Utilization of microcontroller-based ultrasonic sensor in railway crossing safety system

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Abstract: Ultrasonic sensors, such as the HCSRF-04, are widely used in various applications due to their ability to detect objects through reflected sound waves. The sensor consists of a transmitter and receiver unit with a piezoelectric crystal, measuring the time it takes for the reflection to return. The HCSRF-04 can measure distances from 3 cm to 3 m, with pulse output proportional to the distance. The system algorithm includes stages like initialization, sensor reading, servo movement, and activation of LEDs and a buzzer to indicate object detection. This study details the working principles of ultrasonic sensors and their application in control systems using an Arduino Uno microcontroller. One such application is in railway crossing systems, where the ultrasonic sensor helps improve road safety by measuring the distance between the sensor and objects to ensure timely responses for safety measures.

Keywords: Ultrasonic sensor, HCSRF-04, Arduino Uno microcontroller, Railway crossing systems

1. INTRODUCTION

Transportation is one of the main problems in Indonesia, which has a vast area with a very large population. The use of trains as a means of transportation is very encouraging, but in practice there are still many problems related to the safety and comfort of passengers. Trains are currently a popular mode of land transportation because they can accommodate large numbers of passengers, save time, reduce congestion, save fares and have a better level of safety (1). The departure schedule is often late, the number of ticket brokers, the number of stowaways, the condition of the carriages that are less well-maintained to the problem of accidents. Of the various problems faced by railways in Indonesia, the most crucial is the problem of accidents that cause fatalities. Over the past 10 years, there have been many train accidents with other vehicles at the railroad crossing. This is certainly a serious problem for the government in its efforts to develop mass transportation to overcome road congestion (2). It is necessary to encourage the growth of people's intention to travel using rail transportation (3).

The development of technology can help humans solve problems and work more easily. In the field of electronics, automation can be used for anything that can reduce the burden of

human work, make it easier to use and speed up problem solving. It is suitable for sensors that are similar to human intelligence. The same will happen to systems based on microcontrollers, motion sensors, and fingerprint sensors. Technological innovations developed are able to express strategies for security identification that are important to be applied in cyber security and information (4). In addition, the analysis to optimize railroad transportation was carried out with differentiation of technological development including through efforts to reduce fuel consumption by referring to the same travel time for the railroad track (5).

With the development of cheap and convenient sensor and microcontroller technology, it has become easier and more efficient for researchers and tool manufacturers to make tools. A few centuries ago, due to the lack of intelligent systems and derived systems, it was still difficult to make tools and difficult to program these tools (6). Changes in train design need to be adapted to passenger needs in adopting new strategies to improve service quality and passenger satisfaction (7).

Railway tracks are vital for mass transportation and logistics. To ensure operational safety and protect passengers and rail workers, the use of advanced technology is a must. Despite the many difficulties gained during predicting the performance of the railroad track because it has complex properties and repeated loading by considering the life of the structure, the characterization of the rate and the reaction of the track that impacts the comfort of passengers (8). One technology that is full of potential to improve safety at railroad crossings is ultrasonic sensors. These sensors can not only detect surrounding objects, but also provide real-time data that is essential for quick and precise decision-making. For the application of transportation safety technology in Indonesia, a cheap and simple technology is needed so that it can be used at an affordable price. One of the technologies that can be applied is automatic control of trains when running on rails, so that it can make it easier for humans to carry out their duties. According to the Director of Railway Safety of the Ministry of Transportation of the Republic of Indonesia, Mr. Edi Nursalam, there are 4,600 no crossing gates (9).

From the data that shows the importance of guarding at the railroad crossing, the railroad crossing guarding system in Indonesia still uses manual guarding operated by officers continuously for 24 hours. As reported by Kedaulatan Rakyat on Monday, July 28, 2014. The guarding of railroad crossings by officers manually has several weaknesses, including the negligence factor of railroad guards which is increasing along with the level of saturation in duty. The railroad crossing guards who are in charge of manually have an important role in maintaining safety at the railroad crossing. However, there are some weaknesses that need to be considered, including negligence that can occur for various reasons. Some weaknesses faced by railroad crossing officers include officers who work for a long time or have a strict work schedule can experience fatigue that can cause a decrease in concentration and increase the risk of negligence. Human mistakes can occur in the form of failure in seeing the approaching train, wrong in operating equipment or forgetting to close the crossing door crossing. Officers who are constantly exposed to the same task are at risk of experiencing saturation that can reduce alertness and rapid response to dangerous situations.

