this study, we demonstrate an interesting relationship between the simple harmonic motion and uniform circular motion trough a simple experiment. The experiment requires a low cost, easily-found materials and free software Tracker. To represent uniform circular motion, we use a tape that is stuck on a fan moving with the constant angular speed. Meanwhile, spring and pendulum motion are used to represent simple harmonic motion. Through Video Tracker analysis, we have shown that the positions (x and y coordinates) of an object undergoes uniform circular motion fit to the sinusoidal function of time, similar to simple harmonic motion. We also analyze the behavior of velocity and acceleration in simple harmonic motion and uniform circular motion. This simple experiment can be used in high school physics courses to lead students in developing a conceptual understanding of uniform circular motion with a less mathematical approach.

Keyword: simple harmonic motion, uniform circular motion, physics demonstration, Tracker

PACS: 01.40.−d; 01.50.−i

INTRODUCTION

Recently, there is a rapid development of imaging technology. Moreover, technology in mobile phones has been improved significantly. Nowadays, mobile phones provide various features such as cameras, internet, a variety of sensors, spreadsheets, games, and so on. The development of imaging technology and the inclusion of cameras on mobile phones can be used for physics teaching and learning activities. By using imaging technology, Tracker has become a useful tool in physics education. Tracker is free software developed on the Open Source Physics Java code library which can be used for video analysis and physics modeling. Tracker includes features such as object tracking with position, velocity, and acceleration overlays and graphs, calibration points and line profiles for analysis of spectra and interference patterns [1].

Some studies have explored the potential of Tracker for pedagogical learning tools [2-5]. Poonyawatpornkul and Wattanakasiwich [3] use Tracker to analyze damped harmonic oscillation; Rodrigues and Simeão Carvalho [6] use Tracker to teach optical phenomena; Wee, Tan, Leong, and Tan [5] integrate Tracker in physics lessons when discussing free-fall motion. Tracker allows students to identify relationships between physical quantities through observation, compare the real world with mathematical modeling, and be trained to construct a model for a particular physical phenomenon [7]

Circular motion and simple harmonic motion are discussed several times in high school physics and introductory college physics courses. Uniform circular motion and simple harmonic motion have close relationships. Simple harmonic motion is a term used when the periodic motion is a sinusoidal function of time. Most students are able to notice simple harmonic motion in the spring-mass system and the simple pendulum. In fact, the x- and y-coordinates of particles' positions in uniform circular motion are also a sinusoidal function of time, similar to simple harmonic motion. Sometimes students face difficulty to relate uniform circular motion and simple harmonic motion trough geometric and mathematical approaches.

In this work, we show a simple experiment using Tracker to compare uniform circular motion and simple harmonic motion. Experiments, representing uniform circular motion and simple harmonic motion, have been conducted with simple materials and tools which can be found easily in daily life. The phenomena were recorded with a mobile phone camera. After that, the videos were analyzed through Tracker.

THEORY

Simple Harmonic Motion in Vertical Spring-Mass System

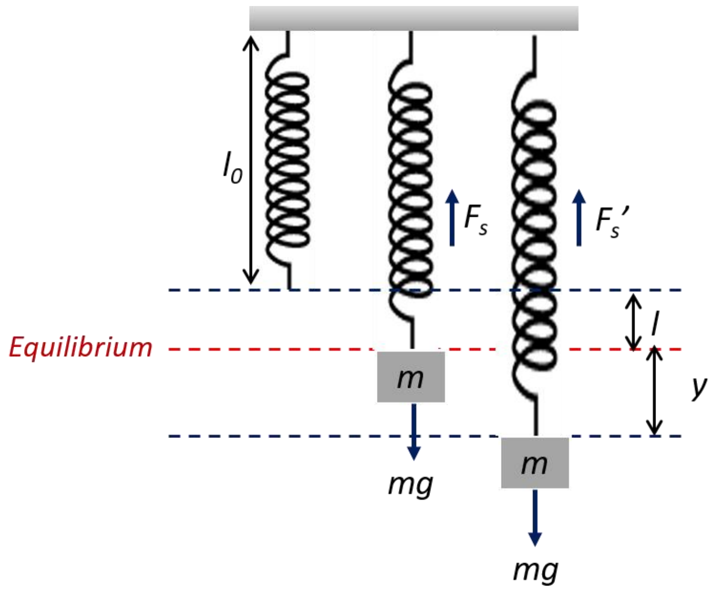

Figure 1. Vertical Spring-Mass System

One of the physical systems representing simple harmonic motion is a vertical spring-mass system. A particle with mass m is attached on vertical spring with an original length of l_o such as shown in Fig. 1. At equilibrium point, the spring force is balanced with the gravitational force, or according to Newton's first law, $\boldsymbol{F_s} + \boldsymbol{F_g} = 0$. Thus,

$$-kl + mg = 0$$

Or

$$kl = mg \tag{1}$$

When the spring is stretched down leaving its equilibrium position, there is acceleration, so that $\Sigma \boldsymbol{F} = m\boldsymbol{a}$,

$$\boldsymbol{F_s'} + \boldsymbol{F_g} = m\boldsymbol{a},$$

$$-k(l + y) + mg = m\frac{d^2y}{dt^2}. \tag{2}$$

Since $kl = mg$,

$$-ky = m\frac{d^2y}{dt^2}, \tag{3}$$

Eq. (3) can be written as:

$$\frac{d^2y}{dt^2} = -\omega^2 y \tag{4}$$

where $\omega^2 = \frac{k}{m}$.

