

Particle trajectory simulation using python and spreadsheet as an online learning alternative

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Education today is required to utilize technological knowledge and skills in preparation for global competition. Along with the rapid development of technology, educators are required to develop learning alternatives. The purpose of this research is to create a particle trajectory simulation that is used as an alternative to online learning. The simulation uses Python programming language and Origin Pro assisted spreadsheet. Simulation in Python programming uses the Euler Cromer method to describe particle trajectories affected by electric and magnetic fields. This paper has successfully simulated particle trajectories affected by electric and magnetic fields with the Python programming language and Spreadsheet. The case where the motion of a charged particle is affected by a combination of electric and magnetic fields is when a positively charged particle moves perpendicular to the magnetic field, it will form a helical trajectory. However, when the electric field is in the direction of the magnetic field, the motion in the direction of the magnetic field will be accelerated by the electric force in the direction of the magnetic field which causes the helix to increase in width.

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1. Introduction

Education today is required to utilize technological knowledge and skills in preparation for global competition. The learning process using technology (online) brings transformation in the world of education. The learning process from teacher-centered to learner-centered learning. Learner-centered learning is based on a constructivist approach that focuses on an active learning approach [1]. In addition, due to the rapid development of technology, computational thinking skills are needed to face the challenges of the future world of work [2].

Computational Thinking is a type of analytical thinking to solve problems and design systems that refer to the basic concepts of computing [3]. Computational thinking is not only used in learning computer science but also other disciplines such as math, science, design, economics and languages [4]. Computational thinking is also a process of solving problems using logic systematically which is needed by students in various fields including physics [2].

Physics is a science that studies natural events and phenomena. Physics learning is aimed at researching, observing and understanding natural phenomena. For some students,

physics is an interesting science, for others it is not. Physics is considered one of the most difficult subjects in school [3]. In addition, there are limitations to physics practice in online learning [4]. Simulation-based learning is one of the alternatives that can be offered in online learning. Computer simulation using python programming language will be used in this article.

Each programming language has its own advantages and disadvantages. Language selection depends on the needs that you want to produce. The advantages of the python programming language are one of the free and open source programming languages [5]. There are many Python libraries such as matplotlib, numpy and scipy that support computational needs so they are widely used in academia [5].

In addition to using Python, this paper also simulates the phenomenon of charged particles in electric and magnetic fields using Spreadsheet. Spreadsheet is one of the software that can be used in teaching physics in the classroom. Spreadsheet has advantages and disadvantages. The advantages of spreadsheets are that they have built-in functions for data processing, are cost-effective, have a simple cell-based structure, and do not require a difficult programming language [6]. The graphical presentation on the spreadsheet was as-

sisted by Origin Pro graphic software due to limitations in three-dimensional plots.

Simulation-based learning can improve learners’ learning outcomes and remember information or messages in equations, pictures and graphs [7]. This is supported by the results of research which states that learning that applies simulation has a significant and positive effect on achievement, motivation, and learning quality [8]. Several studies have successfully used simulation-based learning including the following [9-12].

Based on this, simulation-based learning by utilizing the Python programming language as a physics learning media was chosen to meet the needs of students. The choice is also based on students who have easy access to personal computers, both in campus and elsewhere. The material used in this article is electricity and magnetism. In the learning process, electricity and magnetism materials are integrated with technology through simulation. The purpose of this research is to create a simulation of particle trajectories influenced by magnetic fields and electric fields as an alternative to online learning.

2. Theory

Particle motion in electric and magnetic fields can be formulated following Lorentz’s law [13]. Written down as follows:

$$\sum \vec{F} = \vec{F}_E + \vec{F}_M. \tag{1}$$

In the equation above, it consists of the electric force (\vec{F}_E) and magnetic force \vec{F}_M so it can be generally broken down into:

$$\vec{F}_E = q\vec{E}, \tag{2}$$

$$\vec{F}_M = q \left[\vec{v} \times \vec{B} \right]. \tag{3}$$

Equation (2) and (3) is substituted into Eq. (1), the Lorentz force is obtained as follows:

$$\sum \vec{F} = q \left[\vec{E} + \left(\vec{v} \times \vec{B} \right) \right]. \tag{4}$$

When particles are fired with an initial velocity (\vec{v}) towards the magnetic field. Particles will be deflected in the direction of the force $\vec{v} \times \vec{B}$ so that it forms a trajectory in the form of a circle. Using these equations, the motion of charged particles can be studied numerically and analytically.

