Review and Design of muon detector for monitoring the building material crack for the earthquake-resistant house in Indonesia

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Abstract. Indonesia is a ring of fire country that often occurs earthquakes. Research on earthquake-resistant houses is very challenging to do, so it needs to be supported by a monitoring system for house building materials. Muon tomography uses an alternative technology that utilizes the 24/7 presence of cosmic muon rays that can be applied to create an image of a building in Indonesia. Muon tomography has the advantage that it does not require radioactive material and has a much deeper penetrating power into the material, up to a scale of hundreds of meters. The objective of this study was to review and design essential elements of a muon detector to detect building quality, especially cracks in houses. Comparative investigations of various muon detection methods concluded that the best method of muon detection in Indonesia is with a scintillation detector, particularly by the plastic material, due to its convenience and resolution. Simulation of visible fluorescent light from a plastic scintillator has used a laser beam-controlled quantity by a microcontroller. The muon detector simulation through a photodiode sensor implemented an optical power meter (OPM) to validate its strength. Experimental results show that the distance between sensors was an important factor in designing a precision muon detector. The location of the muon detector should be laid on the foundation, beams, and column of the earthquake-resistant house design.

INTRODUCTION

Many of the victims crushed by cracked buildings [1] due to earthquakes are a severe problem for Indonesia as a ring of fire country [2]. Earthquake-resistant houses [3] need to be developed as one of the solutions to these challenges. The technology for monitoring the quality of building materials requires alternative methods to support earthquake-resistant housing research in Indonesia. The monitor for the microstructure of building material [4] commonly used X-ray technology [5]. However, there are several disadvantages of the X-ray method related to its ease and operational costs. Therefore, it is necessary to apply alternative technology in monitoring the cracking [6] of building materials in the house.

In the last two decades, new pioneering technology has emerged for imaging the interior of a solid, namely muon tomography [7]. This technology uses the 24-hournon-stop presence of cosmic muon rays to create images. This circumstance will save more energy in the use of operational costs. In addition, muon tomography has the advantage that it does not require radioactive material. Even muon techniques have penetrating power that goes much deeper into the matter, on a scale from hundreds to thousands of meters, particularly for building material application [8]. Therefore, muon tomography is an alternative technology that has several advantages over technology that uses X-rays.

There are several techniques for detecting[9] muons. Scintillation detectors are a commonly used method in addition to nuclear emulsion detectors. Another method that can be used to detect cosmic muons is gaseous detectors [7]. Comparative analysis of technology between muon detectors needs to be carried out to find a suitable detection method for the application of observation of building material cracks in earthquake-resistant houses. This research aims to review and design a muon detector to monitor building material cracks in earthquake-resistant housing applications in Indonesia. The ease of application and the precision between muon detector techniques were investigated to design an optimal method suitable for the development of earthquake-resistant houses in this earthquake-prone country. Related simulations are carried out to get the best design.

LITERATURE AND METHODOLOGY

Indonesia is located over the seismic series of the *Ring of Fire* that stretches around the Pacific from the American Southwest to southeast Australia [2]. Along with this route, frequent seismic activity occurs. It triggers earthquakes, volcanic activity, and other potential natural disasters due to tectonic plate shifts. Therefore, earthquakes occur frequently. Almost all islands in Indonesia such as Sumatra [10], [11], Sulawesi [12]and Ambon [13], often experience earthquakes, except for Borneo and a small number of others as shown in Figure 1. The rubble of buildings crushed many lives after the earthquake occurred. Therefore, the development of earthquake-resistant houses [3] is interesting to establish in earthquake-prone countries such as Indonesia.