To reduce these weaknesses, several steps that can be taken include the need to conduct routine training and simulations to maintain the readiness and skills of officers. The importance of combining technology, such as automatic sensors and early warning systems to assist officers in detecting approaching trains. Arrange work schedules that ensure officers get adequate rest and reduce the risk of fatigue. Perform periodic supervision and evaluation of officers' performance to ensure safety standards are maintained. Provide psychological support to help officers manage stress and work saturation. By paying attention to these factors and taking the right steps, the safety in the railroad crossing can be significantly increased. To overcome this problem, a shift system is carried out, but it still does not

guarantee the accuracy of workers with the high level of accidents due to negligence of officers at the crossing proves that the system is less effective in terms of security (2). The study aims to provide a solution or practical application to a concrete problem, such as improving railroad crossing security.

2. METHOD

This study is categorized as experimental research or development research includes system testing using experimental methods to collect empirical data. Experimental research is used to find the effect of treatment under controlled conditions (10), control of the variables tested is carried out during the testing time (11). The main focus of the study is on the development or prototyping of a new system or technology. For example, the construction of a prototype railroad crossing security system using ultrasonic sensors and microcontrollers. This approach can involve the development of technologies that can be implemented in real situations. The main focus of the research is on the design of innovative systems or technologies, such as the integration of ultrasonic sensors and microcontrollers in railway crossing security systems.

Figure 1. Research flowchart

3. RESULT AND DISCUSSION

3.1 Sensor

A sensor is a piece of equipment that functions to detect symptoms or signals derived from changes in an energy such as electricity, physical energy, chemical energy, biological energy, mechanical energy and so on. A device that tells the control system what is happening is called a sensor or also known as a transducer. For example, the human body has a remarkable sensor system that informs the human brain continuously with images of the surrounding environment. For a control system, it must first ascertain what parameters will need to be monitored. Most sensors work by converting some physical parameter such as temperature or position into an electrical signal. This is why the sensor is also known as a transducer, which is a converter of energy from one form to another (12).

Ultrasonic sensors have played an important role in the creation of advanced and reliable railroad security systems. Ultrasonic sensors play a vital role in improving the safety, efficiency and reliability of modern railway systems. With accurate and reliable detection capabilities, these sensors help prevent accidents, monitor infrastructure conditions, and

ensure safe and efficient operations. The integration of ultrasonic sensors in various aspects of train operations creates a more sophisticated and responsive system, increasing safety for passengers and operators, and reducing the risk of damage and operational costs. The following are some research results that show how ultrasonic sensors can be used in train safety systems: they measure the air pressure of train brakes and transmit the data to the microcontroller. They are also able to detect objects very accurately even in erratic weather conditions. The system also incorporates the measurement of train brake air pressure.

3.2 Microcontroller

In this system, the microcontroller functions as the main controlling device as well as the device for monitoring the system. The microcontroller used is ATMega328 which has been integrated in the Arduino Uno module. This module is used because it has specifications that are deemed sufficient for the needs of this instrumentation system. Arduino Uno has specifications: ADC 10 bits; PWM (6 channels) 8 bits; 14 digital I/O pins; 6 analog input pins; 32 kB flash memory; 2 kB static RAM; clock speed 16 MHz; and input voltage 7-12 V. Arduin is one type of microcontroller module that is currently widely used for instrumentation system applications. Arduin uses the C/C++ programming language. This device also features an integrated compiler, ArduinoIDE. Arduino is also open source, making it easier for users to develop the applications they design. In this system, Arduino is used because it is integrated with the Processing interface device. Thus, system design will be easier to do (13).

Microcontrollers process data and regulate actuators to open and close door bars, turn on warning lights, and trigger sirens. Microcontrollers allow systems to be changed to meet specific needs easily. Microcontrollers have the ability to connect to communication networks, which allows them to transmit and receive commands. Systems that use ultrasonic sensors and microcontrollers are typically cheaper and easier to use than conventional technologies. Microcontrollers are a key element in modern, sophisticated and reliable railway security systems. With the ability to process sensor data efficiently, regulate actuators with precision, adapt easily to meet specific needs, and connect to communications networks, microcontrollers ensure that train safety systems can function optimally, responsively, and cost-effectively. The integration of microcontrollers with ultrasonic sensors provides a cheaper, easier to use and effective solution than conventional technology, making it ideal for deployment in a wide range of rail security applications.