Euler-Cromer

Besides analytic solution, we have another alternative which is numerical solution. The Euler-Cromer method is used in this article

$$y_{next} = y_{current} + a_n \Delta x. \tag{5}$$

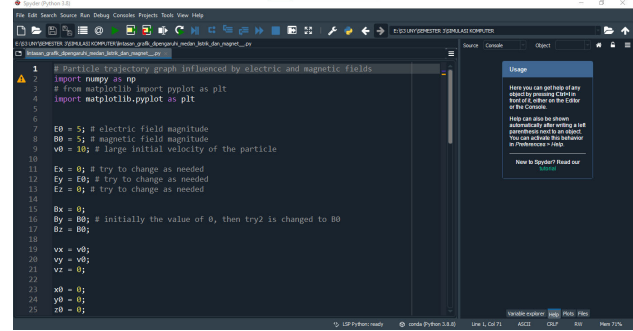


FIGURE 1. Python coding.

3. Method

The simulation uses Python programming language with Spyder Anaconda software. This study uses the Euler Cromer method to describe the trajectory of particles affected by electric and magnetic fields. The coding display used in Python programming is shown in Fig. 1.

Figure 1 shows the coding for the simulation using Spyder Anaconda software. In Python there is a library that can be used to visualize data. The visualization used is made into 3D and 2D forms. The coding in Fig. 1 starts with typing a library like Matplotlib. Matplotlib is a library for visualizing data built on NumPy arrays. To import matplotlib in the following way import matplotlib.pyplot as plt. The next step is data initialization or initial data input such as electric field, magnetic field, initial velocity, and initial position.

The initial electric field is written E_0 with a value of 5, the initial electric field is written B_0 with a value of 5, the initial speed is written V_0 with a value of 10. Then create initial coordinates with an x value of 0, y value of 0, and z value of 0. Then create a matrix containing speed, time and coordinate data. After that, all data is collected and plotted graphically using 3D plots. Meanwhile, Spreadsheet is used to study particle motion analytically.

Excel spreadsheet programming to study the motion of charged particles in uniform electric and magnetic fields is

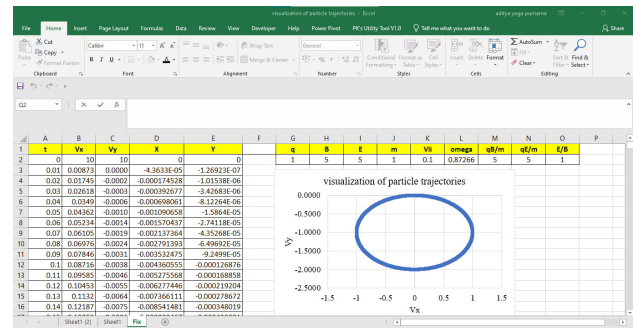


FIGURE 2. Screenshot of spreadsheet used to study the motion of the charged particle in the uniform electro-magnetic (EM) field.

TABLE I. Description of terms in spreadsheet commands.

Column/Cell	Variable	Description	Spreadsheet Command
A3	t	Time	=0.01
B3	V_x	x -component of velocity	=O\$2*SIN(L\$2*A3)
C3	V_y	y -component of velocity	=O\$2*(COS(L\$2*A3)-1)
D3	x	x displacement	=(O\$2/L\$2)*((COS(L\$2*A3))-1)
E3	y	y displacement	=(O\$2/L\$2)*(((SIN(L\$2*A3))-L\$2*A3))
G2	q	Charged	=1
H2	B_z	Uniform magnetic field	=5
I2	E_x	Uniform electric field	=5
J2	m	Mass	=1
K2	V_{xi}	Initial Velocity	=0.1
L2	ω	Cyclotron frequency	=PI*(I\$2*J\$2)/(180*K\$2)
M2	qB_z/m	Acceleration due to magnetic field	=G2*H2/J2
N2	qE_x/m	Acceleration due to electric field	=G2*I2/J2
O2	E_x/B_z	Ratio of electric to magnetic field strength	=1

shown in Fig. 2. Table I describes the various terms in the Spreadsheet command.

