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Automation of Trolley Wire Adjustment to Improve Safety of Deviation Maintenance on Japanese Type Catenary Networks

Guang Yang Haou[1], Li Chiau[1], Whu Jiadong[1,2]

[1]Faculty of Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, CHINA
[2]State Key Laboratory of Advanced Technology Transmission Technology, Global Energy Interconnection Research Institute Co., Ltd., Beijing 102209, CHINA

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Abstract

The deviation Maintenance is an examination activity including measurement of the trolley wire deviation angle, the height of the trolley wire to the rail, and adjust the deviation of trolley wire on the catenary system or Overhead Contact Systems (OCS). All maintenance activities are carried out along railway lines and handled directly by workers. Implementation of this deviation maintenance is very rich and full of risks, because all work is still done manually by the workers. In this research we will create a prototype of automatic trolley wire measurement and adjustment equipment using Arduino uno microcontroller and some supporting sensors such as ultrasonic sensor and laser receiver sensor. For drives using a dc motor actuator that serves to pull or push the trolley wire to form an appropriate angle deviation.

Keywords: Upper Flow Electricity, Deviation Treatment, Microcontroller, contact wire

Corresponding Author:

Name: Guang Yang Haou
Email: Guang haou@ymail.com

1. Introduction

KRL or Electric Rail Train is a rail-based mass transportation mode which is one of the main modes of transportation in Jakarta and its surroundings. KRL uses an electrical energy source as its driver. The electric power is sourced from the PLN substation which is distributed to the traction substation which specifically supplies KRL power.

KRL is divided into two parts, namely the electrical transmission section which is usually called Top Flow Electricity (LAA) and the power supply source itself which includes direct current (DC), alternating current (AC) and magnetism. KRL in Jabodetabek uses DC current of 1500V, the use of DC current can minimize disruption and is adjusted to the distance between stations that are relatively close, so the use

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of DC current is more profitable to see from the number of KRL trips that can reach 1 million passengers per day.

To meet these needs, the KRL power supply transmission equipment must always be in a reliable condition and ready to operate, so routine maintenance is carried out on the LAA network. LAA network maintenance is carried out by the LAA resort which only exists in DAOP 1 Jakarta. In the KAI document the Guidelines for the Treatment of Disorders no. doc: STE-IK-AMPT-8.1.3-26 regarding catenary network maintenance includes, contact wire maintenance (height, deviation, diameter), deviation maintenance is the measurement and deviation setting as well as the height of the trolley wire to the rail asses.

Currently the treatment is still done manually Deviations carried out by 3 LAA resort personnel. Because of this the measurement process becomes inaccurate and ineffective because the time required in the measurement and maintenance of deviation is relatively long. errors in measuring deviations that are not in accordance with the standard can cause the pantograph to be loosened or stuck to the Trolley wire, in addition there is a high level of risk related to safety and security for field workers carrying out measurements and arrangements for Trolley wire deviation.

The solution to improve safety and safety while increasing the effectiveness of the measurement and regulation of trolley wires in the maintenance of Top Flow Electric deviation is by updating the technology used, from manual to automatic.

Objectives are things that will be achieved from research, based on the identification of problems that there are goals to be achieved in the study are as follows; 1). To find out how the measurement procedure and Trolley wire deviation settings are related to the safety and security of workers. 2). To find out the process of making and assembling a prototype measuring instrument and setting automatic deviation. 3). To find out the program used in Arduino to control the measurement tool prototype and automatic deviation settings. 4). To find out how the test results are and whether this prototype can function according to plan.

2. Research Method

LAA maintenance is a routine activity carried out to maintain and or repair Top Flow Electric network equipment so that it is always in a reliable condition and ready to operate, according to KAI document "Syntax Care Guidelines" (STE-IK-AMPT-8.1.3-25) , LAA maintenance or catenary network is divided into 2, namely one monthly LAA treatment and 3 monthly LAA maintenance.

3-month checks and maintenance include activities consisting of wire troly, WCM, and earth measurements. Some parameters measured are:

1. Wire Trolly:
2. Height;
3. Deviation;
4. Diameter.
5. WCM height;
6. Ground value

Work tools and parts needed are: mistel, digital calipers, grounding tester, lorry tower, stairs, lighting, stationery, fluorescent safety vests, PPE (electric gloves, safety shoes, and safety helmets). Personnel needed at least 3 resort staff.