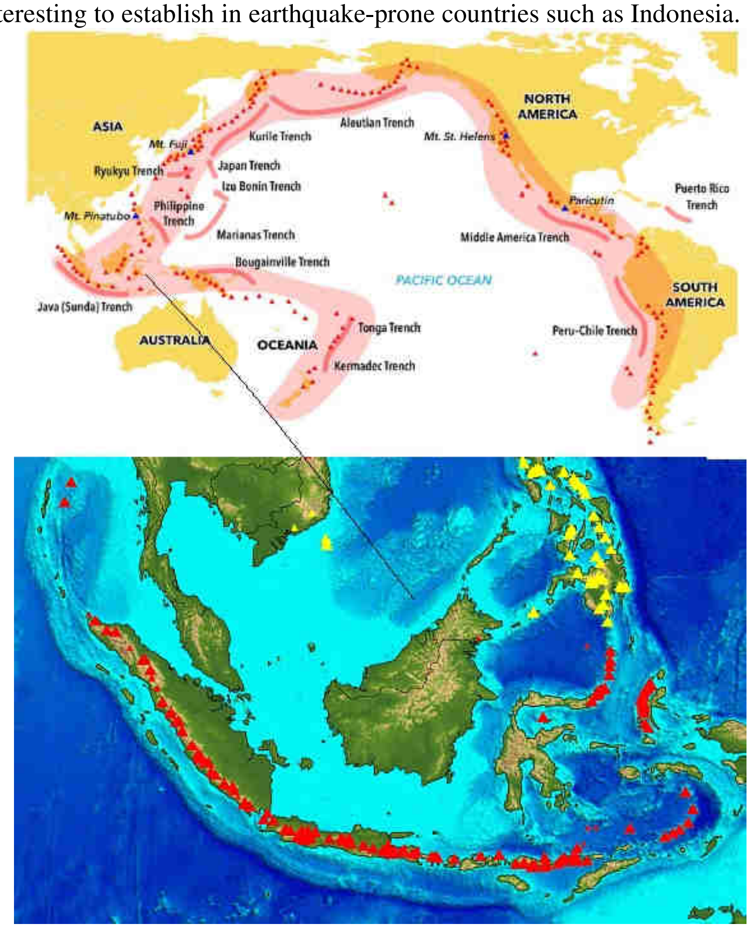

FIGURE 1. The earthquake-prone countries of Indonesia in Ring of Fire

Earthquake-resistant [14] house building is mandatory to decrease casualties and physical damage to house buildings if an earthquake occurs at any time. In most buildings, structural designers rarely include earthquake considerations resilience in planning a building, even though the calculation of earthquake resistance must also be considered because the majority area has geological conditions prone to earthquakes. Architects should strengthen the design of the quality of the building to withstand earthquake shocks. The standard principles of earthquake-resistant house building components are as follows in Figure 2. Muon (often also denoted by the Greek letter μ) is one of the elementary particles in the universe. The properties of muons that are important to know for muon tomography [15] are:

a) Muons have the same electric charge as electrons, which are other elementary particles that are part of atoms.
b) Muons have a mass of about 206 times the mass of electrons.
c) The interaction of muons with matter is much weaker than the electrons due to having larger mass. Consequently, muons can penetrate very thick material up to hundreds of meters.
d) The electric charge on the muon makes it possible to detect muons with standard techniques for detecting the motion of electrically charged particles.
e) The muon decays in Figure 3 with a half-life of 2.2×10^{-6} seconds into an electron and two neutrinos. Neutrinos are particles that have no electrical charge.

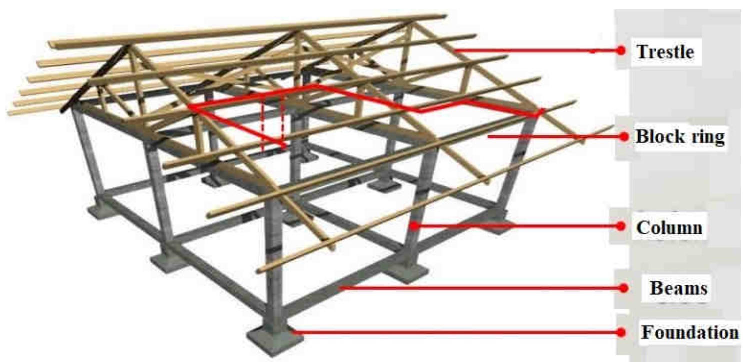

FIGURE 2. The principle of earthquake-resistant houses buildings (PUPR Regulation No. 5 of 2016)

