p-ISSN 2089 – 0133 e-ISSN 2477-6416
URL : https://jurnal.uns.ac.id/ijap/article/view/53124
Indonesian Journal of Applied Physics (IJAP) Vol. 12 No. 1 page 12
DOI : https://doi.org/10.13057/ijap.v12i1.53124

THE SIMULATION OF COVID-19 DROPLET TRANSMISSION WITH HAMILTONIAN MONTE CARLO METHOD

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Received 10-07-2021, Revised 02-10-2021, Accepted 02-11-2021,
Available Online 17-03-2022, Published Regularly April 2022

ABSTRACT

Corona Virus 2019 (COVID-19) pandemic has impacted every sector in the world. This virus spread through the droplet from coughing and sneezing, and then infected healthy people. This study developed a simulation to model a virus spread just after the infected was coughed or sneezed. In the simulation, humidity, wind velocity, and temperature were considered. The simulation was conducted with Hamiltonian Monte Carlo, where was set a random initial velocity and angle for every 200 droplets with 500 iterations of each. The transmission data was derived from three groups: the age of 15 to 30 years old, 31 to 50 years old, 51 to 68 years old. At the age of 12 to 30 years, the droplet range and height were 3.13 meters and -0.77 meters. At the age of 31 to 50 years old, the droplet range and height were 3.22 meters and -0.83 meters. At the age of 51 to 68, the droplets range and height were 2.82 meters and -0.58 meters. The highest droplet range was from the age of 31 to 50 years old. Therefore, the age of 31 to 50 years old or the productive age was considerable with the highest risk in the droplet transmission and virus spread. This study can be adopted to consider the effective prevention in controlling the virus outbreaks.

Keywords: COVID-19; monte carlo method; simulation; droplet transmission.

INTRODUCTION

The Corona Virus 2019 (COVID-19) was reported for the first time in Wuhan, China, in December 2019[1]. This virus caused bad pneumonia to the infected person and transmitted from human to human through droplets and aerosol[2]. After infected a lot of people in China, this virus also infected many people in the world and became a pandemic[3].

Based on some investigation, Covid-19 dispersion was like the other pandemic, e.g., Middle East Respiratory Syndrome (MERS). Those viruses spread through the airborne droplet, direct and indirect contact with the infected person[4,5]. In addition, previous research showed that airborne droplets contributed to a significant dispersion while talking, sneezing, and coughing[6]. Unfortunately, human eyes could not see the airborne transmission. Besides, the droplets number while coughing and sneezing were in thousand to ten thousand with various sizes[7–9]. Moreover, the droplets duration in the air was around two minutes. Therefore, the probability of virus transmission was also high after coughing and sneezing[10].

The simulation of Covid-19 dispersion should be developed to predict the virus range after the infected people coughing and sneezing. Furthermore, effective prevention can be arranged based on this simulation. The Covid-19 dispersion can be built with Monte Carlo Methods to get the droplets randomized steps. In previous research, the Monte Carlo method was applied to study droplets nucleation[11]. Besides, the method was also applied in neutron transport[12], particle dynamics in bi-dispersed colloidal droplets[13], droplet evaporation[14], lattice random-walk models[15]. With Monte Carlo Method, this study developed a simulation to model a virus spread just after the infected coughing or sneezing. This study can be adopted to consider the effective prevention in controlling the virus outbreaks.

METHODS

Metropolis Monte Carlo Method was conducted in this study to develop the simulation of Covid-19 dispersion. The simulation development was divided into three steps: the droplet distribution probability at the initial time, the dispersion, and validation. In the droplet distribution probability, the droplet sizes and velocity were conducted from secondary data. However, the droplet distribution is random for each human[8,16–18]. Yet in this study, the droplet sizes were conducted from the Zayas et.al., experiment[17]. Zayas measured 44 samples at the respondents' age of ≤ 30 years old, 30 <age ≤50 years old, and >50 years old, meanwhile the simulation conducted 200 samples with a balanced ratio of five droplets sizes. The sizes are $N < 0.5\ \mu m$, $0.5\ \mu m < N < 1\ \mu m$, $1\ \mu m < N < 2.5\ \mu m$, $2.5\ \mu m < N < 10\ \mu m$, $10\ \mu m < N < 100\ \mu m$. In the simulation, the droplets sized were randomized and configured to be a probability distribution. The probability distribution determined the droplet number in the simulation.