Treatment Procedures:

1. The executor carries out the annual catenary network 1 annual maintenance activities based on the Monthly TABLO and the Work Request Note from the local KAT;

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2. KAT prepares work tools and parts needed for the implementation of the 1-year maintenance of the catenary network;
3. KAT coordinates with KS / PPKA;
4. Upon arrival at the station concerned, the executor submits a note (if any), provides verbal information to the station officer (KS / PPKA) regarding the implementation of the annual inspection of the catenary network;
5. The executor pays the results of the examination on the Catenary Network 1 Year Care Examination Sheet form;
6. Standards for the execution of work are a maximum of 1 working day;
7. If the condition of the equipment is found outside the standard specifications / references, the implementer must record the problem with the LP, and report the matter to KAT;
8. KAT presents the problem to KARES, and coordinates the settlement according to the disposition of KARES;
9. The inspection work completed has been approved by the signatures of Officer at the Station (KS / PPKA);
10. The Executor submits the LP no later than 1 (one) day after the inspection, the measurement and maintenance are declared complete.

3. Results And Discussion

This research is included in research that requires data, in collecting data using two methods, as follows: 1. Primary data, in this study are using experimental data collection methods and field surveys. Experimental data collection methods in this study, the authors make experiments or experiments, namely by making prototypes of measurement tools and automatic deviation settings according to the design. Making prototypes in this study based on LAA network design obtained from the results of secondary data collection, namely from a literature study of literature searches on Upper Flow Electricity. 2. Secondary data in this study is literature study / literature study in which researchers look for data / literature on Upper Flow Electricity, especially its components and working systems. Secondary data in this study is used as a reference and comparison of the level of safety and effectiveness in making a new design about the modification of the Stim Pipe for the maintenance of trolly wire deviation. 3. The analytical method used to answer the main problem in this study is using the Evaluation analysis method. This evaluation method is a research method that uses evaluation in each research result obtained and implemented to improve any deficiencies until this study gets the expected results of the study with comparative parameters of the results of the study compared with the level of safety of trolly wire wire maintenance procedures currently implemented.

3.1. Analysis of LAA Deviation Treatment Procedures

LAA deviation maintenance procedure refers to PM number 50 of 2018 which is a discussion of PM number 12 of 2011 concerning the requirements of railroad electrical installation and refers to the SYNTHETIC maintenance guidelines for STE-IK-AMPT-8.1.3-25 document number. In the document describes the monthly and annual maintenance procedures for the Upper Flow Electricity network. The guidelines describe the measurement procedure, level or height, and LAA deviation settings. At present all of these maintenance activities are carried out with a three-month work period.

Deviation treatment is a treatment with a long period of work with a standard working time up to 1 working day. In one day the deviation measurement can complete a road plot with a distance between stations up to 3km, it takes 2 to 3 hours to complete the measurement of deviation and altitude only, for deviation settings will be carried out if deviations are found that exceed the standard and will be done during windowtime where the KRL is not operating. Before the implementation of deviation

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arrangements, officers are required to use PPE or personal protective equipment. LAA deviation setting work is usually carried out at 00.00, with the following procedures:

1. Reports on the substation to turn off the voltage at the location carried out by the deviation arrangement;
2. Grounding cable installation on trolley wire to remove residual stresses;
3. Voltage check on wire trolley using a voltage detector;
4. If it is declared safe, one LAA officer will climb the LAA pole using a ladder of more than 5 meters to prepare to shift the pull-off;
5. One other officer monitors the trolley wire deviation value using a mistel;
6. And the last officer holds the lorry or stairs;
7. Officers who climb the stairs begin to loosen the bolts and nuts in the pull-off fittings until the pull-off fittings can shift. The process of pulling the pull-off fittings must be right because if it is too loose, what happens is the trolley wire that will pull the pull-off, when the pull-off fittings have begun to loosen the officer will hit the pull-off ftf several times to the right or left until pull-off off shift that will pull the trolley wire, for example the wire trolley has a deviation of 27 cm right of the straight line (over the maximum limit), then the officer must shift the pull-off fittings to a minimum of 7 cm to the left, then the deviation will be 20 cm right (maximum standard deviation in the straight line).
8. When the officers work on the deviation control process, they must remain vigilant with the long distance train that will pass, if there is a long-distance train that will pass, all maintenance activities must be stopped and remove all equipment from the railway, after the train passes, activities treatment can be resumed;
9. If the wire deviation of the trolley has been set according to the standard, the officer will again tighten the bolts and nuts on the pull-off fittings and the LAA deviation arrangement is completed.