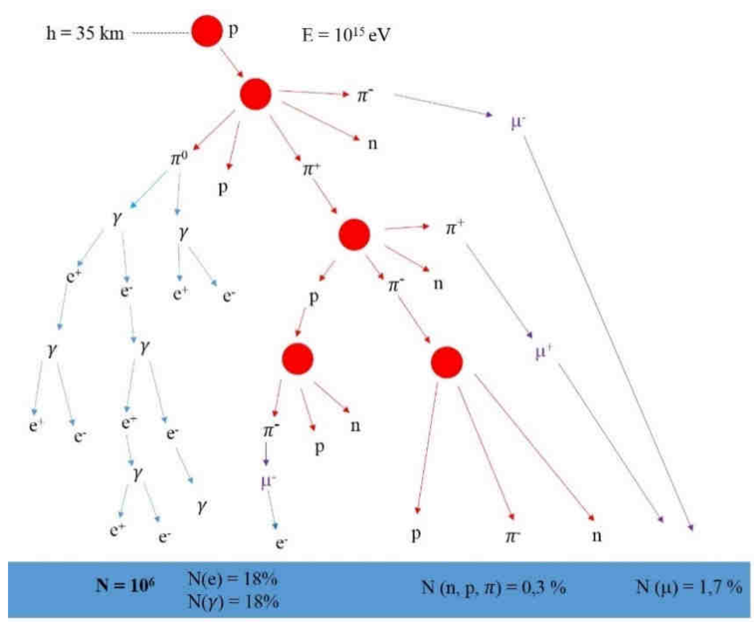

FIGURE 3. Cascade reaction of cosmic rays

In the earth's atmosphere, muons are created by the collision of cosmic rays of high-energy protons (See Figure 3) from outer space with protons and neutrons in the nuclei of gas atoms in the atmosphere. This collision triggers a chain reaction that can produce muons as one of the products in the chain reaction. This process takes place continuously, 24/7 so that muons are created in the atmosphere and poured out to the earth's surface. The muons created in this continuous reaction process in the atmosphere have relativistic velocities close to the speed of light and kinetic energy of about 10 to 40 times the muon's rest mass. The reference frame of observations on the earth's surface, the decay time of muons seems much longer than the normal decay time. Special relativity theory stated about time dilation effect. This relativistic velocity and time dilation impact most of the muons created at high altitudes can reach the earth's surface. The muon flux at sea level is estimated to be around 10 000 muons/sqm/sec.

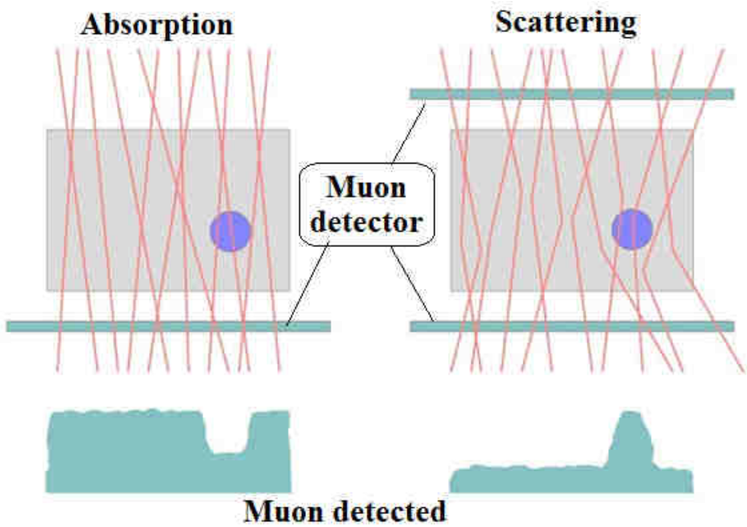

FIGURE 4. Comparison between absorption and scattering of muon tomography.

The combination of the muon flux that is available over time and the muon's ability to penetrate matter allows the use of muons to create an image of the interior of a solid object. This technique is called muon tomography. There are two types of muon tomography which describe in See Figure 4, namely:

- Absorption Tomography. In absorption tomography, muons are only detected after passing through the object.
- Scattering Tomography. In scattering tomography, muons are detected before and past the object.

Muon tomography can be used to view the inside of buildings (Figure 5). Some of the more specific applications of both are looking for possible hazardous materials in buildings and look for the presence of reinforcing bars and cracks in concrete and building structures. The presence of muon cosmic rays can be known by a muon detector. There are several methods of detecting cosmic ray muons and the following are some of the most widely used types of muon detectors which illustrate in Figure 6.

1. Scintillation detectors

   Some materials will contain fluorescent when exposed to cosmic muons. This scintillation method utilizes the fluorescent properties of the material in detecting the presence of muons. When hit by incoming particles, luminous material absorbs its energy and scintillate, for example, crystals, liquids, and Plastic.

2. Gaseous detectors

   The principle of the gas detection method is that when a muon crosses a volume of gas, it will leave an ionized trail behind it. This detector based on ionization of gas is an ideal choice for applications where angular resolution is one of the critical design parameters. In general, gas detectors take advantage of low muon fluxes using fewer and relatively simple electronic channels through gas amplification. Then it translates into high resolution and large surface detectors.