Meanwhile, the droplet's initial velocity was obtained from human cough particle image velocimetry of the Vansciver et al., experiment[19]. The Vansciver experiment modified Akima piecewise cubic Hermite interpolation to get the initial velocity. The Vansciver only experimented on humans aged 20 to 50 years old. Consequently, this study has to categorize the initial velocity based on the simulation need. The categories were 12 to 30 years old, 31 to 50 years old, and 51 to 68 years old because there are different strengths of sneezing and coughing in each age. The strength was related to losses of physical function[20–22]. The initial velocity probability was 97% for 12 to 30 years, 100% for 31 to 50 years old, and 88% for 51 to 68 years old.

The droplet dispersion system can be explained by the classical mechanics. The simulation conducted 200 droplets and simulated the simulation for five seconds. The droplet was considered as a particle at a two-dimension axis (x, y). The x and y axis was conducted as follow.

$$dx = v_{0x}\, dt \tag{1}$$

$$dy = -v_{0y}\, dt - \frac{1}{2} a t^2 \tag{2}$$

where v_{0x} and v_{0y} was initial velocity at x and y axis, respectively. Meanwhile, a was droplet acceleration at time t. where the droplet momentum is obtained from the following equation.

$$m_p \frac{d\vec{v}_p}{dt} = m_p \vec{g}\left(1 - \frac{\rho_p}{\rho_g}\right) - C_d \pi r_p^2 \frac{\rho_g |\vec{v}_p - \vec{v}_g| (\vec{v}_p - \vec{v}_g)}{2} \tag{3}$$

$$\frac{d\vec{v}_p}{dt} = \vec{g}\left(1 - \frac{\rho_p}{\rho_g}\right) - \frac{3 C_d \rho_g |\vec{v}_p - \vec{v}_g| (\vec{v}_p - \vec{v}_g)}{8 \rho_p r_p} \tag{4}$$

where Re_p was a Reynold number, m_p is the droplet mass, $\vec{v}_p$ is the droplet velocity, g is gravitation, ρ_p is droplet dencity, ρ_g is air dencity, r_p is the droplet diameter, and C_d was the friction coefficient which was obtained from following equation.

$$C_d = \begin{cases} 0.424 & \text{if } Re_p > 1000 \\ \frac{24}{Re_p}\left(1 + \frac{Re_p^{2/3}}{6}\right) & \text{otherwise} \end{cases} \quad (5)$$

Meanwhile, the Reynold number depened on the environment of droplet and it can be obtained from the following eaquation.

$$Re_p = \frac{\rho_g d_p |\vec{v}_p - \vec{v}_g|}{\mu} \quad (6)$$

where μ is the air viscosity which was obtained from the following equation.

$$\mu = \mu(p, T) \quad (7)$$

where p was air pressure and T was the themperature. Here, the air pressure was 1006 hectopascal, the temperature was 27°C, and the wind velocity was constant 2 m/s.

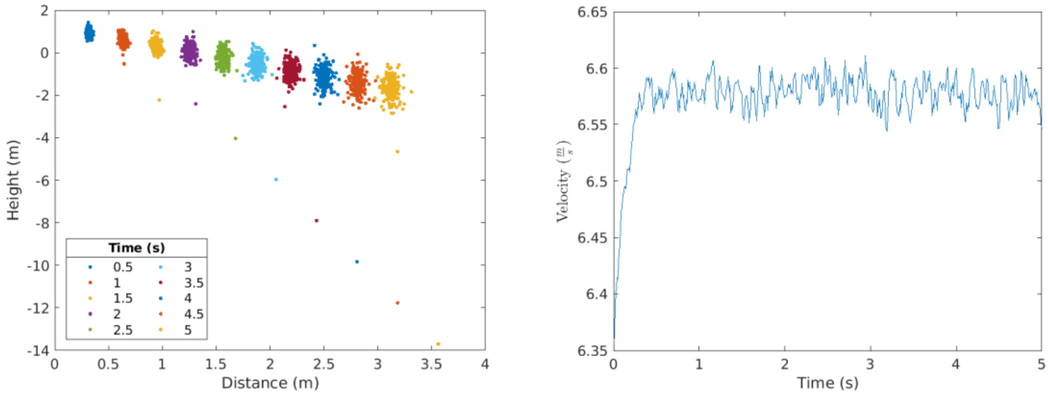
The droplets were considered as a circle, and they collided with elastic momentum. The droplet velocity afer the collision was obtained from the following equation.