3.3 System Algorithm

Here, we will discuss what happens to the system when it is running. Starting from activating the system to the process of turning on the buzzer, LED, and servo motor, there are several stages of the process. The stages in implementing the algorithm system include system activation, initialization, sensor reading, servo movement and LED Ignition. System activation is the initial stage in setting up the system, which activates the input and output components that are already connected. This process involves activating and verifying that all connected input and output components are working properly. Initial activation allows verification that all input and output devices are properly connected and functioning and ensures that communication paths between various components and algorithms are functioning properly. By activating connected input and output components at an early stage, the algorithm system can be set and configured to function optimally. This step not only ensures that all system elements operate as planned but also reduces the risk of failure, increases efficiency, and ensures long-term operational success.

Initialization is the next stage, which initializes all components that are already connected to the system. Initialization is the process of setting the initial conditions of all connected components so that they are ready to carry out predetermined tasks. Initialization ensures that all variables and parameters are in a consistent initial state to prevent problems that may arise due to undefined or random values. By setting consistent initial conditions, the system can run stably without experiencing failures or unexpected behaviour. Overall, initialization is an important step that ensures that all components in the algorithm system are in optimal condition to operate. This helps reduce risk, increase efficiency, and ensure that the system can function properly from the beginning to the end of operations.

Sensor Reading, here the sensor will read the object to be used as a microcontroller input. Sensor reading is a critical stage in microcontroller-based systems, especially in applications that require interaction with the physical environment. The sensor functions as a bridge between the real world and the microcontroller, allowing data to be captured which is then processed to produce an appropriate response. Accurate sensors ensure that the data obtained is an accurate representation of the physical conditions being measured, such as temperature, humidity, pressure, or movement. Accurate data can improve overall system reliability, allowing the microcontroller to make appropriate decisions based on the input received. Sensor readings play a key role in ensuring that microcontroller-based systems can function effectively, efficiently, and safely. With accurate data from sensors, the microcontroller can make the right decisions and control the system better to meet specific application goals and needs.

Servo movement, when the sensor reads the object, the servo motor will move, and when the sensor does not detect the object, the buzzer will be activated. When the sensor does not detect the object, the buzzer will be disabled. Servo movement and buzzer activation based on sensor readings are simple examples of automatic control systems. In this scenario, the sensor acts as the main trigger that determines the next action, namely servo movement or buzzer activation. A responsive system can react quickly to changes in the environment, increasing efficiency and reliability where when the sensor detects an object the servo can immediately move to take the necessary action. This setup allows real-time interaction with the environment, which is important in applications such as robotics, industrial automation, or security systems. Additionally, by moving the servo only when needed, the system optimizes energy use and reduces wear on mechanical components. By regulating servo movements and buzzer activation based on sensor readings, the system becomes more efficient, responsive and reliable. This arrangement enables deployment in a wide range of applications from security systems to industrial automation and ensures that each component functions according to its role and supports overall system performance.

LED ignition in systems involving sensors and buzzers has an important role as an additional visual indicator. An LED that lights up when the sensor detects an object provides clear visual confirmation that the system has detected the object and the buzzer will be activated. LEDs can be used to indicate the operational status of the system such as whether the system is in active or standby detection mode. By incorporating LED ignition in the system gets powerful visual confirmation of the system status and condition, increasing awareness, safety and overall operational efficiency.

3.4 Ultrasonic Sensor

Ultrasonic sensors are sensors that work based on the principle of sound wave reflection and are used to detect the presence of an object or object in front of the working frequency in the area above the sound waves from 20 kHz to 2 MHz (14). The ultrasonic sensor consists of

two units, namely the transmitter unit and the receiver unit of the transmitter and receiver unit structure. It is very simple that a piezoelectric crystal is connected to a mechanical anchor and only connected to an alternating voltage vibrating diaphragm that has a working frequency of 20 kHz to 2 MHz (14). The atomic structure of piezoelectric crystals causes contraction to expand or shrink, a given voltage polarity and this is called the piezoelectric effect on ultrasonic sensors (15).