Based on the data above it can be said that the measurement and regulation of LAA deviations is a work activity that is classified as dangerous by having a high risk. According to Act No. 1 of 1970 article 2 on work that has sources of danger for workers is:

1. Workplace where there is construction, repair, maintenance, cleaning or dismantling of houses, buildings or other buildings;
2. Doing work at an altitude above the surface of the land or waters;
3. A place where there are machines, equipment or installations that can cause accidents;
4. Work carried out generation, relating to electricity, gas, oil, or water;
5. Work that has the danger of falling, falling, falling, or falling objects.

Therefore special protection equipment is needed that must be used when carrying out maintenance of the LAA network namely PPE, but PPE will not eliminate the danger of the work but only reduce the consequences. The cause of work accidents consists of several things, namely the conditions of the work environment, equipment, and the worker itself (human error). According to the theory of causes of accidents, human factors have the highest percentage of about 85% of accidents that occur. This is because workers (humans) do not fulfill safety, for example due to neglect, carelessness, drowsiness, fatigue, and so on.

Risks or dangers that exist in work done directly or manually cannot be eliminated or prevented. However, prevention can be done by replacing the work system itself with a better and more reliable work system without involving workers carrying out the work directly or can be said to be Automation. Prevention is very important, as stipulated in article 3 of 1970 article 3 concerning the safety requirements, including:

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1. Prevent and reduce accidents;
2. Obtain harmony between workforce, work tools, environment, methods and processes of cooperation;
3. Adjust and improve security for dangerous work.

Based on these data, a new technology is needed that can be applied to LAA deviation maintenance procedures so that the safety and security of workers can be guaranteed without any risk where the technology has better reliability and effectiveness than the current deviation maintenance procedures.

3.2. Concept Tools

In the concept, the author will modify the LAA network, especially on the cantilever stimulation pipe and pull-off as a part that can be shifted to determine the deviation from the contact wire. A pull-off previously mounted on a straight iron rod will be removed and mounted on a DC motor-powered electric actuator that functions to convert the rotary motion of the DC motor into translational motion on the mechanical arm of the actuator, the actuator stick automatically by utilizing laser modules and laser receivers, modules the laser will be attached to the pull-off part and two laser receivers will be installed in the rail bearing section. the laser module will emit laser light all the way down, and the receiver laser sensor will be installed on the left and right sides of the laser light fall. So if there is a shift on the rail that makes a deviation in the deviation, then the laser light will hit the laser receiver and instruct the actuator to move according to the distance deviation until the laser light will fall on its original position and keep the value of the deviation maintained in its normal position. this system uses Arduino Uno as a microcontroller to control at least 2 actuators. This system will regulate the deviation from contact wire more accurately. While the ultrasonic sensor will be installed on the top of the pull-off to measure the deviation that will be displayed on the LCD screen. With this modification the implementation of deviation treatment will be more effective, accurate, and the main thing is safer.

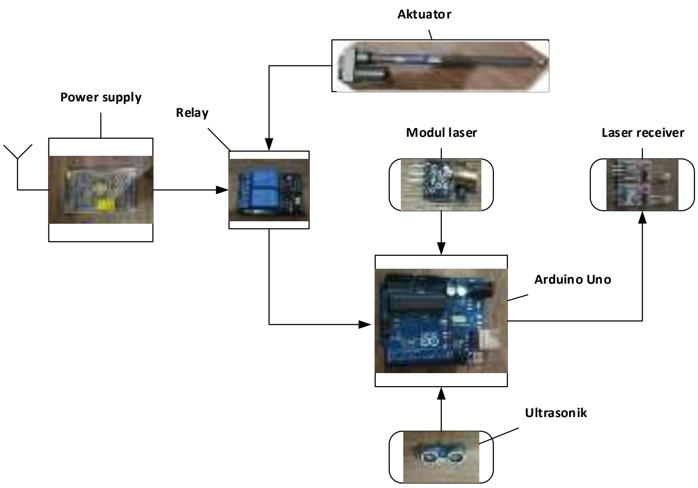

Figure 1. Concept of Tool

In the diagram above has been described about the components used to make prototype setting tools and automatic deviation measurements with the following information:

1. Power Supply, as a voltage converter from 220 volts AC to 24 volts DC to supply the actuator via relay.
2. 5v 2 channel relay, as an electrical switch to change the direction of motor rotation on the actuator.