3. Nuclear emulsion detectors

   The nuclear emulsion is a particular type of thick photographic plate with uniform and fine-sized (order m) grains. Charged The particles pass through the nuclear emulsion, leaving traces that can be seen in the microscope after expanding the plate.

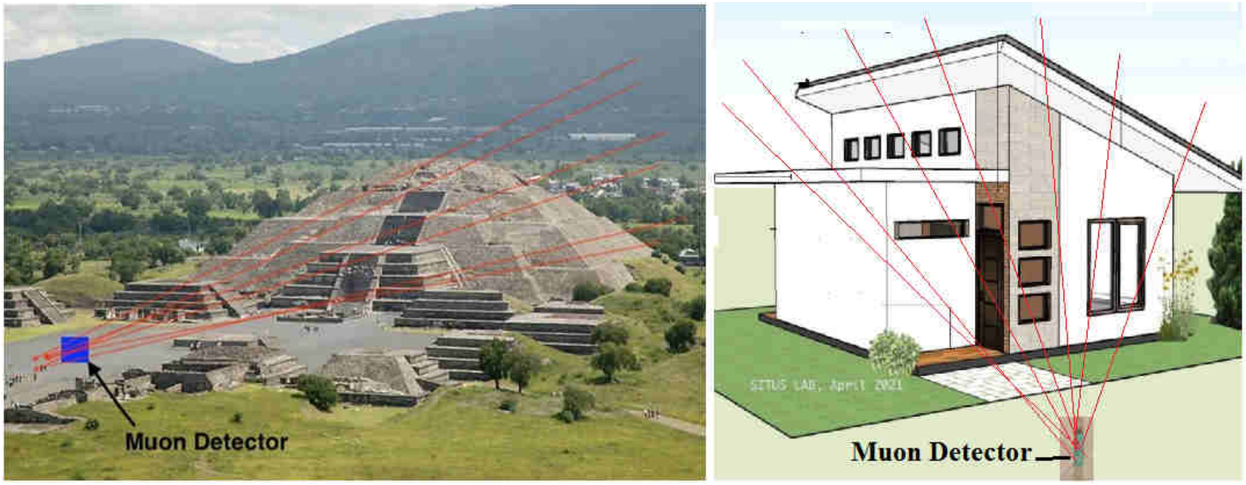

FIGURE 5. Monitoring application example of the interior building by muon tomography.

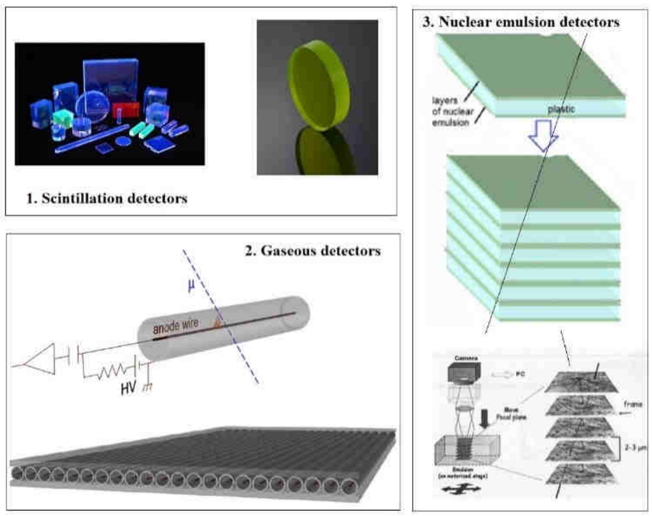

FIGURE 6. Illustration of muon detector type.

DESIGN, DISCUSSION AND SIMULATION RESULTS

The difficulty in operating a muon detector in the field is one of the criteria for selecting the suitable type of muon detector for a particular application. The scintillation detector is a robust muon detector suitable for applications in harsh environments and has a relatively fast response to detect cosmic muon rays. Another attractive that plastic scintillators are easier to shape in various geometries, from squares to rectangles to triangular rods (See Figure 6). The fibers scintillator has the best resolution (approximately 0.1 mrad) [7]. For instance, which can be used to obtain a position-sensitive detection layer with a relatively low number of readout channels. In general, they allow Excellent customization of detector geometry. Despite the success and advantages of gas detectors, there are many problems regarding their operation detectors in muon tomography applications that are not under supervised laboratory conditions. The detector usually requires continuous gas flux, which means they need to supply and refill gas bottles where the measurement is made. This detector is also riskier because it requires steady flammable gas flow, very high voltage around 10 kV, and can be permanently damaged by random spark accidents between electrodes.