$$v' = v - \frac{2m}{m_1 - m_2} \frac{\langle V_1 - V_2, x_1 - x_2 \rangle}{\| x_1 - x_2 \|^2} (x_1 - x_2) \quad (8)$$

v and v'were droplet velocity before and after the collision, respectively. m_1 was mass of droplet 1 and m_2 was mass of droplet 2. Those equations were conducted for the computer simulation to study the droplet dispersion. The computer simulation is a bridge between theory and experiment, which builds a system through an appropriate algorithm and approaching the natural condition when an experiment cannot do so because the object is too small, too big, too expensive, or dangerous. The simulation also validates a theory through a mathematics algorithm. Therefore, simulation is the best solution for a system that can not obtain from an experiment or a theory[23]. The simulation was built with Hamiltonian Monte Carlo (HMC), which conducted samples randomly. Therefore the result approaches the actual condition of the sample[12]. Finally, the simulation was then validated with numerical calculation.

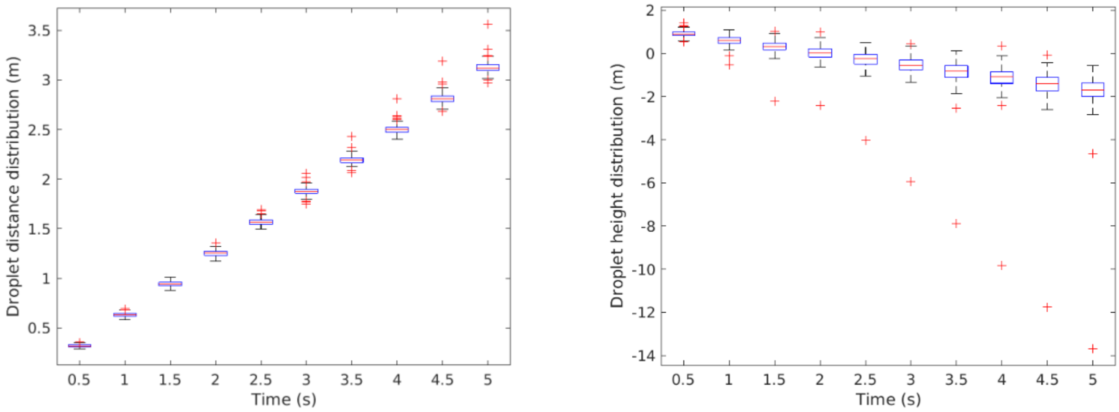
RESULTS AND DISCUSSION

The simulation was conducted 200 droplets with 500 iterations. The simulation results were showed in the following figure.



(a) (b)

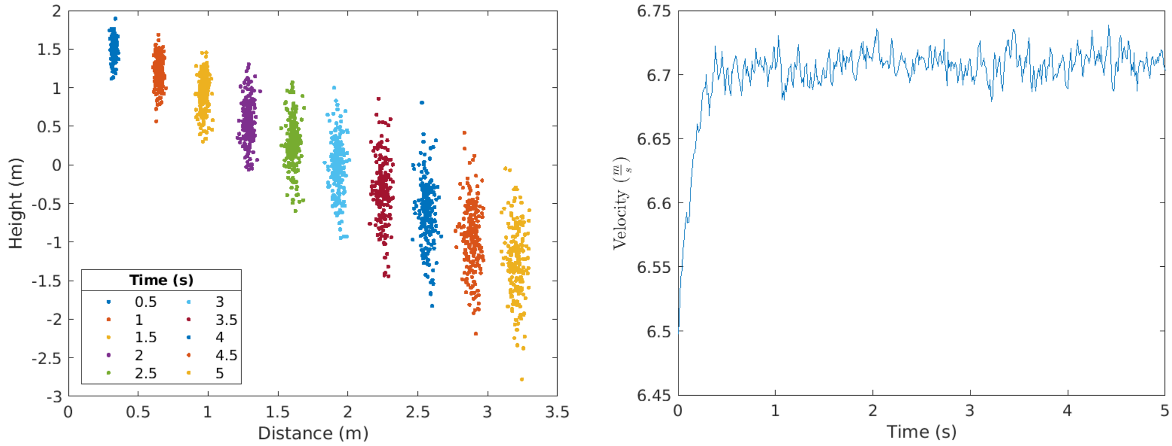
Figure 1. Droplet dispersion at the age of 12 to 30 years. (a) The dispersion after 5 seconds. (b) the average of droplet transmission velocity