By solving the second-order differential equation in Eq. (4), we yield a solution for the particle's position as follows:

$$y(t) = A\cos(\omega t + \phi), \tag{5}$$

where A is the amplitude and ϕ is the initial phase. Both of A and ϕ depend on the initial condition of the particle. As described in Eq. (5), the particle's periodic motion is a sinusoidal function of time, in which the sinusoidal function is a cosine function. It is the main characteristic of simple harmonic motion. Furthermore, we can determine the velocity and acceleration of the particle by taking the first and second derivative of Eq. (5), respectively. Thus,

$$v(t) = \frac{dy(t)}{dt} = -A\omega\sin(\omega t + \phi) \tag{6}$$

$$a(t) = \frac{d^2y(t)}{dt^2} = \frac{dv(t)}{dt} = -A\,\omega^2\cos(\omega t + \phi) \tag{7}$$

Uniform Circular Motion

A particle moves within uniform circular motion when it moves in a circular path with a constant angular speed. The angular position of a particle is given as:

$$\theta(t) = \phi + \omega t \tag{8}$$

where ω is angular speed, whereas ϕ is the initial angular position or initial phase.

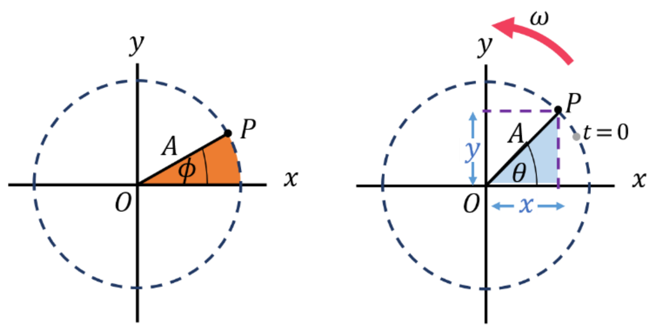

Figure 2. Particle P goes through the uniform circular motion with a constant angular speed of ω. The figure on the left is the initial particle's position. The figure on the right side is the particle's position at time t.

Particle P in Fig. 2 is moving in a uniform circular motion. It moves in a circle with a radius of A and constant angular speed ω. The x-coordinate of particle P is given by

$$x(t) = A\cos\theta = A\cos(\omega t + \phi) \tag{9}$$

The x-coordinate of particle P is a sinusoidal function of time, analogous to the simple harmonic motion. The x-component of velocity and acceleration are given in Eqs. (10) and (11), respectively.

$$v_x(t) = \frac{d}{dt}x(t) = -A\omega\sin(\omega t + \phi) \tag{10}$$

$$a_x(t) = \frac{d}{dt}v_x(t) = -A\omega^2\cos(\omega t + \phi) \tag{11}$$

The y-coordinates of particle P is also analogous to SHM motion, following the sinusoidal function of time (see Eq. (12)).

$$y(t) = A\sin\theta = A\sin(\omega t + \phi) \tag{12}$$

$$v_y(t) = \frac{d}{dt}y(t) = A\omega\cos(\omega t + \phi) \tag{13}$$

$$a_y(t) = \frac{d}{dt}v_y(t) = -A\omega^2\sin(\omega t + \phi) \tag{14}$$

EXPERIMENTAL SETUP

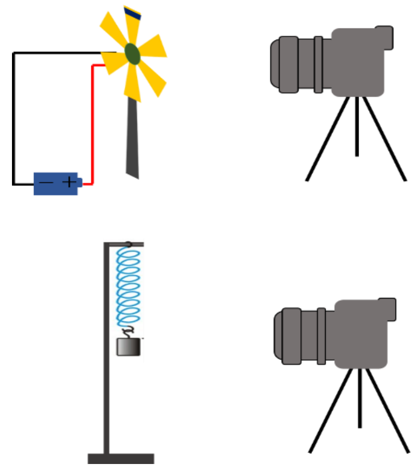

Figure 3. Experimental set-up of (a) uniform circular motion using an electrical fan, (b) simple harmonic motion using spring and slotted weight.

The experimental setup is simple, as shown in Fig. 3. The behavior of uniform circular motion is investigated by recording the motion of tape, which is stuck on an electric fan (see Fig. 3a). The recorded video is then analyzed with Tracker. Through Tracker, we get data about position, velocity, and acceleration as a function of time. Meanwhile, the behavior of simple harmonic motion is represented by the motion of a slotted weight which is attached to a vertical spring (see Fig. 3b).

RESULT AND DISCUSSION

The position of an object attached to a fan which moves with constant angular speed has been analyzed through Tracker. As time goes on, the x-coordinate of the object goes down and up following cosine function (see Fig. 4) as predicted in theory. Although it is not perfectly smooth, the x-component of linear velocity tends to follow sine function with an initial phase (ϕ) of π radians. Meanwhile, the x-component of acceleration tends to follow negative cosine function, consistent with Eq. (11).

As shown in Fig. 5, the y-coordinate of the object on uniform circular motion smoothly fits with the sine function in Eq. (12). On the other hand, the y-component of velocity and acceleration graph are not as smooth as the position graph. However, the y-component of velocity and acceleration still tend to follow cosine and negative sine function, respectively. These results demonstrate that uniform circular motion has symmetry with simple harmonic motion.