On the other hand, the emulsion was one of the earliest particle detectors and contributed to the seminal results. However, there is an essential issue regarding its use. First, the emulsion film begins to record the traces of the particles from the very beginning. Therefore, the emulsion sandwich must be assembled right at the beginning of the observation campaign to undo the information about the previously obtained track. In addition, they suffer from cold temperatures (<10 °C) and humidity. Because of these reasons, the scintillator plastic-type muon detector has the most superficial operational level in using it in the field, mainly in fortification-resistant housing construction.

Table 1. Comparison of varied muon detector technologies

Type of Detector	Operation	Resolution
Scintillator	Easy	High (fiber)
Gaseous	Difficult	High (drift, resolution plate)
Nuclear Emulsion	Hard	Low

Gaseous detectors have excellent resolution (drift and resolution plate chambers by around 0.1 mrad) [7], while the typical choice in many cases is plastic scintillators because their spatial resolution is of little concern. Another attractive advantage is scintillator plastic material with a relatively cheap price/performance ratio. The selection of the type of muon detector for crack monitoring applications for earthquake-resistant houses can be investigated according to resolution and operational considerations. The advantages and disadvantages of the muon cosmic ray detection methods are analyzed in Table 1. The most appropriate for monitoring cracks in earthquake-resistant house building materials is the scintillation detector, particularly the plastic material [16], both from the consideration of ease of operation and resolution of readings. Furthermore, the design should understand and concern the principle of muon detection by the plastic scintillator in energy conversion knowledge.

Muon cosmic rays can be detected with a scintillator. Some of the muon's cosmic energy is absorbed and converted into fluorescent light by the scintillator. The light can be delivered to the photodiode converted into an electrical signal. Fiber scintillator facilitates the distribution of fluorescent light data acquisition due to the detection of cosmic muons, especially for high resolution tomography applications. The voltage produced by the photodiode needs to be amplified with an amplifier to meet the operational standards of the microprocessor, namely at a voltage of 0-3.3 or 5 Volt DC, which has Analog to Digital Converter (ADC) and data processing facilities. Data acquisition (DAQ) design consists of a signal amplifier, ADC, and data processing for human understanding on the monitor screen. The detection of cosmic muons is based on the concept of the law of energy conservation. The scintillator converts some cosmic ray energy into light energy (visible)and then partially converts it into electrical energy by a photodiode. Electrical signals [17] can be easily manipulated via the DAQ to be displayed into data that is easy for humans to understand and analyze as Figure 7.