(a) (b)

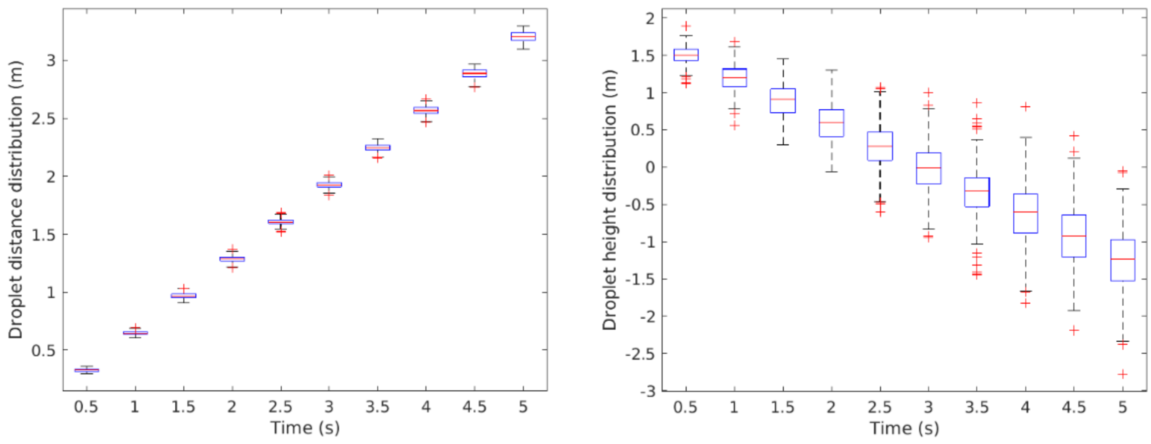
Figure 2. Droplet dispersion at the age of 12 to 30 years with boxplot distribution. (a) The droplet range (distance) x after $t = 5$ seconds. (b) The plot of droplet height y to the time interval

The figure 1 and 2 showed the droplet dispersion of people aged 12 to 30 years old, 31 to 50 years old, and 51 to 68 years old. At the age of 12 to 30 years, after five seconds, the droplet range (distance) and height were 3.13 meters and -0.77 meters. At 0 meters height, the range (distance) was 2.25 meters after 3.58 seconds.



(a) (b)

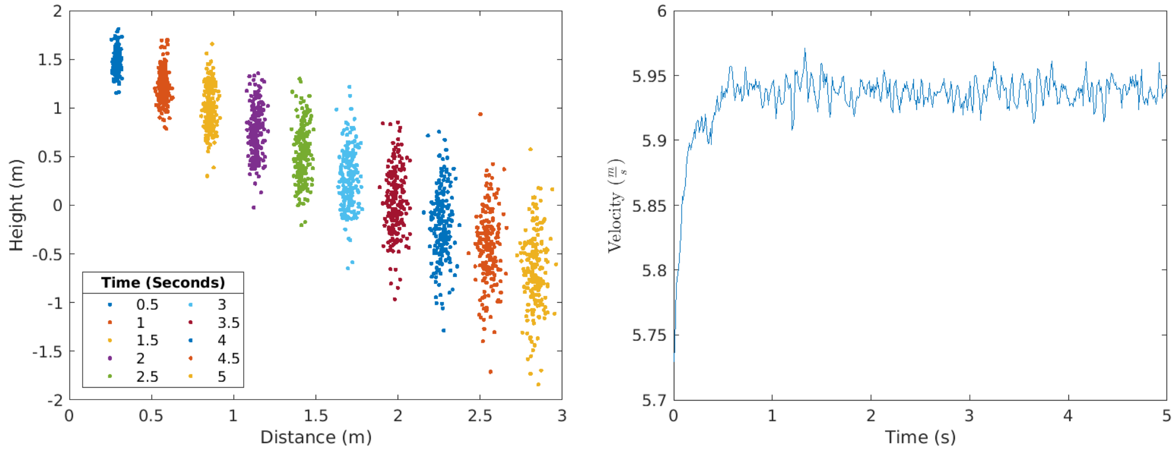
Figure 3. Droplet dispersion at the age of 31 to 50 years. (a) The dispersion after 5 seconds. (b) the average of droplet transmission velocity