The reflection of ultrasonic waves occurs when there is a certain object and the reflection of ultrasonic waves will be received back by the receiving sensor unit. Furthermore, the receiving sensor unit will cause the vibrating diaphragm to vibrate and the piezoelectric effect produces an alternating voltage with the same frequency. For more details about the working principle of the ultrasonic sensor can be seen the principle of the ultrasonic sensor in Fig. 2.

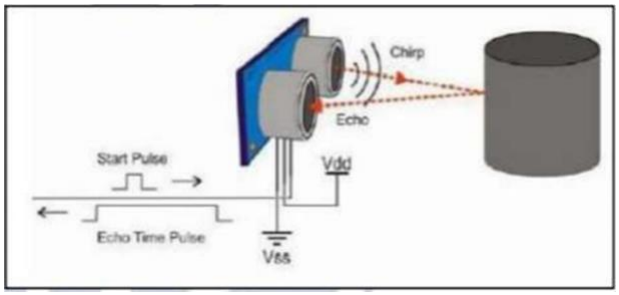

Figure 2. Reflection of ultrasonic waves (working principle of ultrasonic waves)

The amplitude of an electrical signal generated by the receiving sensor depends on the proximity of the object to be detected as well as the quality of the transmitter and receiver sensors. The sensor process carried out on this sensor uses the reflection method to calculate the distance between the sensor and the target object. The reflection principle of the ultrasonic sensor can be seen in Figure 3.

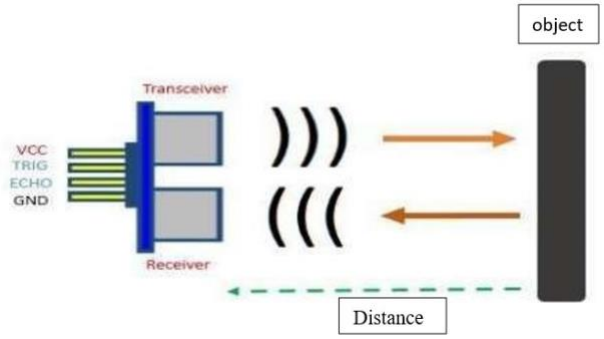

Figure 3. How an ultrasonic sensor works

An ultrasonic sensor is a sensor that converts physical quantities (sound) into electrical quantities. In this sensor, ultrasonic waves are generated through an object called piezoelectric. This piezoelectric will produce ultrasonic waves with a frequency of 40 kHz when an oscillator is applied to the object. Ultrasonic sensors are commonly used for a variety of touchless disclosures such as distance measurement applications. They generally emit ultrasonic sound waves towards a target that reflects the waves back towards the sensor. The system then measures the time it takes for the waves to travel back to the sensor and calculates the distance of the target using the speed of sound in the medium (15). In ultrasonic sensors, ultrasonic waves are generated through a device called a piezoelectric with a certain frequency. This piezoelectric will produce ultrasonic waves (generally 40kHz frequency) when an oscillator is applied to the object (16).

3.5 HC SRF-04 Ultrasonic Sensor

The working principle of this sensor is that the transmitter sends an ultrasonic wave and then measures the time it takes until the reflection from the object. The length of time is proportional to twice the distance between the sensor and the object. The Hcsrf-04 can measure distances in the range between 3cm-3m with an output pulse length proportional to the distance of the object. This sensor only requires 2 I/O pins to communicate with the microcontroller, namely Trigger and Echo. To activate the HCSRF-04 the microcontroller sends a positive pulse through the Trigger pin for at least 10ms, then the HCSRF- 04 sends a positive pulse through the Echo pin for 100ms to 18ms, which is proportional to the distance of the object. The specifications of the HCSRF-04 ultrasonic sensor are as follows:

a. Dimensions: 24mm (P) x 20mm (L) x 17mm (T).
b. Current Consumption: 30 mA (average), 50 mA (max).
c. Range: 3 cm-3 m.
d. Sensitivity: Able to detect objects with a diameter of 3 cm at a distance of > 1m.