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3. Actuator, acts as a regulator of deviation on the wire trolley by lengthening or shortening the arm of the actuator.
4. Laser module, this module emits laser light which will trigger the laser receiver sensor.
5. Laser receiver, receive light from the laser and give input to Arduino to activate the relay.
6. HY SRF-05 ultrasonic sensor, as a distance meter in the form of a value of trolley wire deviation.
7. Arduino Uno, as a control to process incoming data from all sensors and forward them.

3.3. Calcilation of Tensile Strength of Actuators against Wire Trolley

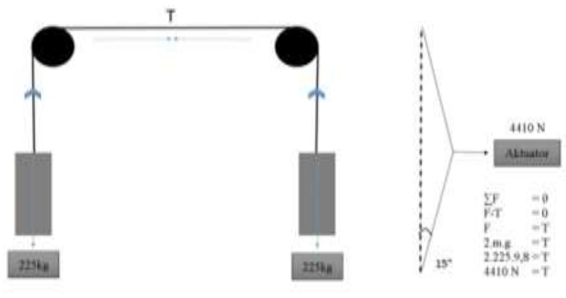

Figure 2. Concept of Wire Trolley

Actuators used in making this prototype are 24 inch and 18 inch satellite dish actuators using 24 volt power source. The strength of this actuator is 2500N-3000N for 24inch actuators and 1500N for 18 inch actuators. following calculation of tension force on wire trolley with ATD type Pulley on one pole and two poles.

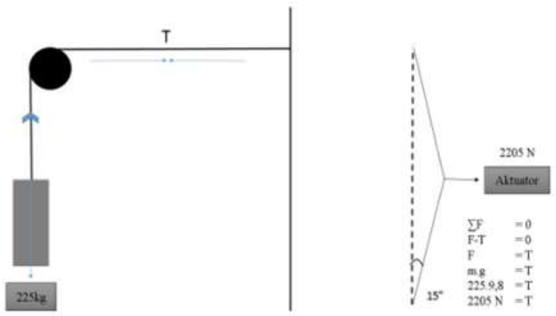

Figure 3. Concept of Wire Trolley

The application of ATD pulley is one pole and two poles depending on the distance between the points of death. Pulleys on one pole are used if the wire length of the trolley is 600 meters up to 800 meters, while the pulley at both ends of the pole is used if the wire length of the trolley is more than 800 meters. Ballast on ATD is a concrete that is arranged in a multilevel, each concrete weighs 25-50kg. beton arrangement consists of 5 levels with 1 concrete weighing 25kg and 4 concrete weighing 50kg with a total weight of 225kg. In the calculation above obtained results:

Table 1. Measuring the tensile strength of the actuator

No	actuator	Pull strength	ATD single pulley (2205N)	ATD double pulley (4410N)
1	18 inch	1500N	-	-
2	24 inch	2500-3000N	√	-

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From table 3.3 it can be concluded that the 18 inch actuator can pull wire trolley with one or two pulley ATD types, while the 24 inch actuator is able to pull the trolley wire with one pulley type ATD but is unable to pull the tolley wire with two ATD pulleys.

