Use of Traffic Signal Lights in Vehicle– to– Vehicle Communication on Underground Mine Ramps*

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Normanyo, E. and Ainoo, L. C. (2022), "Use of Traffic Signal Lights in Vehicle- to- Vehicle Communication on Underground Mine Ramps", *Ghana Mining Journal*, Vol. 22, No. 1, pp. 50-55.

Abstract

To minimise collisions and road accidents, road safety systems require Vehicle– to– Vehicle (V2V) and Vehicle– to– Road (V2R) communication infrastructure. Two-way traffic flow dynamics in single-lane underground mine haulage ramps do affect productivity of ramp in times of ore transportation to the surface for processing. Optical wireless communication offers no health hazard, low power consumption, non-licensed channels and high bandwidth. In this research, V2V communication on an underground mine ramp has been actualised making use of traffic signal lights, Radio Frequency (RF) Transmitters (Tx) and Receivers (Rx), and a traffic signal lights module. Simulation outcomes confirm orderly movement of two heavy vehicles on the haulage ramp. This development stands to minimise the incidents occurrence rate in mine ramp haulage systems.

Keywords: Control, Heavy Vehicle, Signaling, Mine Ramp, Underground

1 Introduction

Underground mining is synonymous with less waste rock removal, less environmental impact, relatively higher-grade ores, constructed access shafts and tunnels, and of paramountcy, health and safety of personnel and machine. In an underground mining operation, the mineral is accessed and hauled to the surface after blasting and excavating, through a network of tunnels, which consists of ramps, hanging walls, stopes, horizontal Load-Haul-Dump (LHD) vehicles and vertical shafts. Incidents due to congestion normally occur in some parts of the underground roads notably on levels where haulage and mining activities take place. According to Morris and Yang (2020), the World Health Organisation (WHO) predicted road traffic injuries to become the seventh leading cause of death by 2030. The National Institute for Occupational Safety and Health (NIOSH), in Anon. (2018), linked twenty-two of the seventy-five underground mine fatalities reported between 2011 and 2015 to powered haulage. The Mine Safety and Health Administration (MSHA), in Anon. (2016), asserts that, using collision avoidance technology, Proximity Detection Systems (PDS) for mobile machines could help prevent the powered haulage-related fatal injuries and incidences.

Road safety systems entail Vehicle– to– Vehicle (V2V) and Vehicle– to– Road (V2R) communication infrastructure in aid of avoidance or minimisation of collisions and road accidents (Zadobrischi and Dimian, 2021). A dual road infrastructure serves as a boost to safety of vehicles and road users. Safety, however, cannot be assured on ramps in underground mines as these ramps accommodate traffic in one direction at a time. Coordinated bi-directional traffic flow of haul truck vehicles is essential to maximum productivity (Pasternak and Marshall, 2016). According to Haviland and Marshall (2015), two-way traffic flow dynamics in single-lane underground mine haulage ramps do affect productivity of ramp with regard to transportation of ore to the surface for processing. Additional road safety measures, such as effective V2V and V2R communication, are needed by operators of the ore hauling Heavy Vehicles (HVs) that use the underground ramps to discharge load at the surface. For the operators of haul trucks on underground mine ramps, effective communication can only be remote.

Radio communication has been proven to be reliable in the mining industry and a wide range of options for site linking, surface and underground mine linking are availed by it. RF-based communication, however, suffers from radio wave usage restrictions, interference and latency issues (Khan, 2017). On the other hand, optical wireless communication offers no health hazard, low power consumption, non-licensed channels and high bandwidth (Khan, 2017). Visible light frequencies vary from 430 THz to 770 THz, which are 10 000 times larger than the entire RF spectrum, hence, optical wireless communication on underground mine ramps is advantageous (Dagli, 2020). Notable research strongly recommends use of Light Fidelity (Li-Fi) technology specifically, Visible Light Communication (VLC) for V2V communication mostly making use of Light Emitting Diodes (LEDs) and photodetectors (Al Barazanchi *et al*., 2021; Dahri *et al*., 2018; Javaid *et al*., 2021; Mallikarjuna *et al*., 2017; Surega *et al*., 2021; Surya *et al*., 2021). The Li-Fi based technology is faster, has high data density, unregulated large bandwidth and more cost and energy efficient in V2V communication than the RF-based technology, but without the light source, data transfer becomes problematic (Lisha *et al*., 2021).

