

적외선 시스템을 이용한 경사 지역에서 열차 운행 속도 제어

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Train Speed Control in Slope Area Using Infrared System

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요약

열차 속도 제어는 운영 트랙에서 안전 운동을 구축하기 위한 열차 보호의 중요한 일부분이다. 경사진 면적과 같은 열차를 보호하는 데 필요한 트랙의 특수한 조건이 있다. 더욱이 반달리즘 문제를 가진 개도국에서 특수한 조건은 트랙 사이드의 장비를 최소화하기 위한 설치가 요구된다. 더욱이 열대 국가에서 트랙 사이드는 수질에서 트랙 사이드 장비의 성능에 영향을 줄 것으로 보인다.

이러한 문제를 해결하기 위하여 적외선 시스템을 이용하여 경사진 면적에 대하여 열차 속도 제어를 제안한다. 전주 배열의 설치에 의해 이 시스템은 보다 적은 도전, 경제적인 민감성, 트랙 사이드의 장비의 최소 설치와 강우 환경에서 신뢰성을 제공한다.

본 논문은 경사진 면적에서 성능 평가를 측정하고 열차 속도를 제어하는데 중점을 준다. 제안한 열차 속도 제어 시스템은 시간 당 약 20km의 제어속도와 최대 3.6%의 경사진 면적에서 속도 제어와 감시가 가능하다.

ABSTRACT

Train speed control is a vital part of train protection to build safe movement at an operation track. There is a special condition of track that needs more attention to protect the train, for example in slope area. Moreover, in developing country with vandalism problem, it requires to install minimized equipment on the trackside. In addition, in tropical country, on trackside it will be potentially pooling water that influences to the performance of trackside equipment. To address these problems, we propose the train speed control for slope area using infrared system. By installing on the pole configuration, the system offers a less challenging, economically sensible, minimized installation of equipment on the trackside and reliability for heavy rain environment. This paper concentrates on the controlling train speed and measurement performance evaluation in slope area. The proposed train speed control system can monitor and control the speed in sloping area with maximum 3.6% and controlled speed about 20 km per h.

키워드

Train Speed Control System, Slope Area, Infrared System, Trackside To Train Communication.
열차 속도 제어 시스템, 경사 지역, 적외선 시스템, 열차 통신 트랙사이드

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I. Introduction

Automatic train control is a computer based system that used for supervising the train driver [5, 9]. It monitors a train speed to ensure the train passes a signal with safe speed or to prevent a possibility of omission driver to check passed signal status. The brake will be applied automatically when the driver fails to do its condition [1-10]. To build communication between trackside and train, some devices are used such as mechanical devices, electrical contacts, electromagnetics and transponder [1],[11-12].

Nevertheless, the main problem of the communication system is sustaining an efficient trackside to train communication [13]. The difficult conditions related to controlling the train in slope area, are the monitoring and controlling speed along the critical slope area, also generating additional information need such on tilt of trackside. Furthermore, some trackside equipment area has to be located on slope in order to controlling the speed of train. Moreover, in tropical country for example Indonesia, heavy rain has to be considered because it can make a puddle on the trackside area that impact to the installed equipment performance on trackside. Also, negligent track maintenance work sometimes can potentially to induce failure of the trackside equipment.

II. Material and Method

2.1 Set up

In this work, the equipment is divided into trackside and onboard. The trackside equipment consists of infrared sensors that function as a transmitter (Tx) and are installed at critical locations. The infrared data association (IrDA) serial infrared with a 9.6-115.2 kb/s data rate is used for communication data protocol. The sensors are classified as S1, S2, and S3 and are installed

on the pole. A solar cell and battery are used for the power supply of the sensors. The S1 sensors are composed of 8 sensors (S1-1 to S1-8), of which S1-8 is installed behind the distant signal and S1-1 to S1-7 are installed in front of the distant signal consecutively.