4. Results and discussion

Physics studies natural phenomena from very small to very large. This causes obstacles in understanding physics concepts that are difficult and abstract [14]. For example, on the subject of particle movement in electric and magnetic fields. In studying these phenomena, simulation through Python software can be used to assist in the learning process. Python is popularly used in scientific simulations. Python has the advantage of being free and open-source numerical libraries of the SciPy community [15]. Here is the Python language script used:

```
import numpy as np
# from matplotlib import pyplot as plt
import matplotlib.pyplot as plt

E0 = 5; B0 = 5; v0 = 10; Ex = 0; Ey = E0;
Ez = 0; Bx = 0; By = B0; Bz = B0;

vx = v0; vy = v0; vz = 0;
x0 = 0; y0 = 0; z0 = 0;

h = 0.01; N = range(1,1001);

vxidata = [vx]; vyidata = [vy]; vzidata = [vz];
```

```
xidata = [x0]; yidata = [y0]; zidata = [z0]
```

```
t0 = 0; t = [t0];
```

```
for i in N:
```

```
    ti = i*h
```

```
    t.append(ti)
```

```
    vxi = vxidata[i - 1]+((Ex+(vyidata[i - 1]*Bz))-
    (By*vzidata[i - 1]))*h;
```

```
    vxidata.append(vxi)
```

```
    xi = xidata[i - 1]+(vxidata[i - 1]*h)
```

```
    xidata.append(xi)
```

```
    vyi = vyidata[i - 1]+((Ey+(vzidata[i - 1]*Bx))-
    (Bz*vxidata[i - 1]))*h;
```

```
    vyidata.append(vyi)
```

```
    yi = yidata[i - 1]+(vyidata[i - 1]*h)
```

```
    yidata.append(yi)
```

```
    vzi = vzidata[i - 1]+((Ez+(vxidata[i - 1]*By))-
    (Bx*vyidata[i - 1]))*h;
```

```
    vzidata.append(vzi)
```

```

zi = zidata[i - 1]+(vzidata[i - 1])*h
zidata.append(zi)

print(vzidata)
plotGrafik = plt.axes(projection='3d')
#grafik untuk 3D garis
z = t; y = vyidata; x = vxidata
plotGrafik.set_xlabel('vx (m/s)')
plotGrafik.set_ylabel('vy (m/s)')
plotGrafik.set_zlabel('t (s)')
plt.plot(z,y)
plotGrafik.plot3D(x, y, z, 'blue')
plt.show()

```

The script above is the coding used to simulate the shape of the particle trajectory. Several Python libraries used in this simulation include NumPy and Matplotlib. NumPy provides ready-to-use functions such as basic arithmetic and other common math operations, matrix multiplication, eigenvalue calculation and Fourier Transformation [16]. While Matplot provides a variety of diverse graph plotting libraries [17]. Both libraries are also available in the GNU Octave and Matlab software but in different writing. The script used above shows the phenomenon of particle trajectories in electric and magnetic fields. The phenomenon of particle trajectories in electric and magnetic fields can be formulated using the Lorentz force equation [13]. In the simulation of particle motion trajectories affected by electric fields (\vec{E}) and Magnetic Field (\vec{B}), input data obtained by entering initial electric field parameters $E_0 = 5$, and the electric field in the y component is equal to the initial electric field $E_y = E_0$,