*Manuscript received September 29, 2021
Revised version accepted June 24, 2022
https://doi.org/10.4314/gm.v22i1.6

Vigorous research regarding effective communication in underground mining environments were conducted using LEDs and photodiodes (Jativa *et al*., 2020; Riurean *et al*., 2021), ZigBee network-based Wireless Sensor Networks (WSNs) (Moridi *et al*., 2018) and magnetic induction (Guo *et al*., 2017; Sun and Akyildiz, 2010). Traffic signal lights are mostly used to moderate vehicle traffic at road intersections as well as for illumination of the surroundings. To date, the use of traffic signal lights for underground mine ramp communication, to the best of our knowledge, has not been reported.

In this paper, we deploy traffic signal lights, Radio Frequency (RF) Transmitters (Tx) and Receivers (Rx) to achieve a V2V communication system in an underground mine ramp environment. We validated the developed system by simulating movement of two HVs on the mine ramp. The rest of the paper is structured as follows: In Section 2, focus is given to the design concept, systems components and computer simulations platform utilised. Section 3 provides the simulation results with the discussion and Section 4 gives the conclusion.

2 Resources and Methods Used

2.1 Design Concept

The conceptual diagram of the mine ramp haulage system is as depicted in Fig. 1. Figure 2 shows the functional block diagram of the proposed system. The design made use of RF Tx and Rx, power supply, two vehicles representing haul trucks, traffic signal lights and a traffic signal light module. In Fig. 1, the red and white boxes represent fans at the 1925 vicinity. The traffic signal lights are installed on the roof of the decline at pre-determined intervals of 40 m to alert drivers of vehicles on the status of the 1925 level with regards to vehicle movement. The RF transmitters are installed on the heavy vehicles and the RF receivers are located on the traffic signal lights to activate them as the HVs travel on the ramp. The RF transmitter of an operating heavy vehicle triggers red warning lights mounted on the backs of ramp within 70-80 metres radius. The green lights indicate right of way to vehicle. The system was developed taking cognisance of being compatible with existing underground mine communication, such as leaky feeder system, programmable and reprogrammable, fast, able to facilitate safe operation, inspection, testing and maintenance; favourable to Organisational Health and Safety (OHS) requirements, and both the RF transmitter and receiver kits were made to have same addresses for correct and reliable operation.

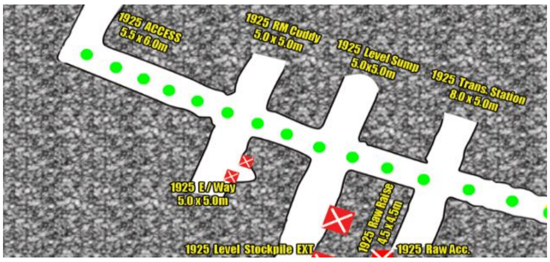

Fig. 1 Conceptual Diagram of System

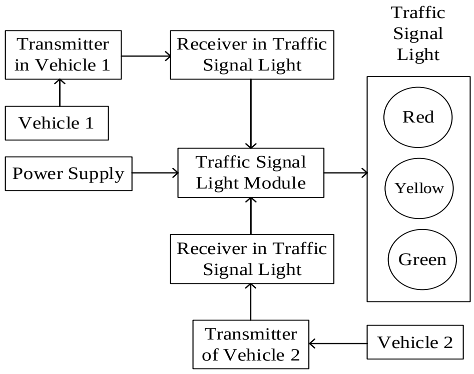

Fig. 2 Functional Block Diagram of System

2.2 System Components

The hardware components employed are the traffic signal lights, traffic lights module, power supply, transmitters and receivers.

2.2.1 Traffic Signal Lights

Figure 3 depicts the traffic lights used. They are mounted on the roof or the backs of the ramp. Each lamp has three coloured lights in them, red, yellow and green as well as a RF receiver. Compared to the traditional type, having incandescent lamps, these traffic signal lights are merited with a consumption reduction of 90%, longer life span of about 10 years and there is no need for frequent lamp change. The specifications of the traffic signal lights are given in Table 1.

Fig. 3 A Picture of the Traffic Signal Lights

Table 1 Specifications of the Traffic Signal Lights

Item	Specification
Power Supply	240 Vac ± 50 Hz ± 15% (on demand 24 Vdc)
Absorbed Power	Light Emitting Dioide (LED) high flux luxeon lumileds type with average consumption less than 9 W
Operating Temperature	Class A, B, C -40 ºC to 60 ºC
Connection	Four (4) wires of 1.5 mm^2 Blue- Neutral Brown- Red light Grey- Amber Light Black- Green Light
Insulation Class	Class 11
Warranty	Three (3) years
Traffic Signal Head	Diameter (Ø) 300 mm and yearly consumption of 876 kW/h

(Source: Pande and Wolshon, 2016)