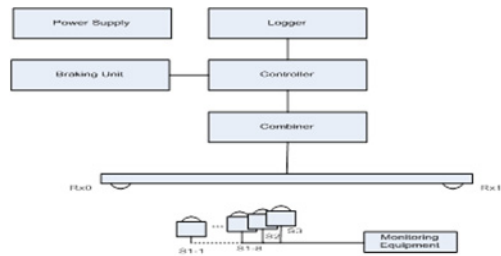


Fig. 1 The block diagram of train speed control system

The onboard equipment consists of an infrared receiver (Rx), a combiner, a controller, a braking unit, a logger, and power supply. The composition of the onboard equipment is shown in Figure 1. Two Rxs (Rx0 and Rx1) are installed, each having the function of receiving data from Tx; also, the time difference of the received data between Rx0 and Rx1 will be calculated by the combiner to obtain the detected speed. The combiner calculates the detected speed, reports to the controller, and receives a self-test signal on Rx in order to monitor the Rx status and demodulate the infrared transmitter (Tx) id data. The controller monitors other modules, gives status information of the onboard equipment, provides the braking decision according to the algorithm, and stores the Tx id database. The braking unit applies braking using air provided by the brake pipe according to the controller unit command. It also reports the solenoid function to the controller. The logger stores all data and processes the onboard equipment for analysis and maintenance. In this system, the logger is equipped with a monitoring system which is placed in the station that has the installed trackside

equipment.

To investigate the performance of onboard equipment and trackside equipment, the CC series locomotive including 47 cars and signal equipment of the Garuntang station were used in critical points of the slope area to control the train speed. The signal aspects are set to apply the stopping train in front of the home signal.

2.2 Operation

S2 and S3 are connected to the home signal, and will transmit id data, revealing their locations to the Rx when the home signal is red, as described in Figure 2. If the home signal is yellow or green, S2 and S3 do not send the data to Rx until the signal status is red. S1-1 to S1-8 always sends id data on their position to Rx when the distant signal is green or yellow.

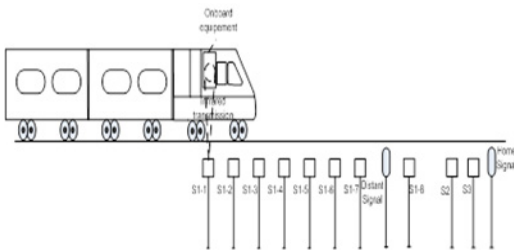


Fig. 2 The Configuration of the Train speed control

The distant signal status follows the home signal status. When the home signal is red, the distant signal status is yellow, but the distant signal will be green if the home signal is green or yellow [15].

To protect the train on the sloped area, the speed will be restricted in order to obtain a safe braking profile. In that area, the train is controlled by onboard equipment to fulfill the safe braking profile. In this work, the train speed of 20 km/h maximum at the S1-1 to S1-8 locations is expected whatever a status of the distant signal. If the train speed exceeds the maximum speed in these areas,

the onboard equipment will apply the braking unit to reduce the speed to 20 km/h. The detected speed is obtained by calculating the time difference between Rx0 and Rx1 after receiving the data from Tx. The onboard system control the speed to keep maximum speed automatically by applying braking if the detected speed is greater than 20 km/h. At the S2 location, the train is controlled to operate at less than or equal to 20 km/h when the home signal is red. If the train speed is more than the expected speed at that condition, the braking unit will be applied automatically by the onboard system to stop the train in front of the home signal. When the home signal is green or yellow, S2 does not transmit data and the onboard equipment is non-active because there is no received data on Rx. S3 is designed to anticipate the condition at which the train does not stop in front of the home signal even though the signal status is red. The maximum speed at the S3 location is 10 km/h. Nevertheless, S3 does not send data to Rx when the home signal status is green or yellow.

2.3 Experimental Measurement & Calculation

The critical points of slope area were measured using global positioning system (GPS) equipment and Google Earth application. To describe the slope area, every point is presented by elevation above sea level, distance between each point, latitude and longitude. Using the position of the point, the maximum, minimum and average slope can be measured.

To get robust data communication, the transmitter (Tx) and receiver (Rx) angle were configured with considering the optimal beam to be obtained by the receiver. The distance between transmitter and receiver was measured with evaluating the effective beam transmission. The installation height of transmitter and receiver were examined to solve the environment problem such as puddle or flood on the trackside.

Using Potential Energy and Kinetic Energy Balance on slope area, the velocity of the train on the end slope can be calculated in which some parameters in the formula are applied as follow:

$$PE_1 + KE_1 = PE_2 + KE_2$$

$$mg\Delta h_1 + \frac{1}{2}mv_1^2 = mg\Delta h_2 + \frac{1}{2}mv_2^2 \quad (1)$$

where m is the mass of the train, g is the gravity acceleration, h_1 is the height to the top of slope, h_2 is the height to the bottom of slope, v_1 is the velocity at the top of the slope, and v_2 is the velocity at the bottom of the slope.