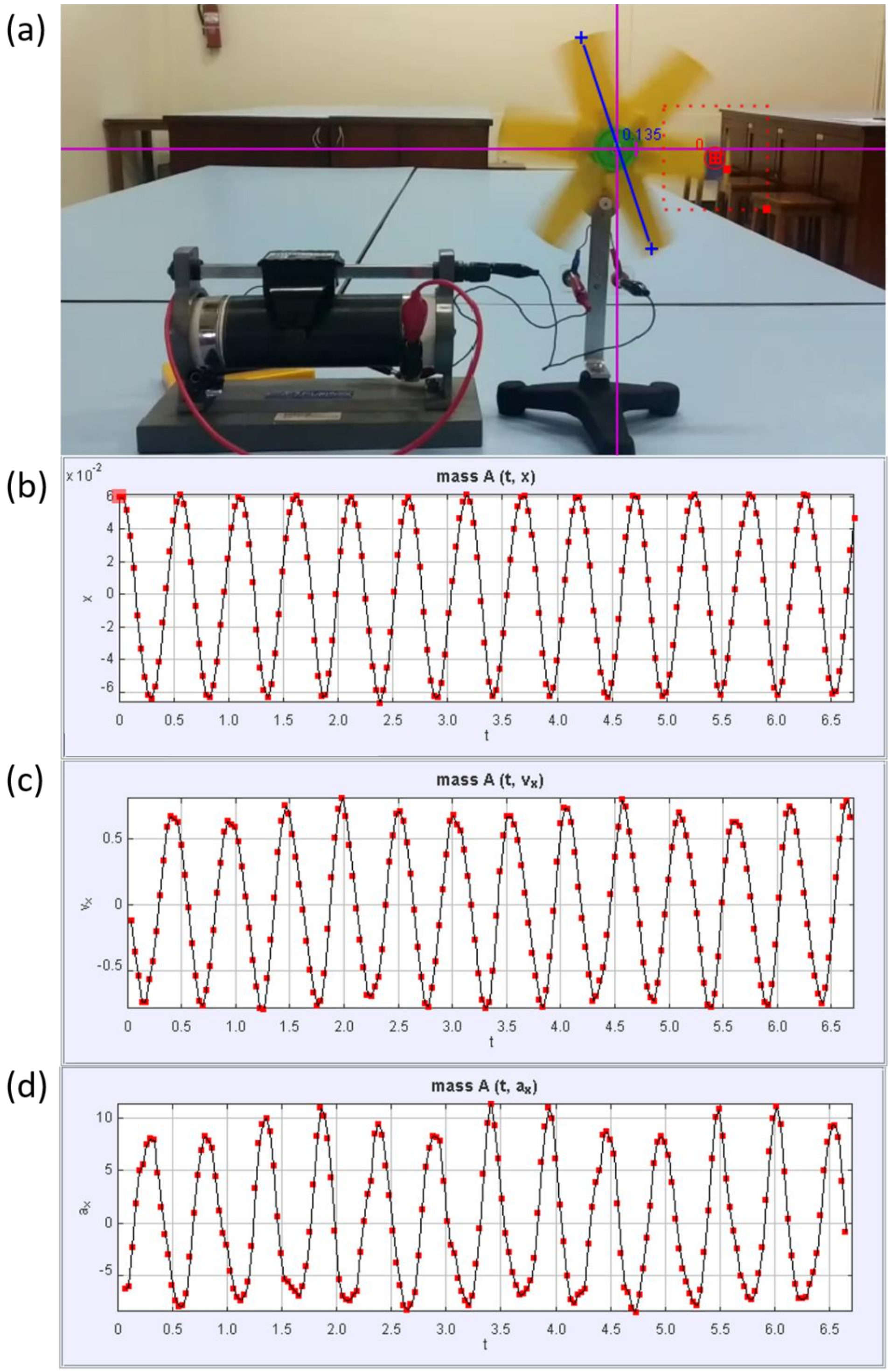

Figure 4. (a) uniform circular motion experiment using an electric fan (b) x-position versus time graph, (d), x-component linear velocity versus time graph, (e) x-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI units.

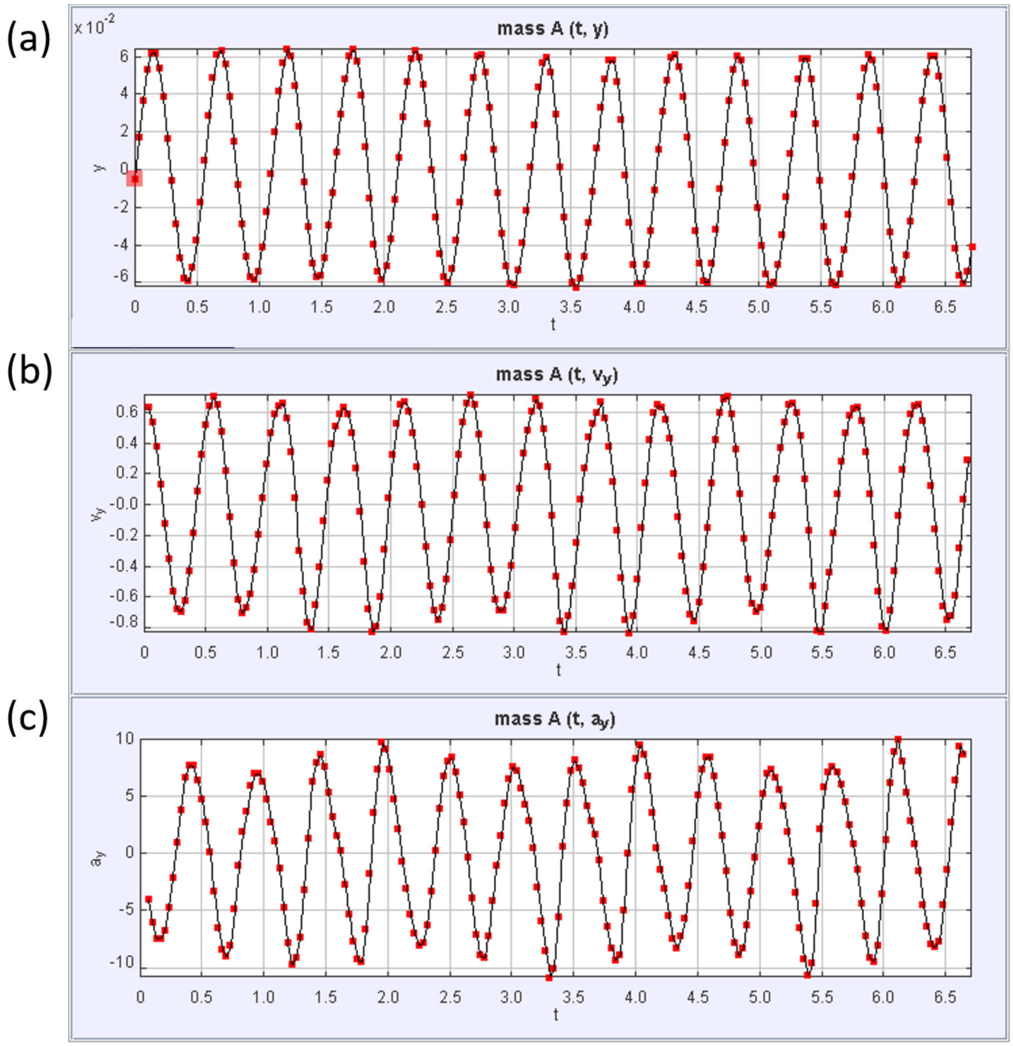

Figure 5. (a) y-position versus time graph, (c), y-component linear velocity versus time graph, (d) y-component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI units.