3.4. Result Design and Assembly

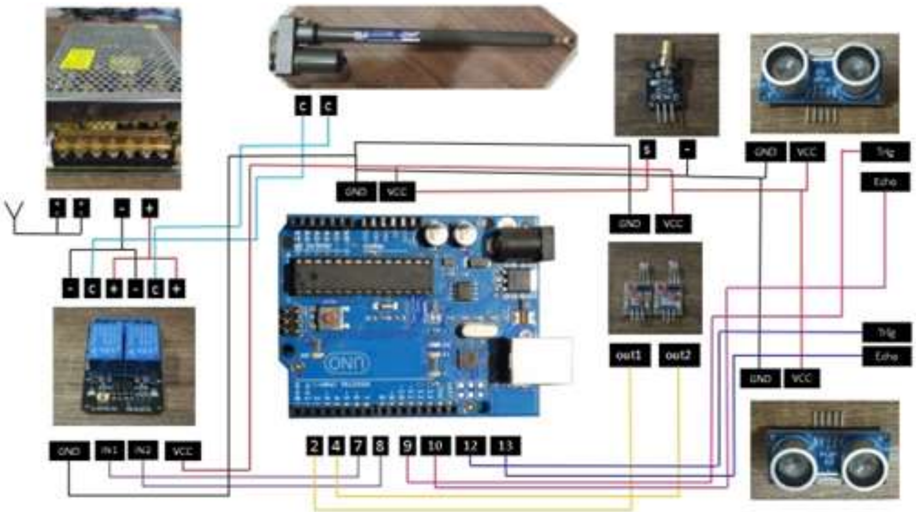

Figure 4. Equipment circuit scheme

Here will be explained about the wiring or wiring of each equipment.

1. Wiring on Power Supply: In the power supply there are two input cables and two output cables in the form of positive and negative cables with 24v DC voltage, the input cable is connected to a 220v ac power source, and a 24v DC output cable will be connected to the positive and negative sockets of the relay.
2. Wiring on the relay: Relay has input and output parts, there are 4 cables from 4 pins, VCC pins (power 5v), GND (ground), in 1 (input 1), and 2 (input 2), VCC cable will be connected on the arduino UNO 5v pin, the GND cable will be connected to the arduino UNO grounding pin, and the in 1 cable will be connected to pin number 7 on the Arduino UNO, and the in 2 cable will be connected to pin number 8 on the UNO arduino. In the output there are 4 cables, each of which is a positive cable, a negative cable, and two COM cables. A positive cable will be connected to the positive power supply, the negative cable will be connected to the negative power supply, and two COM cables will be connected to the actuator motor.
3. Wiring on the actuator: In the actuator there are two cables namely the cable connected to the motor, the two cables are connected to the relay. Both of these cables are connected to the COM socket on the relay.
4. Wiring on two Laser Receiver sensors: In the laser receiver there are two input cables, VCC cable (5v power) and IN (input) cable. The VCC cable of both sensors will be connected to the 5v arduino pin, the cable in each sensor will connect to pin number 2 and 4 of the Arduino UNO.
5. Wiring on Ultrasonic: The SRF-05 ultrasonic sensor used has 5 pins where 4 pins will be used on this device, namely the vcc pin as the 5v voltage source which will be connected to the 5v pin on the arduino, the GND pin that will be connected to the GND pin on the arduino, TRIG pin or trigger that will be connected to the 12 arduino pin number, and the Echo pin that will be connected to pin number 13 on the Arduino. In this tool, two ultrasonic sensors SR SR-05 will be installed in each

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unit, in which a total of 4 sensors will be installed in the simulation. This sensor will measure the distance to be processed into the deviation value and height of the wire trolley.

6. Wiring on the laser module: The KY-008 type laser module has 3 pins where there are 2 pins that will be used on this device, namely the VCC and GND pins, each of which will be connected to the VCC and GND pins on Arduino.
7. Wiring on Arduino UNO: On Arduino UNO there is one power cable to power the Arduino which is connected to a power source such as a laptop or power bank, for the input and output cables have been explained previously.