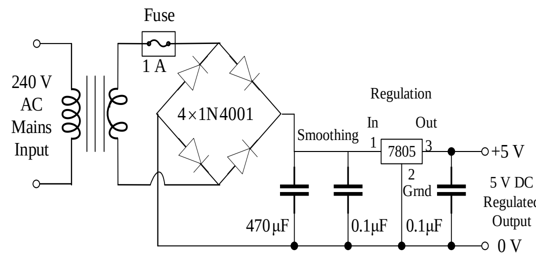

Fig. 4 Block Diagram of the Complete Power Supply Unit

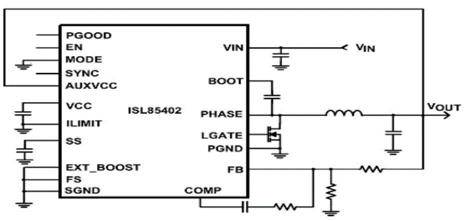

Fig. 5 Schematic Diagram of Traffic Signal Light Module

2.2.2 Power Supply Unit

The RF receivers, the traffic lamp and the traffic module are all electrically powered, taking their source from an alternate current power source which is then transformed, rectified, filtered and regulated to their desired direct current voltage of 5 V DC. But for RF transmitters, they take their power supply source from the vehicle and equipment. The power supply source, however, for the RF transmitters are a direct current type. For this, the DC power source is normally 12/24 V DC, which is transformed using a step-down transformer, filtered and regulated to 5 V DC. Fig. 4 is the block diagram of the complete regulated power unit.

2.2.3 Traffic Signal Light Module

The electrical schematics of the traffic light module is presented in Fig. 5. The synchronous buck controller ISL85402 with a 125 mΩ high-side MOSFET and low-side driver integrated supports a wide input range of 3 V to 36 V in buck mode. It supports 2.5 A continuous load under conditions of 5 V V_{OUT}, V_{IN} range of 8 V to 36 V, 500 kHz and +105 °C ambient temperature with still air. The ISL85402 has comprehensive protection against various faults including overvoltage and over-temperature protect-ions.

2.2.4 Radio Frequency Transmitter Unit

The block diagram of the RF transmitter unit is presented in Fig. 6 and it consists of the switches, encoder and the RF transmitter. Encoder IC (HT12E) receives parallel data in the form of address bits and control bits from the switches. The control signals from remote switches along with 8 address bits constitute a set of 12 parallel signals. The encoder HT12E encodes these parallel signals into serial bits. Transmission is enabled by providing ground to pin 14, which is active low. The control signals are given at pins 10-13 of HT12E. The serial data is fed to the RF transmitter through pin 17 of HT12E. Fig. 7 shows the electrical schematic diagram of the RF transmitter unit. In the transmitter part of Fig. 7, use is made of the HT12E for encoding data from parallel to serial. The serial output from the encoder is fed to the data IN of the RF transmitter. Four switches, namely SW0, SW1, SW2, and SW3, are used to input data to the decoder. These switches are pushbutton switches with active low states and the default state is '1'.