In addition, we performed an experiment with a well-known simple harmonic motion system, i.e., mass-spring system and simple pendulum. Fig. 6b-d shows the position, velocity, and acceleration of a slotted weight attached on a vertical spring as functions of time. The spring was initially stretched down. As predicted, the position of slotted weight fits sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$, whereas the acceleration fits cosine function or sine function with $\phi = \frac{\pi}{2}$.

The analysis of simple pendulum motion is presented in Fig. 7. Consistent with the mass-spring system, the periodic motion of the pendulum is a sinusoidal function of time. The ball was swung to the left initially. The position of the ball perfectly follows the sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\frac{\pi}{2}$. Meanwhile, the acceleration graph fits the sine function with $\phi = \frac{\pi}{2}$.

We have shown through analysis with Tracker that uniform circular motion has symmetry with simple harmonic motion. The linear position, velocity, and acceleration in uniform circular motion fit the sinusoidal function of time, which is the same in simple harmonic motion.

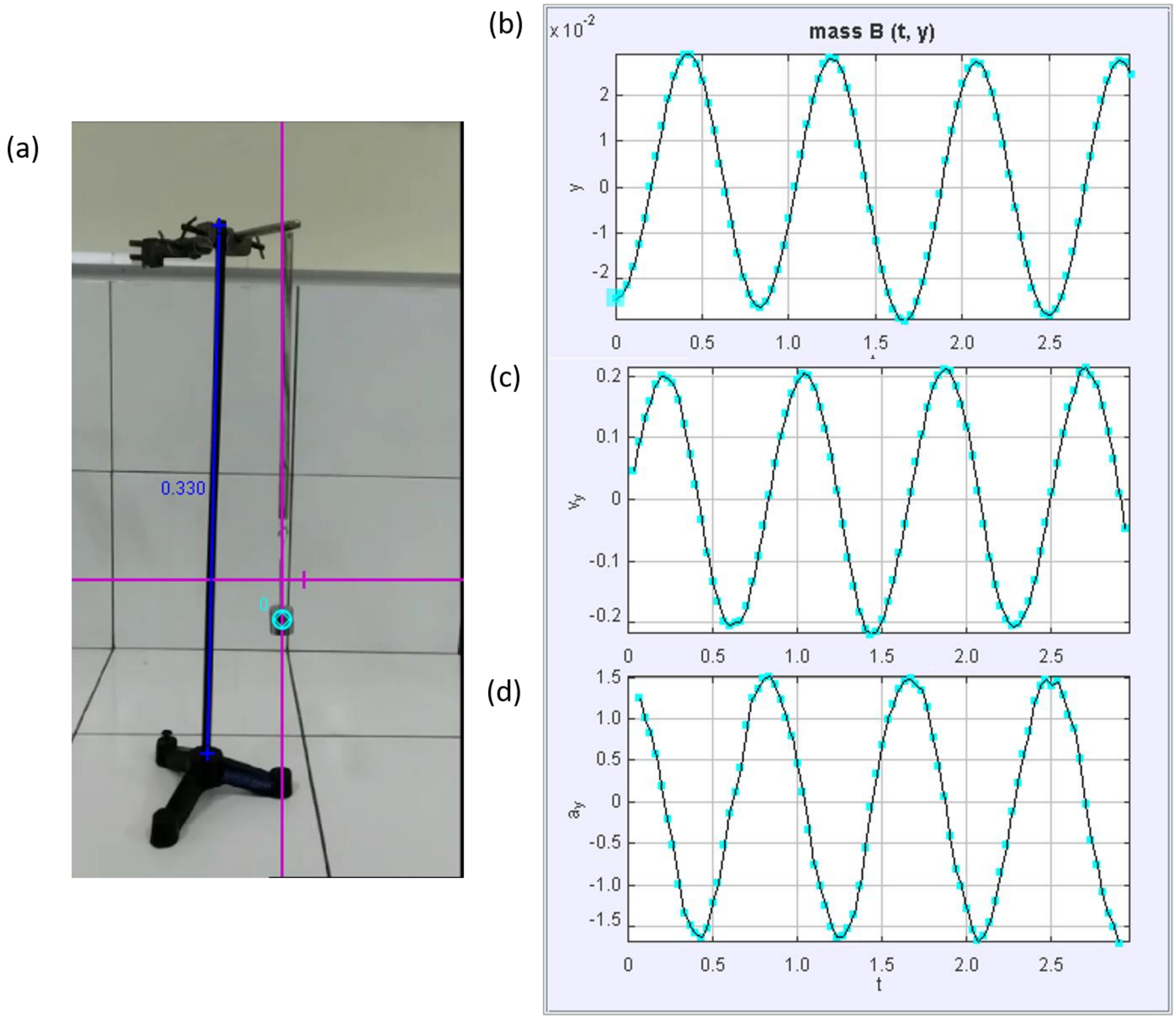

Figure 6. (a) simple harmonic motion experiment using spring and slotted weight, (b) y-position, (c) y-component velocity, (d) y-component acceleration of mass as functions of time in the simple harmonic motion of a spring-mass system. All quantities are presented in SI unit.