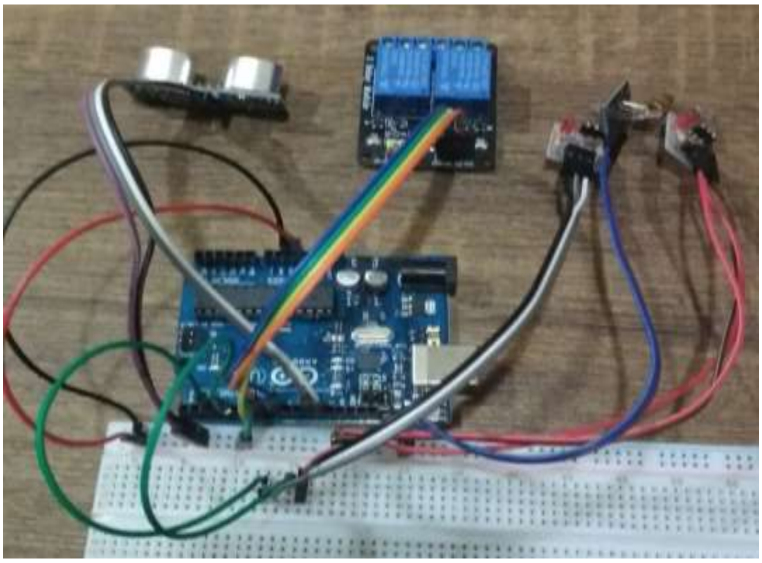

Figure 5. Display of all Component Wiring

3.5. Equipment Testing

Tests carried out on equipment are carried out in two stages. In the first stage the testing is carried out on each sensor to determine the accuracy of the sensor output value. The second test is performed to test the overall function of the equipment. The second test was carried out with indoor demonstration simulations reflecting the situation on the ground.

Table 2. voltage measurement results on the Power Supply

No	Input AC	Output DC
1	228,3	24,32
2	228,1	24,34
3	227,4	24,36
4	227,3	24,36
5	227,8	24,37
6	114,5	24,31
7	114,8	24,29
8	113,4	24,34
9	114,7	24,32
10	113,2	24,35

Table 3. results of distance measurement of ultrasonic sensor HY SRF-05

No	Distance on ruler	Distance on ultrasonic	Error
1	10 cm	10 cm	0
2	20 cm	20 cm	0
3	30 cm	30 cm	0

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4	40 cm	39 cm	1
5	50 cm	50 cm	0
6	60 cm	63 cm	3
7	70 cm	72 cm	2
8	100 cm	101 cm	1
9	200 cm	197 cm	3
10	300 cm	298 cm	2

Table 4. Prototype Tests

	Direction of rail shift	**Shift distance**	**Status**	
1	Right	1 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 16cm Ultrasonic 2 : 23 Actuator : LOW
2	left	1 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 14cm Ultrasonic 2 : 23 Actuator : LOW
3	Right	2 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 17cm Ultrasonic 2 : 23 Actuator : LOW
4	left	2 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 13cm Ultrasonic 2 : 23 Actuator : LOW
5	Right	3 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 18cm Ultrasonic 2 : 23 Actuator : LOW
6	left	3 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 12cm Ultrasonic 2 : 23 Actuator : LOW
7	Right	4 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 19cm Ultrasonic 2 : 23 Actuator : LOW
8	left	4 cm	Modul Laser : HIGH Laser Receiver : LOW	Ultrasonic 1 : 11cm Ultrasonic 2 : 23 Actuator : LOW
9	Right	5 cm	Modul Laser : HIGH Laser Receiver : HIGH	Ultrasonic 1 : 20cm Ultrasonic 2 : 23 Actuator : HIGH
10	left	5 cm	Modul Laser : HIGH Laser Receiver : HIGH	Ultrasonic 1 : 10cm Ultrasonic 2 : 23 Actuator : HIGH

Note: Low: Off and High: Active

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From the results of testing the overall tool prototype in table 4.5 has shown the deviation value and the height obtained from the utrasonic distance sensor HY SRF-05, and the active actuator when the rail shifts ± 5cm compared to the laser beam concerning the laser receiver sensor, as a result the deviation value will be maintained at a predetermined standard. Then it can be concluded that the tool functions according to the program entered

4. Conclusion

a) Deviation maintenance consists of measurements and deviation settings as well as the height of the trolley wire to the axle. treatment of deviations included in work that endangers workers in accordance with the criteria of work that is dangerous according to Act No. 1 of 1970 concerning occupational health and safety.
b) Prototype of automatic trolley wire deviation gauges and regulators that have been designed and made using the Arduino Uno microcontroller as data processing obtained from several sensors, namely the laser receiver sensor, KY-008 laser module, and the HY SRF-05 ultrasonic sensor. As a driver, this prototype uses an electric motor dc actuator that converts the rotational motion of a dc motor into translational or linear motion of the actuator's arm. This linear motion of the arm will adjust the deviation of the wire trolley, while to measure the deviation and height of the wire the trolley uses 2 HY SRF-05 ultrasonic sensors, one measuring deviation sensor and one measuring the height of the wire trolley.
c) Programming on this prototype using IDE software specifically for programming arduino microcontrollers, this software is an application that is used to write commands or sketches, compiling or compiling sketches, and uploading sketches to the arduino board. The equipment will execute the command according to the uploaded sketch. Sketch made includes the command to detect laser light compared to the measurement of the distance of a shift to move the actuator, then as the output seen on the monitor is the result of the deviation measurement, and the height of the wire trolley.
d) The testing is carried out in two stages, namely testing for each component to find out whether the component can function properly and the overall testing of the tool in accordance with the design.