In addition, the Indonesian Railway regulation restricts the speed to a maximum of 20 km/h in sloped areas [16]. Furthermore, to protect the train speed on the slope area, the train speed is monitored and controlled from S1-1 to S3 location. The train will first be detected at the S1-1 location and the control system will check the speed. If the train speed is more than 20 km/h, the system will apply braking automatically to reduce the speed to 20 km/h; otherwise, the system keeps the speed less than or equal to 20 km/h. This condition is similar at the S1-2 to S1-8 locations in order to maintain the train speed of 20 km/h. When the train is passing the S2 and the system will check the speed to prepare stopping the train if the home signal is red. If the train speed is more than 20 km/h, the system will apply the braking to stop the train automatically; otherwise, the system also stops the train automatically. At the S3 location, if the train is still running, braking is applied by the system automatically to stop the train. In addition, the maximum operating speed at the Garuntang line is 45 km/h.

To control the speed of train, it is required at least the position and detected speed of the train to apply the safe braking in order to protecting the train in slope area. The detected speed of train can be calculated using the time difference of obtained

data on the receiver 0 (Rx0) and the receiver 1 (Rx1) by applying the formula as follow:

$$V_{train} = \frac{s}{\Delta t} \quad (2)$$

where V_{train} is detected train speed, s is the distance between Rx0 and Rx1, and Δt is time difference between Rx0 and Rx1. The position of the train can be obtained by installing some Tx in the critical area to send the position data with particular Tx identity.

Furthermore, to keep the speed from S1-1 to S2 is 20 km/h and stop the train at S2 or S3 location, the deceleration of the system at that area can be calculated by applying the formula (1) if the previous speed was detected, as follow:

$$v_t^2 = v_0^2 + 2as \quad (3)$$

Where v_t is the expected velocity, v_0 is the previous velocity, a is the deceleration and s is distance. The required deceleration of the system can be obtained to protect the train in the slope area by controlling the speed.

III. Result & Discussion

The S2 sensor was located 250 meters in front of the S3. The S3 is placed between S2 and the home signal about 10 meters from the home signal



a. Position



b. Elevation
Fig. 3 The location of Sensors

The S1-8 is located between the distant signal and the S2 and set 250 meters in front of the S2. The S1-1 to S1-7 are placed forefront the S1-8 consecutively. The interval distance of each sensor from S1-8 to S1-1 is 250 meters.

Using a GPS equipment and the Google Earth application, the position of the sensors can be described as Figure 3 and Table 1. Figure 5a shows sensors location in some points to get critical position in order to control the train speed on the slope area. In addition, Figure 5b describes the elevation of controlled area to determine the maximum slope. According the Table 1, the maximum slope is 3.6% for S1-3 sensor and the minimum slope in this area is 1.1% at S1-1 position. The Garuntang station is located 5.76 km from Tanjung Karang station.

Table 1. Data of sensors installation

Sensor	Position	Elevation (m, above sea level)	Distance from Tanjung Karang Station (m)	Slope (%)
Tanjung Karang Station	5°24'22.52"S 105°15'39.08"E	120	0	-
S1-1	5°25'44.13"S 105°16'36.33"E	81	±3460	1.1
S1-2	5°25'53.20"S 105°16'34.55"E	77	±3710	2.0
S1-3	5°26'01.34"S 105°16'36.81"E	68	±3960	3.6
S1-4	5°26'03.91"S 105°16'42.34"E	63	±4210	2.0
S1-5	5°26'02.28"S 105°16'05.12"E	60	±4460	1.2

S1-6	5°26'03.23"S 105°16'59.16"E	54	±4710	2.4
S1-7	5°26'05.21"S 105°17'07.39"E	48	±4960	2.4
S1-8	5°26'07.04"S 105°17'14.27"E	44	±5210	1.6
S2	5°26'10.15"S 105°17'22.21"E	39	±5460	2.0
S3	5°26'09.59"S 105°17'28.55"E	36	±5710	1.2

According to Table 1, the incline area takes place in Garuntang lines and the critical points are spanned 2,260 meters from the home signal of Garuntang station to the signal. The height of the critical points is 81 meters above sea level for first installed infrared sensor and the end of the sensor is placed at 36 meters above sea level. Furthermore, the maximum slope can be described as 21 m per kilometers or 21 mille. In the slope area, the train has to be reduced its speed along the critical points in order to stopping it in front of the home signal, if the signal is red.

Refer to the angle range of the transmitter between 15o and 30o for a half angle field of view [17-18] and 15o for the receiver, the transmitter (Tx) angle was set to 19.65o half angle for transmitting the beam and the receiver (Rx) angle was set to 15o half angle to obtain optimal beam in order to getting effective data communication.