while for the electric field the x and z components are 0 or can be written as $E_x = E_z$ in an electric field. While the initial magnetic field is worth 5 or can be written down $B_0 = 5$, and the magnetic field of the y and z components is equal to the initial magnetic field or can be written as $B_y = B_z = B_0$ in a magnetic field. As for the initial velocity of the particle, it can be written $v_0 = 10$ and for the particle velocity in the y component is equal to the initial velocity of the particle or can be written as $v_y = v_0$, While the particle velocity in the x and z directions is 0. After entering the initial parameters, a coding matrix is created as a container for the value to be searched as an example `vxidata = [vx]`. The Euler-Cromer method is one method that can be used to solve differential equations by utilizing the Taylor series [19]. Researchers use the Euler-Cromer method with consideration of simplicity as done by previous researchers [20]. The simulation results that have been created using the Python programming language are shown in Fig. 3.

Figure 3 shows a depiction of the motion of a circular particle. When a particle with a velocity of In Fig. 3 has been shown depicting the motion of a circular particle. When a particle with velocity (\vec{v}) in a constant magnetic field, the force acting is magnetic force only. Vector determination using the right-hand rule. The force direction of the particle will correspond to $\vec{v} \times \vec{B}$ thus forming a circular pattern. The direction of deflection of positively and negatively charged particles is opposite. The case where the motion of charged particles is affected by a combination of electric and magnetic fields is when positively charged particles move perpendicular to the magnetic field, it will form a helical trajectory. However, when the electric field is in the direction of the magnetic field, the movement in the direction of the magnetic field will be accelerated by the electric force in the direction of the magnetic field which causes the helix to increase in width.

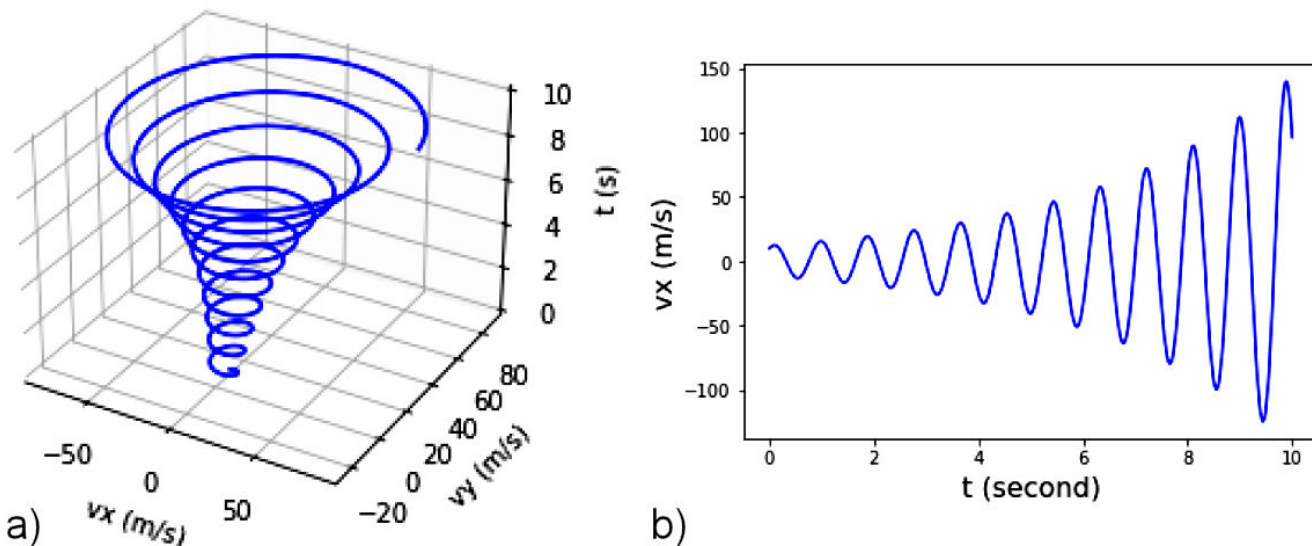


FIGURE 3. a) 3-dimensional simulation of particle trajectories; b) 2-dimensional simulation of particle trajectories in Python software.