(a) (b)

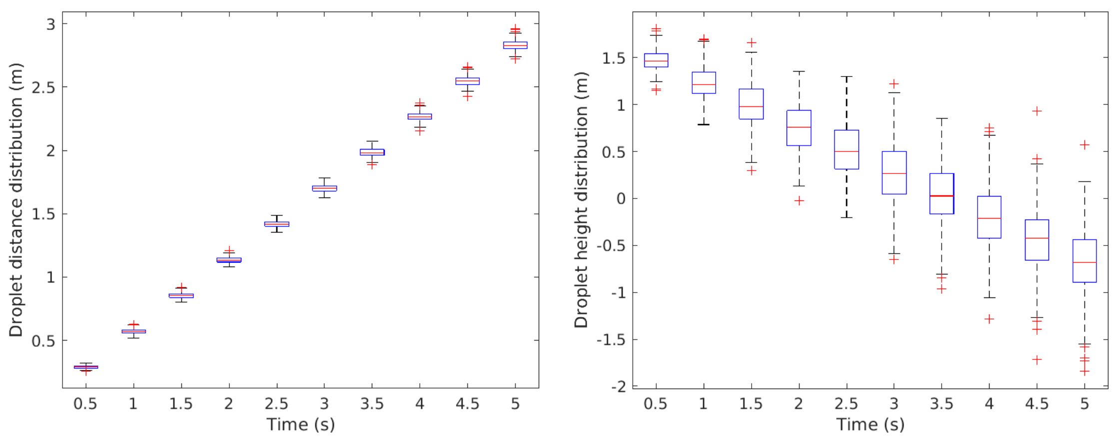
Figure 4. Droplet dispersion at the age of 31 to 50 years with boxplot distribution. (a) The droplet range (distance) x after $t = 5$ seconds. (b) The plot of droplet height y to the time interval

Figure 3 and 4 showed that at the age of 31 to 50 years old, the droplet range (distance) and height were 3.22 meters and -0.83 meters. At 0 meters height, the range (distance) was 2.26 meters after 3.54 seconds.



(a) (b)

Figure 5. Droplet dispersion at the age of 51 to 68 years. (a) The dispersion after 5 seconds. (b) the average of droplet transmission velocity



(a) (b)

Figure 6. Droplet dispersion at the age of 51 to 68 years with boxplot distribution. (a) The droplet range (distance) x after $t = 5$ seconds. (b) The plot of droplet height y to the time interval

Figure 5 and 6 showed that at the age of 51 to 68, the droplets range (distance) and height were 2.82 meters and -0.58 meters. At 0 meters height, the droplet range (distance) was 2.25 meters after 3.83 seconds.

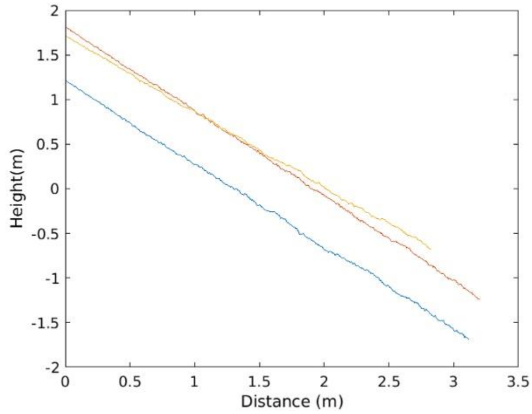


Figure 7. Droplet range (distance) and height at certain age. The blue line was droplet dispersion at the age of 12 to 30 years old, the red line was droplet dispersion at the age of 31 to 50, and the yellow line was droplet dispersion at the age of 51 to 68 years old

Figure 7 is the summary of figure 1 to figure 6. Therefore, it showed that the biggest droplet range (distance) was from the age of 31 to 50 years old and followed by the age of 12 to 30 years old. Finally, the lowest droplet range (distance) was from the age of 51 to 68 years old.

CONCLUSIONS

The simulation of droplet transmission after sneezing or coughing has been developed. The data showed that the age of 31 to 50 gave the highest range of droplet transmission. Meanwhile, the lowest range of droplet transmission was from the age of 51 to 68 years old. Therefore, the age of 31 to 50 years old or the productive age was considerable with the highest risk in the droplet transmission and virus spread.

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