Figure 4. HC-SR04 Ultrasonic Sensor

3.6 HCSRF-04 Ultrasonic Sensor Working Principle

The working principle of HCSRF-04 is that the transmitter emits a beam of ultrasonic signals (20 KHz) in the form of pulses, then if there is a solid object in front of HCSRF-04, the receiver will receive the reflection of the ultrasonic signal The receiver will read the pulse width (in the form of PWM) reflected by the object and the difference in transmission time. With these measurements, the distance of the object in front of the sensor can be known for more details, see the picture below:

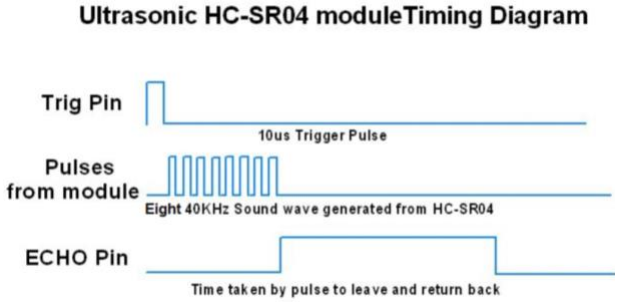

Figure 5. Timing Diagram for HC-SR04 Ultrasonic Sensor

The trigger and echo pins are connected to the microcontroller. To start measuring the distance, the microphone outputs a high output on the trigger pin for at least 10 µS. The incoming high signal makes the HCSRF-04 sensor emit ultrasonic sound waves. Then when

the reflected sound returns to the HCSRF- 04 sensor, the sound will be received and make a high signal output on the echo pin which then becomes input to the HCSRF04 microcontroller which will give a pulse of 100 µs - 18ms at the output depending on the distance information of the object's reflection received. The duration of the high signal from the echo is what is used to calculate the distance between the HCSRF-04 sensor and the object that reflects the sound in front of the sensor.

3.7 Overview of Tools

The design of an arduino based railroad crossing warning safety device is a device used to give a warning at a railroad crossing when a train is coming across. The goal is to warn road users with alarms in the form of lights and buzzers for SAR knowing that there will be trains that will pass.
The Arduino Uno is a microcontroller board based on the ATmega328P M The Arduino Uno has 14 digital output put pins (of which 6 can be used as PWM outputs), a 16 MHz Arsa VISA JI, USB connection, power plug, ICSP header and reset button. It contains everything needed to support a microcontroller; simply connect it to a computer with a USB cable or power up with an AC-to-DC adapter or battery to get started. The Arduino Uno can be tinkered with without too much worry of making mistakes, the worst cases scenario being to replace the ATmega328P chip and start all over again.
Using microcontroller-based ultrasonic sensors as level crossers in railroad crossing safety systems is an innovative step to improve safety. Measures the distance between the sensor and objects (such as vehicles or pedestrians) in the vicinity of the crossing.
Main components of the system:

- Microcontroller (serves to control the ultrasonic sensors, process the data, and activate the warning system),
- Warning Signals (including lights, sirens, or alarms that are activated when an object is detected at the crossing),
- Automatic Door Barriers (driven by actuators controlled by the microcontroller based on sensor data) and
- Communication System (serves to monitor the state of the crossing by connecting sensors and microcontrollers to a centralized system or supervisor).

4. CONCLUSION

Ultrasonic are sensors that work on the principle of sound wave reflections and are used to detect the presence of an object or a certain body in front of the working frequency in the area above the sound waves from 20 kHz to 2 MHz. The HCSRF-04 sensor is a transmitter that sends ultrasonic waves and then measures the time it takes for the reflection of the object to arrive. The microcontroller functions as the main controlling device as well as the device to perform system monitoring. The system algorithm is discussed by the system when it is run.

Application of system work in this study included ultrasonic sensors are placed at strategic locations around the railroad crossing to identify pedestrians and vehicles that are passing through. To find out if there is an object in the danger zone, compare the measured distance with the threshold. If an object is detected to be within the danger zone, the microcontroller activates a warning system, such as flashing lights and sirens, to alert road users. If the vehicle or pedestrian remains in the danger zone as the train approaches, the door bar is automatically lowered to prevent accidents. The system has a supervisory mechanism

that monitors the operation of sensors and microcontrollers and ensures that all components are operating properly. Regular maintenance is carried out to ensure the reliability and accuracy of the system.

REFERENCES

Wu, L., Zhang, J., Fujiwara, A., Chikaraishi, M. (2012) Analysis of tourism generation incorporating the influence of constraints based on a Scobit model. *Asian Transport Studies*, 2(1), 19-33.