The distance between transmitter and receiver is fitted on 70 cm as shown in figure 4. The infrared system as shown in figure 4 was configured with 70 cm between transmitter and receiver to provide robust trackside to train communication. The transmitter is mounted along the critical points and connected to the distant signal for S1-1 to S1-8, the other is connected to the home signal.

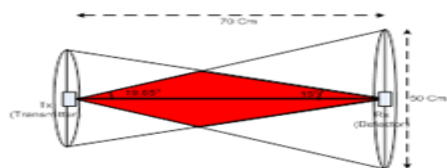


Fig. 4 The infrared system configuration

The installation height of transmitter and receiver are 2.5 meters from the track level. In other hand, the receiver was divided into Rx0 and Rx1 that installed beside the train cabin to receive the beam. The IrDA SIR with 9.6-115.2 kb/s data rate was applied as the protocol of infrared data communication to achieve reliable communication system. According to the maximum operation speed in Indonesia, 95 km/h, the distance between Rx0 and Rx1 is set at 83 cm, so the time difference between Rx0 and Rx1 is 30 milliseconds [16]. Furthermore, the speed can be calculated from the time difference between Rx0 and Rx1 when the data has been received from Tx by applying the formula (2), and it was obtained as follow:

$$V_{train} = \frac{83 \times 10^{-4} \text{ km}}{\Delta t} \tag{4}$$

where V train is detected train speed in kilometers per hour (Km/h), 83×10^{-4} km is the distance between Rx0 and Rx1 installed beside driver cabin, and Δt is time difference between Rx0 and Rx1 when received the data from Tx. Using the formula (4), the detected train speed at particular location can be obtained after getting the time difference.

The train speed in slope area is not only controlled by the cabin of train but also influenced by the gravity force. According to the potential energy and kinetic energy balance in the slope area as shown by the formula (1), the gravity force takes effect to velocity of the train movement when passes it and the effected velocity can be described as shown in figure 5:

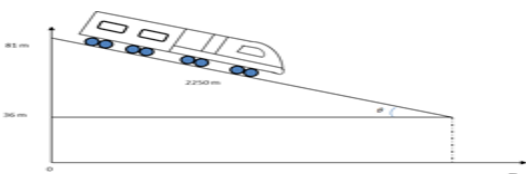


Fig. 5 The train motion on the incline

where α is angle of slope. According to equation (1) with assumption $g = 9.8 \text{ m/s}^2$, $v_1 = 0$ and $h_2 = 0$, the v_2 can be obtained as follow:

$$mg\Delta h_1 = \frac{1}{2}mv_2^2, \quad v_2 = \sqrt{2g\Delta h_1}$$

where h_1 is 45 m, v_2 is 29.70 m/s and the velocity in the other location can be calculated as shown in Table 2.

To keep the safe speed of train in the slope area, the required deceleration can be calculated by employing the formula (3) as described in the Table 3 and Figure 6. The train passed probably in the slope area with various speed and its detected speed was compared with the expected speed to obtain the required deceleration.

Using the CC202 series locomotive including 47 cars on the Garuntang line, the system was investigated and the speed in the slope area was controlled successfully as shown on the Table 4 and Table 5. In Indonesia, the train has to be stopped in front of the home signal when the home signal is red and the distant signal is yellow [15].

Table 2. Gravity effect on velocity

Sensor	Elevation (m, above sea level)	Distance from Tanjung Karang Station (m)	Velocity effected by gravity (S1-1 location is starting point) (m/ s)
S1-1	81	±3460	0.00
S1-2	77	±3710	8.85
S1-3	68	±3960	15.96
S1-4	63	±4210	18.78
S1-5	60	±4460	20.29
S1-6	54	±4710	23.00
S1-7	48	±4960	25.43
S1-8	44	±5210	26.93
S2	39	±5460	28.69
S3	36	±5710	29.70

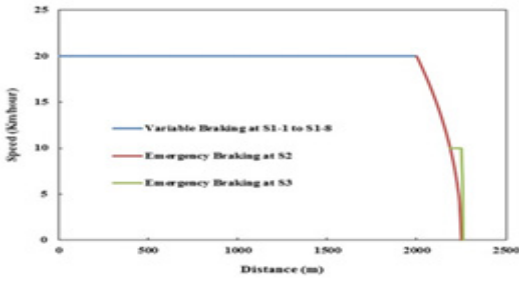


Fig. 6 The designed braking profile on slope area

The Table 4 shows that at S1-1 and S1-7 sensor location, when the detected speed is less than expected speed, the system will not apply the braking to reduce the train speed. Nevertheless, at S1-2 to S1-6 and S1-8 location, when the detected speed is greater than expected speed and the distant signal is yellow, the system will apply the braking using variable braking to reduce the train speed until 20 km/h. Furthermore, at S2 sensor location, the system applies the braking to stop the train automatically using the braking profile in the Figure 6. If there is delayed stopping train until 10 km/h, the braking is applied by the system to stop the train automatically at S3. The result clearly shows that the system has effectively protected the train movement in the slope area by implementing infrared system for the trackside to train communication.