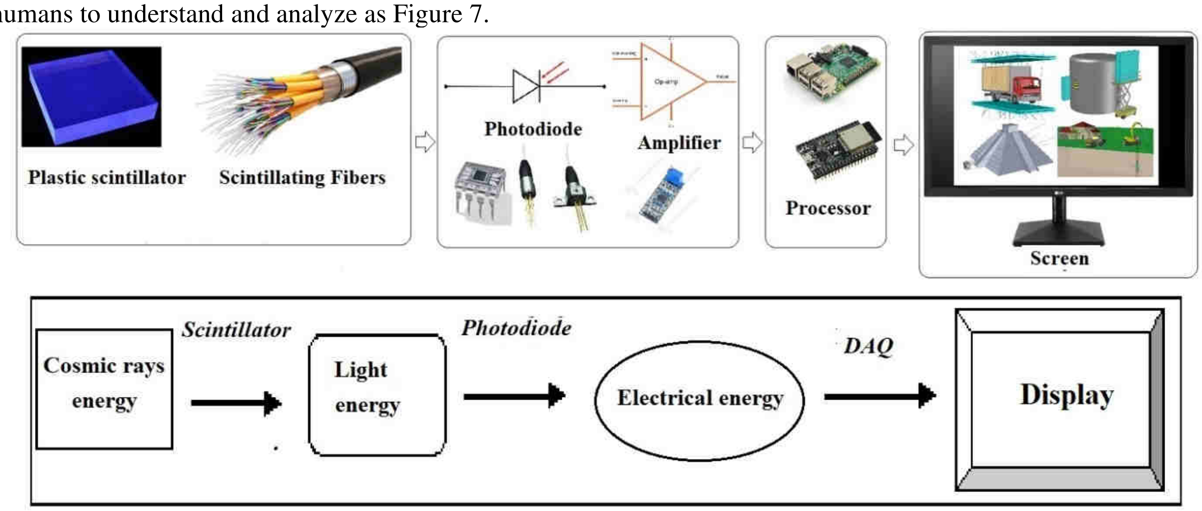

FIGURE 7. Design of plastic scintillator as muon detector

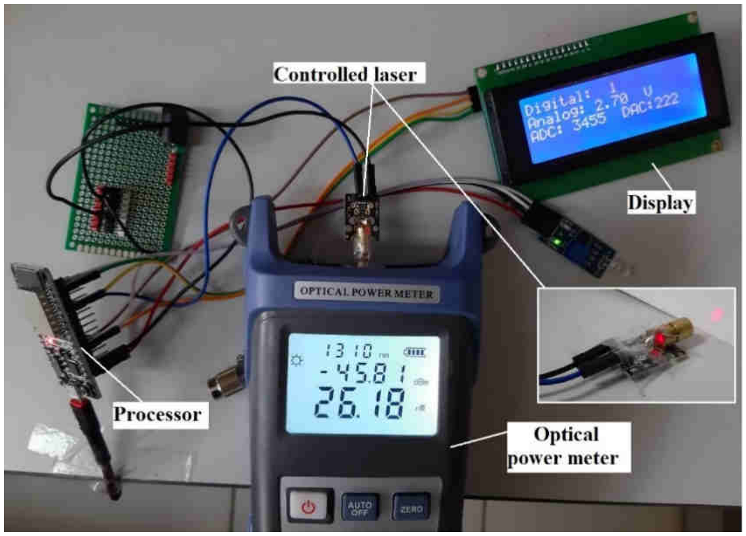

FIGURE 8. Validation of controlled laser beam strength by OPM.

Visible light coming out of the plastic scintillator will be simulated using visible light from a laser [18]. The magnitude of the power of the scintillation light [19] will be analogous to the variation of the optical power of the laser beam. The microcontroller controls the power of the laser beam through its voltage using a Digital to Analog Conversion (DAC) facility. On the other hand, the measurement of the scintillation light simulator uses a photodiode with an Analog to Digital Conversion (ADC) facility on the processor device. Validation of light strength using an OPM in Figure 8 so that measurement results can be trusted according to standards traceability [20],[21]. The validation of the power control of the laser beam through the voltage variation has shown a linear relationship with the optical power.

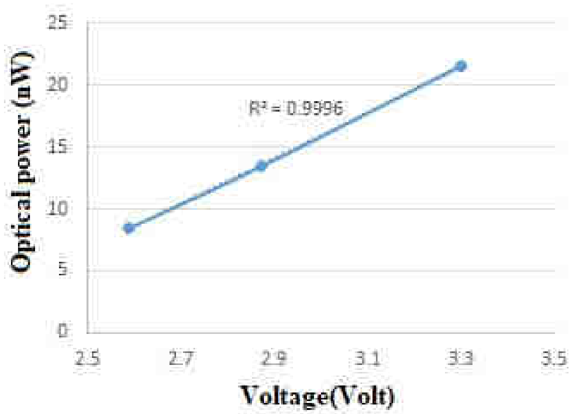

FIGURE 9. Relation between energy control and measured optical power of the laser beam

Figure 9 has described a linear relationship between the voltage-controlled via the DAC and the OPM measured laser beam power. The greater the voltage applied to the laser, the greater the optical power of the beam. In designing [16] the electronic and mechanical aspects of the muon detector for crack monitoring applications for earthquake-resistant houses, variations in the distance between the plastic scintillator and photodiode sensor (d) will need to be simulated in an experiment of Figure 10. The experimental results in Figure 11 have shown that the effect of distance varieties has a different relationship for each response to the measurement of the laser beam power. Distances of 10 mm and 15 mm have given measurement results that occur unresponsive and random. Although distances of 0 mm and 5 mm have had better results. The effect of the distance [22] was taken into consideration in designing the position of the plastic scintillator and photodiode sensor. The case of Fig. 11 explained the optimal photodiode response value at a distance of 5 mm by having a more consistent pattern and uncertainty [23]. A distance of 0 mm also showed a sound pattern with a slight disturbance in the measurement from 5 to 9. This performance [24] indicated an optimal distance to design the position of both items. Light sensors other than photodiodes such as Silicon photomultipliers (SiPM) [25] need to be investigated and compared to get the best design. In summary, the plastic scintillator as muon detector primary sensor (See Fig. 7) should implemented to earthquake-resistant houses buildings. From the visual analysis in Figure 2, the crucial components such as foundation, beams and columns must be monitored by the inserted muon detector.