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References

[1] Hofler, H.; Dambacher, M.; Dimopoulos, N.; Jetter, V. Monitoring and inspecting overhead wires and supporting structures. In Proceedings of the IEEE Intelligent Vehicles Symposium, Parma, Italy, 14–17 June 2004; IEEE: Piscataway, NJ, USA, 2004.
[2] Arastounia, M. Automated Recognition of Railroad Infrastructure in Rural Areas from LIDAR Data. *Remote Sens.* 2015, 7, 14916–14938.

DOI: https://doi.org/10.71225/jstn.v1i2.53

[3] Chen, L.; Xu, C.; Lin, S.; Li, S.; Tu, X. A Deep Learning-Based Method for Overhead Contact System Component Recognition Using Mobile 2D LiDAR. *Sensors* 2020, *20*, 2224.

[4] Harter, M.; Schipper, T.; Zwirello, L.; Ziroff, A.; Zwick, T. Detection of Overhead Contact Lines with a 2D-Digital-Beamforming Radar System for Automatic Guidance of Trolley Trucks. *Int. J. Veh. Technol.* 2013, *2013*, 914351.

[5] Puschmann, R.; Wehrhahr, D. Ultrasonic measurement of contact wire position. *eb—Elektrische Bahnen* 2011, *109*, 323–324.

[6] Chen, P.; Xu, C.; Li, Z.; Xu, Z. Design and implementation of non-contact detection system for catenary based on double linear array cameras. In Proceedings of the 5th International Conference on Computer-Aided Design, Manufacturing, Modeling and Simulation, Busan, Korea, 22–23 April 2017.

[7] Yu, L.; Gao, S.; Zhang, D.; Kang, G.; Zhan, D.; Roberts, C. A Survey on Automatic Inspections of Overhead Contact Lines by Computer Vision. *IEEE Trans. Intell. Transp. Syst.* 2021, 1–22.

[8] Aydin, I.; Karakose, M.; Akin, E. Anomaly detection using a modified kernel-based tracking in the pantograph-catenary system. *Expert Syst. Appl.* 2015, *42*, 938–948.

[9] Efanov, D.; Sedykh, D.; Osadchy, G.; Barch, D. Permanent monitoring of railway overhead catenary poles inclination. In Proceedings of the 2017 IEEE East-West Design & Test Symposium, Novi Sad, Serbia, 29 September–2 October 2017.

[10] Efanov, D.; Osadchy, G.; Sedykh, D.; Pristensky, D.; Barch, D. Monitoring system of vibration impacts on the structure of overhead catenary of high-speed railway lines. In Proceedings of the 2016 IEEE East-West Design & Test Symposium, Yerevan, Armenia, 14–17 October 2016.

[11] Boffi, P.; Cattaneo, G.; Amoriello, L.; Barberis, A.; Bucca, G.; Bocciolone, M.F.; Collina, A.; Martinelli, M. Optical Fiber Sensors to Measure Collector Performance in the Pantograph-Catenary Interaction. *IEEE Sens. J.* 2009, *9*, 635–640.

[12] Massat, J.P.; Nguyen Tajan, T.M.L.; Maitournam, H.; Balmès, E. Fatigue analysis of catenary contact wires for high speed trains. In Proceedings of the 9th World Congress on Railway Research, Lille, France, 22–26 May 2011.

[13] Wu, T.X.; Brennan, M.J. Dynamic stiffness of a railway overhead wire system and its effect on pantograph-catenary system dynamics. *J. Sound Vib.* 1999, *219*, 483–502.

[14] Arnold, M.; Simeon, B. Pantograph and catenary dynamics: A benchmark problem and its numerical solution. *Appl. Numer. Math.* 2000, *34*, 345–362.