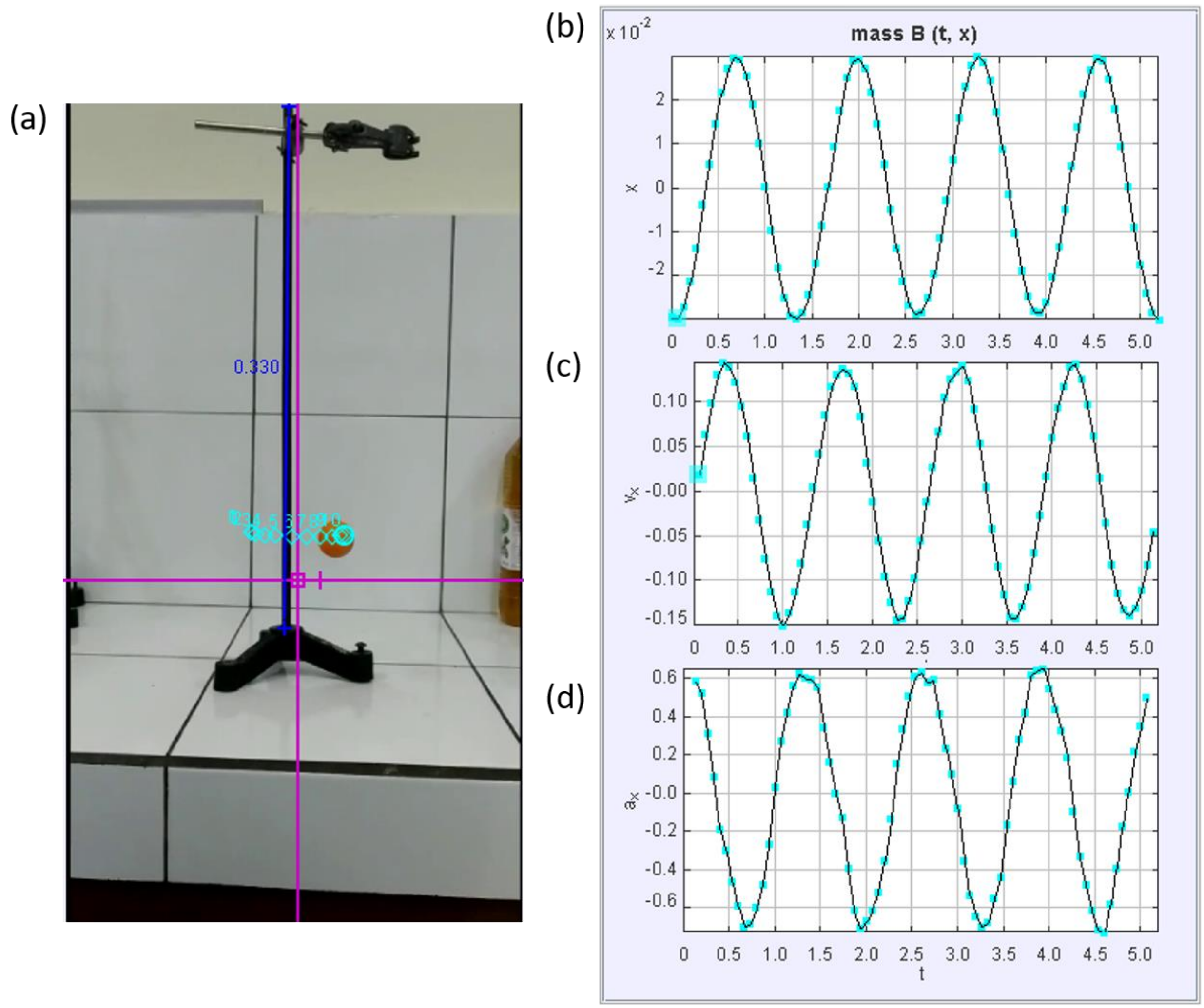

Figure 7. **(a) simple pendulum experiment, (b) x-position, (c) x-component velocity, (d) x-component acceleration of mass as functions of time in a simple harmonic motion of simple pendulum system. All quantities are presented in SI unit.**

STRATEGIC IMPLEMENTATION IN CLASS

A simple experiment with Tracker could potentially be included in physics classroom to enhance students' conceptual understanding in a uniform circular motion and simple harmonic motion. There are some possible ways to implement this simple experiment in the classroom. For example, the teacher can bring a recorded video about uniform circular motion and simple harmonic motion in class. At the beginning of the class, the videos are distributed to students. With teacher guidance, students are asked to analyze the videos with Tracker. In the scenario, students, individually or in a group, can record the uniform circular motion and simple harmonic motion by themselves with the teacher's help. This scenario will engage students more in the experiments and hopefully, students become more motivated in learning physics.

The teacher can make this activity as project, laboratory activity, homework or class demonstration. After the activity, the teacher can discuss the relation between simple harmonic motion and uniform circular motion in class through a mathematical approach. The discussion will enrich the students' conceptual knowledge about simple harmonic motion and circular motion.

CONCLUSION

In summary, we have demonstrated the relationship between uniform circular motion and simple harmonic motion by a simple experiment using Tracker with non-mathematical approach. The equation of motion of an object which moves in a uniform circular motion is analog to an object which moves in simple harmonic motion such as in spring-mass or pendulum system. The x- and y-coordinates of an object undergoes uniform circular motion, fit to the sinusoidal function of time. The velocity and acceleration also fit the sinusoidal function of time. In other words, we can say that simple harmonic motion can be considered as a projection of uniform circular motion. This demonstration can be embedded in high school physics classes to enhance students' conceptual understanding of simple harmonic motion and uniform circular motion.