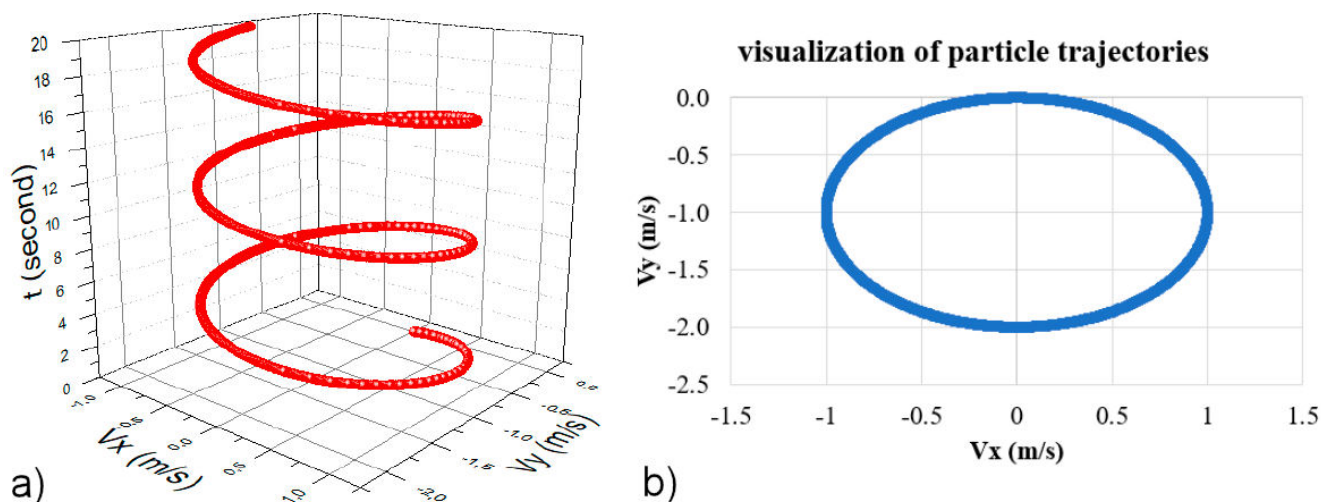


FIGURE 4. a) 3-Dimensional simulation of particle trajectories using Origin Pro; b) 2-Dimensional simulation of particle trajectories using spreadsheet.

In addition to Python, particle trajectory simulations can be described with spreadsheets. Spreadsheets have proven useful for performing calculations and visualizing data [21]. The spreadsheet program can be used as a learning media that supports students to understand physics material more easily and interestingly. In Fig. 4a), 3-dimensional simulation of particle trajectories with the help of Origin Pro is shown. The use of Origin Pro software is used because of the limitations in spreadsheets that cannot show 3-dimensional picture. The 3-dimensional image in the spreadsheet can only be made like Fig. 4b). Therefore, the analysis results obtained in the spreadsheet are entered into Origin Pro to visualize in 3 dimensions.

Figures 4a) and 4b) are obtained from spreadsheet processing as shown in Table I. The input parameters are in Cell G2:O2. The trajectory is an $x-y$ graph drawn with 1998 data points. In this simulation, the velocity of each x and y component is calculated. The velocity step is calculated in Cell K2. Figure 4 is drawn based on the velocity results in the x component shown in Cell B3:B2000, and the y component

shown in Cell C3:C2000. In using the spreadsheet, this paper agrees with [22] that spreadsheets have some shortcomings, especially in complex algorithms that are difficult to implement.

5. Conclusion

A simulation of particle trajectories influenced by electric and magnetic fields has been obtained using the Python programming language and spreadsheets. The case where the motion of a charged particle is affected by a combination of electric and magnetic fields is when a positively charged particle moves perpendicular to the magnetic field, it will form a helical trajectory. However, when the electric field is in the direction of the magnetic field, the motion in the direction of the magnetic field will be accelerated by the electric force in the direction of the magnetic field which causes the helix to increase in width. Python is better at creating graph visualizations than spreadsheets. However, Python has a more complex programming language than spreadsheets.

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