[15] Park, T.-J.; Han, C.-S.; Jang, J.-H. Dynamic sensitivity analysis for the pantograph of a high-speed rail vehicle. *J. Sound Vib.* 2003, *266*, 235–260.

[16] Gregori, S.; Tur, M.; Nadal, E.; Aguado, J.; Fuenmayor, F.; Chinesta, F. Fast simulation of the pantograph-catenary dynamic interaction. *Finite Elem. Anal. Des.* 2017, *129*, 1–13.

[17] Benet, J.; Cuartero, F.; Rojo, T.; Tendero, P.; Arias, E. A Dynamic Model for the Study and Simulation of the Pantograph–Rigid Catenary Interaction with an Overlapping Span. *Appl. Sci.* 2021, *11*, 7445.

[18] Nåvik, P.; DeRosa, S.; Rønnquist, A. Development of an index for quantification of structural dynamic response in a railway catenary section. *Eng. Struct.* 2020, *222*, 111154.

[19] Wu, J. *Pantograph and Contact Line System*; Academic Press: London, UK, 2018.

[20] Kia, S.H.; Bartolini, F.; Mpanda-Mabwe, A.; Ceschi, R. Pantograph-catenary interaction model comparison. In Proceedings of the 36th Annual Conference on IEEE Industrial Electronics Society, Glendale, AZ, USA, 7–10 November 2010; IEEE: Piscataway, NJ, USA, 2010.

[21] Bruni, S.; Ambrosio, J.; Carnicero, A.; Cho, Y.H.; Finner, L.; Ikeda, M.; Kwon, S.Y.; Massat, J.-P.; Stichel, S.; Tur, M.; et al. The results of the pantograph-catenary interaction benchmark. *Veh. Syst. Dyn.* 2015, *53*, 412–435.

DOI: https://doi.org/10.71225/jstn.v1i2.53

[22] Song, Y.; Antunes, P.; Pombo, J.; Liu, Z. A methodology to study high-speed pantograph-catenary interaction with realistic contact wire irregularities. *Mech. Mach. Theory* 2020, *152*, 103940.
[23] Zhang, W.; Zou, D.; Tan, M.; Zhou, N.; Li, R.; Mei, G. Review of pantograph and catenary interaction. *Front. Mech. Eng.* 2018, *13*, 311–322.
[24] Avila-Sanchez, S.; Lopez-Garcia, O.; Cuerva, A.; Meseguer, J. Assesment of the transverse galloping stability of a railway overhead located above a railway bridge. *Int. J. Mech. Sci.* 2017, *131–132*, 649–662.
[25] Song, Y.; Liu, Z.; Wang, H.; Zhang, J.; Lu, X.; Duan, F. Analysis of the galloping behaviour of an electrified railway overhead contact line using the non-linear finite element method. *Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit* 2018, *232*, 2339–2352.
[26] Kraus, M.; Hagedorn, P. Aeolian vibrations: Wind energy input evaluated from measurements on an energized transmission line. *IEEE Trans. Power Deliv.* 1991, *6*, 1264–1270.
[27] Song, Y.; Liu, Z.; Wang, H.; Lu, X.; Zhang, J. Nonlinear analysis of wind-induced vibration of high-speed railway catenary and its influence on pantograph–catenary interaction. *Veh. Syst. Dyn.* 2016, *54*, 723–747.
[28] Song, Y.; Zhang, M.; Wang, H. A Response Spectrum Analysis of Wind Deflection in Railway Overhead Contact Lines Using Pseudo-Excitation Method. *IEEE Trans. Veh. Technol.* 2021, *70*, 1169–1178.
[29] Sanchez-Rebollo, C.; Velez, E.; Jimenez-Octavio, J.R. Numerical characterization of real railway overhead cables. *Wind Struct. Int. J.* 2015, *21*, 105–117.
[30] Chu, W.; Song, Y.; Liu, Z. A Comparative Study on the Wind Deflection of Railway Overhead Contact Line Based on Empirical Formula and Finite Element Approach. *Shock Vib.* 2021, *2021*, 5737457.
[31] Ngamkhanong, C.; Kaewunruen, S.; Calçada, R.; Martin, R. *Failure of Overhead Line Equipment (OHLE) Structure under Hurricane*; Springer: Cham, Switzerland, 2019; pp. 54–63.

DOI: https://doi.org/10.71225/jstn.v1i2.53