REFERENCES

1. D. Brown, "Tracker: Video Analysis and Modeling Tool", Physlets.org, https://physlets.org/tracker/.
2. A. Amoroso and M. Rinaudo, Study of oscillatory motion using smartphones and Tracker software, *J. Phys. Conf. Ser.* **1076** (2018) 012013, https://doi.org/10.1088/1742-6596/1076/1/012013.
3. J. Poonyawatpornkul and P. Wattanakasiwich, High-speed video analysis of damped harmonic motion, *Phys. Educ.* **48** (2013) 782, https://doi.org/10.1088/0031-9120/48/6/782.
4. M. Rodriges, M. B. Marques, and P. Simeão Carvalho, How to build a low cost spectrometer with Tracker for teaching light spectra, *Phys. Educ.* **51** (2015) 014002, https://doi.org/10.1088/0031-9120/51/1/014002.
5. L. K. Wee, K. K. Tan, T. K. Leong, and C. Tan, Using Tracker to understand 'toss up' and free fall motion: a case study, *Phys. Educ.* **50** (2015) 436,https://doi.org/10.1088/0031-9120/50/4/436.
6. M. Rodrigues and P. Simeão Carvalho, Teaching optical phenomena with Tracker, *Phys. Educ.* **49** (2014) 671, https://doi.org/10.1088/0031-9120/49/6/671.
7. P. Aguilar-Marín, M. Chavez-Bacilio, and S. Jáuregui-Rosas, Using analog instruments in Tracker video-based experiments to understand the phenomena of electricity and magnetism in physics education, *Eur. J. Phys.* **39** (2018) 035204, https://doi.org/10.1088/1361-6404/aaa8f8.

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Relating simple harmonic motion and uniform circular motion with Tracker

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Relating simple harmonic motion and uniform circular motion with Tracker

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In this study, we demonstrate an interesting relationship between the simple harmonic motion and uniform circular motion trough a simple experiment. The experiment requires a low cost, easily-found materials, and free software Tracker. To represent uniform circular motion, we use a tape that is stuck on a fan moving with the constant angular speed. Meanwhile, spring and pendulum motion are used to represent simple harmonic motion. Through video analysis with Tracker , we have shown that the positions (x and y coordinates) of an object undergoes uniform circular motion fit to the sinusoidal function of time, similar to simple harmonic motion. We also analyze the behavior of velocity and acceleration in simple harmonic motion and uniform circular motion. This simple experiment can be used in high school physics courses to lead students in developing a conceptual understanding of uniform circular motion with a less mathematical approach.

Keywords: Simple harmonic motion; uniform circular motion; physics demonstration; Tracker

PACS: 01.40.-D; 01.50.-I DOI: https://doi.org/10.31349/RevMexFisE.17.141

1. Introduction

Recently, there is a rapid development of imaging technology. Moreover, technology in mobile phones has been improved significantly. Nowadays, mobile phones provide various features such as cameras, internet, a variety of sensors, spreadsheets, games, and so on. The development of imaging technology and the inclusion of cameras on mobile phones can be used for physics teaching and learning activities. By using imaging technology, Tracker has become a useful tool in physics education. Tracker is a free software developed on the Open Source Physics Java code library which can be used for video analysis and physics modeling. Tracker includes features such as object tracking with position, velocity, and acceleration overlays and graphs, calibration points and line profiles for analysis of spectra and interference patterns [1].

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In this work, we show a simple experiment using Tracker to compare uniform circular motion and simple harmonic motion. Experiments, representing uniform circular motion and simple harmonic motion, have been conducted with simple materials and tools which can be found easily in daily life. The phenomena were recorded with a mobile phone camera. After that, the videos were analyzed through Tracker.

2. Theory

2.1. Simple harmonic motion in vertical spring-mass system

One of the physical systems representing simple harmonic motion is a vertical spring-mass system. A particle with mass m is attached on vertical spring with an original length of l_o such as shown in Fig. 1. At equilibrium point, the spring force is balanced with the gravitational force, or according to Newton's first law, $\boldsymbol{F}_s + \boldsymbol{F}_g = 0$. Thus,

$$-kl + mg = 0,$$

or

$$kl = mg. \tag{1}$$

When the spring is stretched down leaving its equilibrium position, there is acceleration, so that $\sum \boldsymbol{F} = m\boldsymbol{a}$

$$\boldsymbol{F}_s + \boldsymbol{F}_g = m\boldsymbol{a},$$

$$-k(l+y) + mg = m\frac{d^2y}{dt^2}. \tag{2}$$

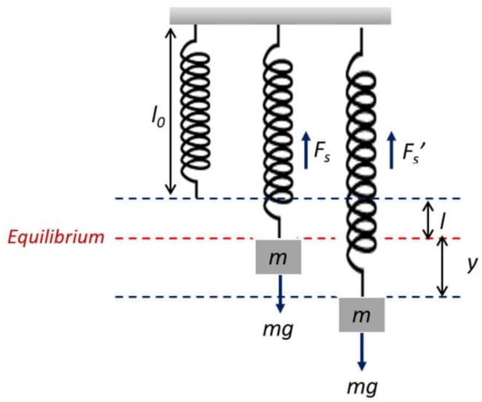

FIGURE 1. Vertical Spring-Mass System.

Since $kl = mg$,

$$-ky = m\frac{d^2y}{dt^2}. \tag{3}$$

Eq. (3) can be written as:

$$\frac{d^2y}{dt^2} = \omega^2 y, \tag{4}$$

where $\omega^2 = k/m$.

By solving the second-order differential equation in Eq. (4); we yield a solution for the particle's position as follows:

$$y(t) = A\cos(\omega t + \phi) \tag{5}$$

where A is the amplitude and ϕ is the initial phase. Both of A and ϕ depend on the initial condition of the particle. As described in Eq. (5), the particle's periodic motion is a sinusoidal function of time, in which the sinusoidal function is a cosine function. It is the main characteristic of simple harmonic motion. Furthermore, we can determine the velocity and acceleration of the particle by taking the first and second derivative of Eq. (5), respectively. Thus,

$$v(t) = \frac{dy(t)}{dt} = -A\omega\sin(\omega t + \phi), \tag{6}$$

$$a(t) = \frac{dv(t)}{dt} = -A\omega^2\cos(\omega t + \phi). \tag{7}$$

2.2. Uniform circular motion

A particle moves within uniform circular motion when it moves in a circular path with a constant angular speed. The angular position of a particle is given as:

$$\theta(t) = \phi + \omega t, \tag{8}$$

where ω is angular speed, whereas ϕ is the initial angular position or initial phase.