Devianto D, Permana D, Arif E, Afrimayani A, Yanuar F, Maiyastri M, et al. An innovative model for capturing seasonal patterns of train passenger movement using exogenous variables and fuzzy time series hybridization. J Open Innov Technol Mark Complex [Internet]. 2024;10(100232):1–14. Available from: https://doi.org/10.1016/j.joitmc.2024.100232

Satrianto DI, Yannik KA, Sasongko S, Sugiarto HS, Wibowo RS. Palang Pintu Otomatis Dengan Countdown Sebagai Upaya Menghindari Kecelakaan Di Perlintasan Kereta. Palang Pintu Otomatis Dengan Countdown Sebagai Upaya Menghindari Kecelakaan Di Perlintasan Kereta. 2016;11(1):24–34.

Lieophairot C, Rojniruttikul N. Factors affecting state railway of Thailand (SRT) passenger train service use decision: A structural equation model. Heliyon [Internet]. 2023;9(e15660):1–18. Available from: https://doi.org/10.1016/j.heliyon.2023.e15660

Zhang W, Liu M, Lu X, Deng L, Fan X, Cheng G, et al. Triboelectric sensor-empowered intelligent mouse combined with machine learning technology strides toward a computer security system. Nano Energy. 2024;126(109666).

Kamel T, Amor P, Polater N, Zhang Y, Tian Z, Hillmansen S, et al. Development of a smart hybrid drive system with advanced logistics for railway applications. Int J Hydrogen Energy [Internet]. 2024;52:559–76. Available from: https://doi.org/10.1016/j.ijhydene.2023.01.293

Kurniawan F, Surahman A. Sistem Keamanan Pada Perlintasan Kereta Api Mengunakan Sensor Infrared Berbasis Mikrokontroller Arduino Uno. J Teknol dan Sist Tertanam. 2021;2(1):7.

Yang J, Shiwakoti N, Tay R. Train passengers' perceptions and preferences for different platform and carriage design features. J Public Transp [Internet]. 2024;26(100085):1–12. Available from: https://doi.org/10.1016/j.jpubtr.2024.100085

Powrie W. Soil mechanics principles for modelling railway track performance. Transp Geotech [Internet]. 2024;47(101265):1–12. Available from: https://doi.org/10.1016/j.trgeo.2024.101265

Hermawan A. Sistem Kendali Otomatis Pada Pintu Perlintasan Kereta Api. J Ilm Mhs Kendali dan List. 2021;1(2):65–70.

Asriningsih KKA, Supardi KI, Wardani S. Pengaruh Model Pembelajaran Inkuiri Terbimbing Berbasis Lingkungan Terhadap Kemampuan Pemahaman Konsep Dan Karakter Pada Siswa Kelas V SD. J Prim Educ. 2015;4(2):132–8.

Arib MF, Rahayu MS, Sidorj RA, Afgani MW. Experimental Research Dalam Penelitian Pendidikan. Innov J Soc Sci Res. 2024;4(1):5497–511.

Barauskas D, Pelenis D, Dzikaras M, Vanagas G, Mikolajunas M, Baltrusaitis J, et al. Highly selective capacitive micromachined ultrasonic transducer–based miniature gravimetric CO2 sensor with in-situ calibration for relative humidity. Sensors Actuators B Chem. 2023;393(134178).

Alawiah A, Rafi Al Tahtawi A. Sistem Kendali dan Pemantauan Ketinggian Air pada Tangki Berbasis Sensor Ultrasonik. KOPERTIP J Ilm Manaj Inform dan Komput. 2017;1(1):25–30.

Arief UM. Pengujian Sensor Ultrasonik PING untuk Pengukuran Level Ketinggian dan Volume Air. J Ilm "Elektrikal Enjiniring" UNHAS. 2011;09(02):72–7.

Arsada B. Aplikasi Sensor Ultrasonik Untuk Deteksi Posisi Jarak Pada Ruang Menggunakan Arduino Uno. J Tek Elektro. 2017;6(2):1–8.

Lestari AP. Pemanfaatan Sensor Ultrasonik Berbasis Arduino Uno Sebagai Peringatan Dini Banjir Bengawan Solo Di Kabupaten Tuban, Jawa Timur. J Geogr Geogr dan Pengajarannya. 2019;17(1):55.