Table 3. Required deceleration

The Previous Speed (km/h)	Expected speed (km/h)	The distance (m)	The deceleration (m/s ²)
25	20	250	0.069
30	20	250	0.154
35	20	250	0.255
40	20	250	0.370
45	20	250	0.502
20	0	250	0.123
10	0	10	0.772

Table 4. The result of controlled speed on the slope area when the home signal is red

Sensor	Detected Speed (Km/h)	Expected Speed (km/h)	Distant Signal Aspect	Home Signal Aspect	Braking by The System
S1-1	16	20	Yellow	Red	Not applied
S1-2	21	20	Yellow	Red	Variable Braking
S1-3	22	20	Yellow	Red	Variable Braking
S1-4	25	20	Yellow	Red	Variable Braking
S1-5	23	20	Yellow	Red	Variable Braking
S1-6	25	20	Yellow	Red	Variable Braking
S1-7	20	20	Yellow	Red	Not applied
S1-8	22	20	Yellow	Red	Variable Braking
S2	24	20	Yellow	Red	Emergency Braking
S3	5	10	Yellow	Red	Emergency Braking

Moreover, the train has to run carefully when the home signal is yellow and the distant signal is green [26]. The sensors S1-1 to S1-8 still transmit the beam in order to keep a safe speed on the slope area when the distant signal is green. However, the sensors S2 and S3 do not transmit the beam when the home signal is yellow. On the Table 5 when the detected speed is less than expected speed, the braking will not be applied by the system to reduce the train speed. Nevertheless, if the detected speed is greater than expected speed and, the system will apply the braking by variable braking to reduce the train speed until 20 km/h. Furthermore, at S2 and S3 sensor location, the system is not applied because the sensors do not transmit the beam when the home signal is yellow or green.

Table 5. The result of controlled speed on the slope area when the home signal is yellow

Sensor	Detect ed Speed (Km/h)	Expect ed Speed (km/h)	Dista nt Signal Aspect	Home Signal Aspect	Braki ng by The System
S1-1	12	20	Green	Yellow	Not applied
S1-2	13	20	Green	Yellow	Not applied
S1-3	19	20	Green	Yellow	Not applied
S1-4	18	20	Green	Yellow	Not applied
S1-5	15	20	Green	Yellow	Not applied
S1-6	11	20	Green	Yellow	Not applied
S1-7	12	20	Green	Yellow	Not applied
S1-8	11	20	Green	Yellow	Not applied
S2			Green	Yellow	
S3			Green	Yellow	

In this study, the infrared communication system uses the SIR data communication to cover trackside to train communication. For additional transmitted data more than 115.2 kb/s, the higher IrDA data communication is required to extend the capacity by using FIR or VFIR data communication. The system was tested using one locomotive type, in order to ensuring compatibility with various locomotive or train set, taking test with other types of locomotive or train can be applied. The system can control the train with maximum speed about 100 km/h, furthermore it is necessary to be considered to redevelop and estimate the system for more high speed.

IV. Conclusion

In this works, the train speed control on slope area using infrared system was proposed and the performance of the system was investigated. The beam angle of the transmitter is a 19.65o half angle and the receiver angle is a 15o half angle to obtain an effective received beam. The distance between transmitter and receiver is set on 70 cm and the installation of transmitter is on the pole to minimalize installing devices on the track and to solve the environment condition such as a puddle. The system was designed for maximum speed 100 km/h and the slope area with maximum slope 3.6%. The train speed is controlled to protect derailment or to keep safe stopping train in front of the home signal. The monitored track for reducing the speed is prepared about 2000 meters with 20 km/h maximum speed involved S1-1 to S1-8 that connected to the distant signal. To ensure safe stopping train, S2 is located to detect the initial train speed in front of the home signal. Finally, S3 is 10 meter in front of the home signal to anticipate delayed stopping. The system provides low cost, minimalized installation of equipment on the trackside, easy to maintenance and reliability for heavy rain environment.

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