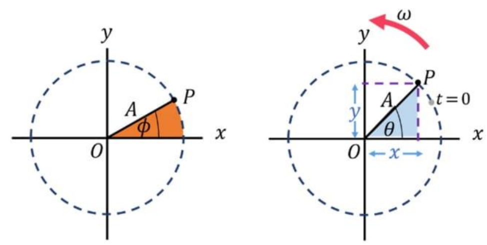

FIGURE 2. Particle P goes through the uniform circular motion with a constant angular speed of ω. The figure on the left is the initial particle's position. The figure on the right side is the particle's position at time t.

Particle P in Fig. 2 is moving in a uniform circular motion. It moves in a circle with a radius of A and constant angular speed ω. The $x-$coordinate of particle P is given by

$$x(t) = A\cos\theta = A\cos(\omega t + \phi). \tag{9}$$

The $x-$coordinate of particle P is a sinusoidal function of time, analogous to the simple harmonic motion. The $x-$component of velocity and acceleration are given in Eqs. (10) and (11), respectively.

$$v_x(t) = \frac{d}{dt}x(t) = -A\omega t\sin(\omega t + \phi) \tag{10}$$

$$a_x(t) = \frac{d}{dt}v_x(t) = -A\omega^2 t\cos(\omega t + \phi) \tag{11}$$

The $y-$coordinates of particle P is also analogous to SHM motion, following the sinusoidal function of time (see Eq. (12)).

$$y(t) = A\sin\theta = A\sin(\omega t + \phi), \tag{12}$$

$$v_x(t) = \frac{d}{dt}y(t) = A\omega\cos(\omega t + \phi), \tag{13}$$

$$a_y(t) = \frac{d}{dt}v_y(t) = -A\omega^2 t\sin(\omega t + \phi). \tag{14}$$

3. Experimental setup

The experimental setup is simple, as shown in Fig. 3. The behavior of uniform circular motion is investigated by recording the motion of tape, which is stuck on an electric fan (see Fig. 3a). The recorded video is then analyzed with Tracker. Through Tracker, we get data about position, velocity, and acceleration as a function of time. Meanwhile, the behavior of simple harmonic motion is represented by the motion of a slotted weight which is attached to a vertical spring (see Fig. 3b).

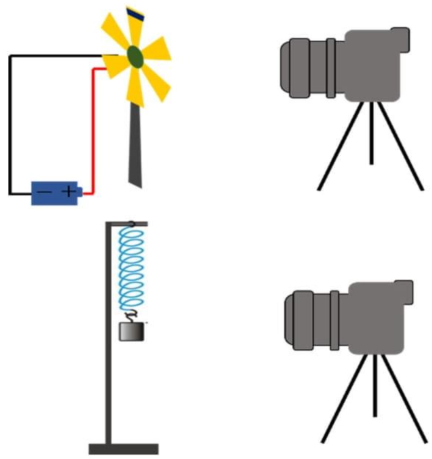

FIGURE 3. Experimental set-up of (a) uniform circular motion using an electrical fan, (b) simple harmonic motion using spring and slotted weight.

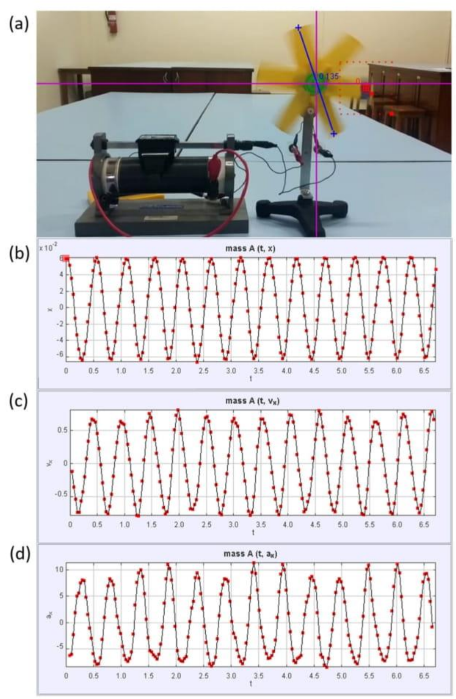

FIGURE 4. (a) Uniform circular motion experiment using an electric fan, (b) $x-$position versus time graph, (c) $x-$component linear velocity versus time graph, (d) $x-$component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI units.

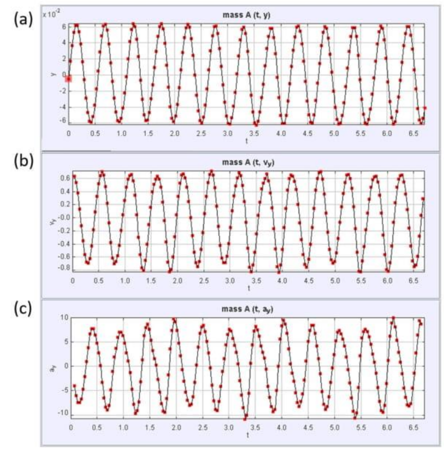

FIGURE 5. (a) $y-$position versus time graph, (b) $y-$component linear velocity versus time graph, (c) $y-$component acceleration versus time graph in a uniform circular motion. All quantities are presented in SI units.

4. Result and discussion

The position of an object attached to a fan which moves with constant angular speed has been analyzed through Tracker. As time goes on, the $x-$coordinate of the object goes down and up following cosine function (see Fig. 4b) as predicted in theory. Although it is not perfectly smooth, the $x-$component of linear velocity tends to follow sine function with an initial phase (ϕ) of π radians. Meanwhile, the $x-$component of acceleration tends to follow negative cosine function, consistent with Eq. (11).

As shown in Fig. 5, the y-coordinate of the object on uniform circular motion smoothly fits with the sine function in Eq. (12). On the other hand, the $y-$component of velocity and acceleration graph are not as smooth as the position graph. However, the $y-$component of velocity and acceleration still tend to follow cosine and negative sine function, respectively. These results demonstrate that uniform circular motion has symmetry with simple harmonic motion.