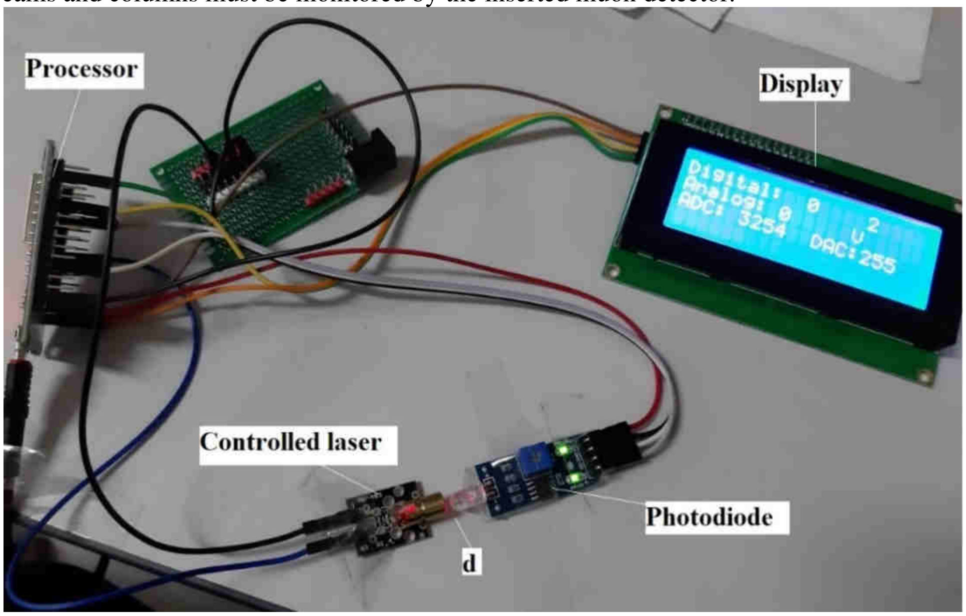

FIGURE 10. Simulation of distance variation between scintillator and photodiode sensor

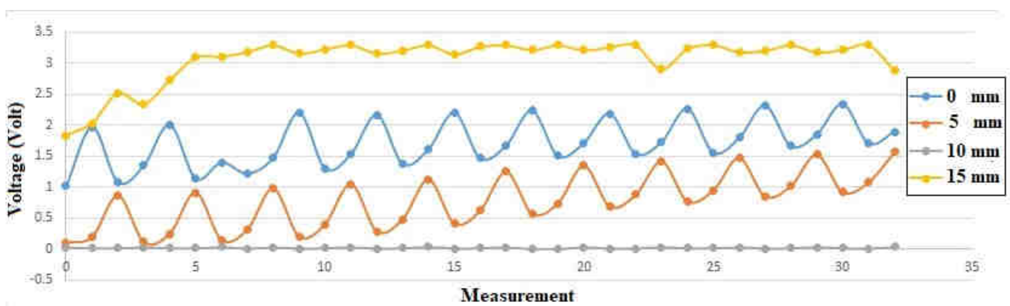

FIGURE 11. Measurement results of photodiode sensor readings by distance variations.

CONCLUSIONS AND SUGGESTIONS

Muon detector technology in tomography offers a promising alternative method in establishing earthquake-resistant housing research in Indonesia regarding advantages in saving and penetrating ability. A comparative study of methods for detecting cosmic muons concluded that the scintillation detector is the best technique suitable for the design of crack monitoring applications in earthquake-resistant houses. Plastic scintillator, principally fiber, is the most optimal primary sensor in designing muon detectors. The law of energy conversion inspired the design of a data acquisition system that converts the light output of the scintillator into user-friendly data on the screen. Experimental results of simulation indicated that the distance between the scintillator and a light sensor such as a photodiode is a vital factor to consider in designing a precise muon detector. Foundations, beams, and columns are recommended as an essential part of installing muon detectors in earthquake-resistant house designs to monitor building cracks early on.

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