In addition, we performed an experiment with a well-known simple harmonic motion system, *i.e.* mass-spring system and simple pendulum. Figure 6b-d) shows the position, velocity, and acceleration of a slotted weight attached on a vertical spring as functions of time. The spring was initially stretched down. As predicted, the position of slotted weight fits sine function with $\phi = -\pi$ radians. The velocity fits cosine function with $\phi = -\pi/2$, whereas the acceleration fits cosine function or sine function with $\phi = \pi/2$.

The analysis of simple pendulum motion is presented in Fig. 7. Consistent with the mass-spring system, the periodic motion of the pendulum is a sinusoidal function of time. The

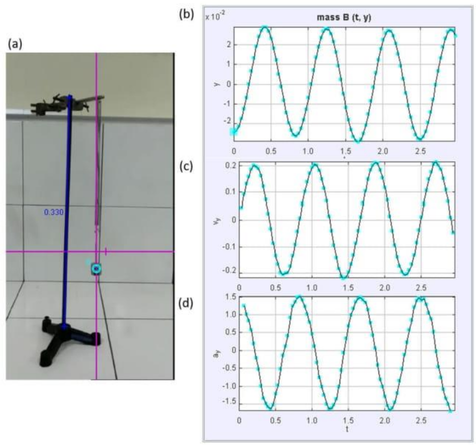

FIGURE 6. (a) simple harmonic motion experiment using spring and slotted weight, (b) $y-$position, (c) $y-$component velocity, (d) $y-$component acceleration of mass as functions of time in the simple harmonic motion of a spring-mass system. All quantities are presented in SI units.

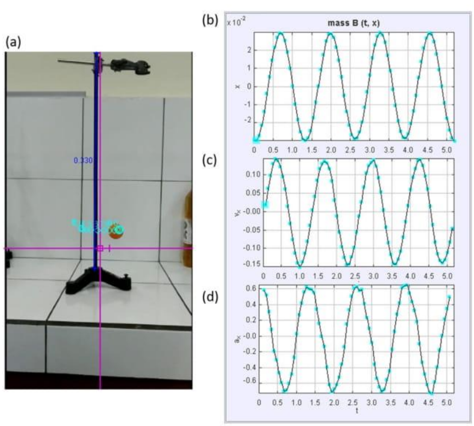

FIGURE 7. (a) simple pendulum experiment, (b) $x-$position, (c) $x-$component velocity, (d) $x-$component acceleration of mass as functions of time in a simple harmonic motion of simple pendulum system. All quantities are presented in SI units.

ball was swung to the left initially. The position of the ball perfectly follows the sine function with $\phi = \pi$ radians. The velocity fits cosine function with $\phi = -\pi/2$. Meanwhile, the acceleration graph fits the sine function with $\phi = \pi/2$.

We have shown through analysis with Tracker that uniform circular motion has symmetry with simple harmonic motion. The linear position, velocity, and acceleration in uniform circular motion fit the sinusoidal function of time, which is the same in simple harmonic motion.

5. Strategic implementation in class

A simple experiment with Tracker could potentially be included in physics classrooms to enhance students' conceptual understanding in a uniform circular motion and simple harmonic motion. There are some possible ways to implement this simple experiment in the classroom. For example, the teacher can bring a recorded video about uniform circular motion and simple harmonic motion in class. At the beginning of the class, the videos are distributed to students. With teacher guidance, students are asked to analyze the videos with Tracker. In the scenario, students, individually or in a group, can record the uniform circular motion and simple harmonic motion by themselves with the teacher's help. This scenario will engage students more in the experiments and hopefully, students become more motivated in learning physics.

The teacher can make this activity as project, laboratory activity, homework or class demonstration. After the activity, the teacher can discuss the relation between simple harmonic motion and uniform circular motion in class through a mathematical approach. The discussion will enrich the students' conceptual knowledge about simple harmonic motion and circular motion.

6. Conclusion

In summary, we have demonstrated the relationship between uniform circular motion and simple harmonic motion by a simple experiment using Tracker with non-mathematical approach. The equation of motion of an object which moves in a uniform circular motion is analog to an object which moves in simple harmonic motion such as in spring-mass or pendulum system. The $x-$ and $y-$coordinates of an object undergoes uniform circular motion, fit to the sinusoidal function of time. The velocity and acceleration also fit the sinusoidal function of time. In other words, we can say that simple harmonic motion can be considered as a projection of uniform circular motion. This demonstration can be embedded in high school physics classes to enhance students' conceptual understanding of simple harmonic motion and uniform circular motion.

1. D. Brown, "*Tracker: Video Analysis and Modeling Tool*", Physlets.org, https://physlets.org/tracker/.
2. A. Amoroso and M. Rinaudo, Study of oscillatory motion using smartphones and tracker software, *J. Phys. Conf. Ser.* **1076** (2018) 012013, https://doi.org/10.1088/1742-6596/1076/1/012013.
3. J. Poonyawatpornkul and P. Wattanakasiwich, High-speed video analysis of damped harmonic motion, *Phys. Educ*. **48** (2013) 782, https://doi.org/10.1088/0031-9120/48/6/782.
4. M. Rodriges, M. B. Marques, and P. Simeão Carvalho, How to build a low cost spectrometer with Tracker for teaching light spectra, *Phys. Educ.* 51 (2015) 014002, https://doi.org/10.1088/0031-9120/51/1/014002.
5. L. K. Wee, K. K. Tan, T. K. Leong, and C. Tan, Using Tracker to understand 'toss up' and free fall motion: a case study, *Phys. Educ.* **50** (2015) 436. https://doi.org/10.1088/0031-9120/50/4/436.
6. M. Rodrigues and P. Simeão Carvalho, Teaching optical phenomena with Tracker, *Phys. Educ.* **49** (2014) 671. https://doi.org/10.1088/0031-9120/49/6/671.
7. P. Aguilar-Marín, M. Chavez-Bacilio, and S. Jáuregui-Rosas, Using analog instruments in Tracker video-based experiments to understand the phenomena of electricity and magnetism in physics education, *Eur. J. Phys.* **39** (2018) 035204, https://doi.org/10.1088/1361-6404/aaa8f8.