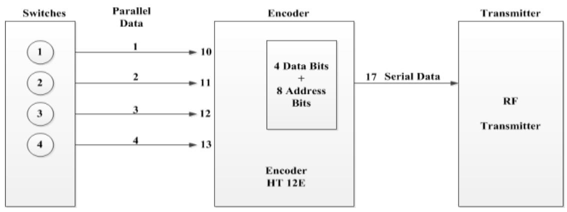

Fig. 6 Block Diagram of the Radio Frequency Transmitter Unit

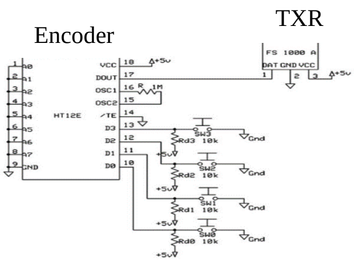

Fig. 7 Schematic Diagram of the Radio Frequency Transmitter Unit

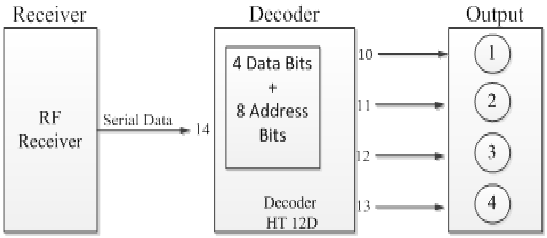

Fig. 8 Block Diagram of the Radio Frequency Receiver Unit

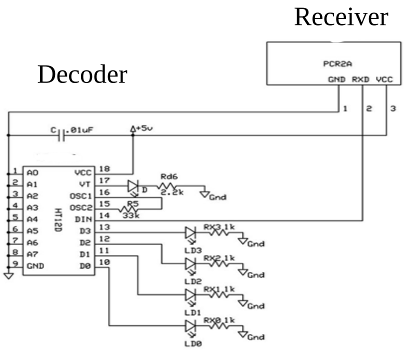

Fig. 9 Schematic Diagram of the Radio Frequency Receiver Unit

2.2.5 Radio Frequency Receiver Unit

In Fig. 8, the RF receiver updates on the wirelessly transmitted signal from the HT-12E encoder IC. The receiver, upon receiving the transmitted signals sends them serially to the pin 14 of HT-12D decoder IC through pin 2. The decoder then retrieves the original parallel signal format from the received serial data. Address bits are configured by using the first 8 pins of both the encoder and decoder ICs. To send a particular signal, address bits must be same at encoder and decoder ICs. By configuring the address bits properly, a single RF transmitter can also be used to control different RF receivers of same frequency. For each transmission, summarily, 12 bits of data are transmitted consisting of 8 address bits and 4 data bits. The signal is received at the receiver's end, which is then fed into decoder IC. If address bits get matched, decoder converts it into parallel data and the corresponding data bits get lowered, which could then be used to drive the traffic signal light through the traffic signal lights module. Fig. 9 shows the electrical schematic of the RF receiver unit. The receiver section has RF receiver and HT-12D decoder IC. The serial data from the receiver is fed into the serial input of the decoder. The parallel data is displayed with the help of LEDs. Another LED at the pin VT of the decoder shows whether a link is established or not. This LED serves as an indicator to indicate valid transmission of data. If it is ON, then everything is OK. Instead, if it is permanently OFF, then there is a link failure.

2.3 Computer Simulations

The design was simulated for a mimic of level 1925 of an underground mine. Traffic lights are installed at the roof of the ramp and they all have RF receivers. RF transmitters are located on top of the heavy vehicles, transmitting within a radius of 80 m. Considered are two scenarios for the simulations, namely, HV moving at the underground mine, and HV ascending with another HV descending. For the scenario of simulation for heavy vehicle moving at the underground mine, there is an HV moving from 1925 access to enter into the main decline. The traffic signal lights turn into red when they are within the transmitting range. This alerts driver of incoming HV of the presence of the HV so as to make reasonable and incident-free decisions. In the simulation scenario for HV ascending and another HV descending, all the HVs transmit within the same RF signal. More so, the traffic signal light shows the same red colour within individual transmitting range of 80 m radius. The ascending HV is given priority of way because it is always assumed to be carrying load. The descending HV parks at the nearest stockpile to give way to the one ascending.

3 Results and Discussion

3.1 Results

Outcomes of simulation for HV moving at the underground mine are as shown in Figs. 10 to 12. The HV moves past the 1925 Access, approached the 1925 Escape Way, approached the 1925 level stockpile extension and the 1925 raw access. In the movement, Tx-Rx communication changes the state of the respective traffic signal lights from green to red for a transmitting range of radius 80 m. Results of two HV interactions are as shown in Figs. 13 to 15. At start of simulation, there was detection of ascending HV by the descending HV (Fig. 13). Descending HV parked at the nearest available space, which is the 1925 E/Way (Fig. 14). Ascending HV then passed by the parked descending vehicle (Fig. 15).

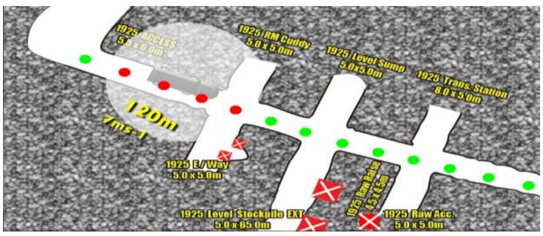

Fig. 10 Heavy Vehicle Moving at the Underground Mine Past the 1925 Access and Approaching the 1925 E/Way

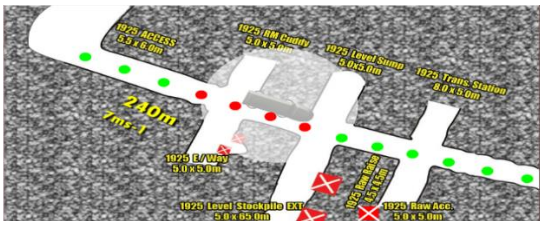

Fig. 11 Heavy Vehicle Moving at the Underground Mine Past the 1925 E/Way and Approaching the 1925 Level Stockpile Ext

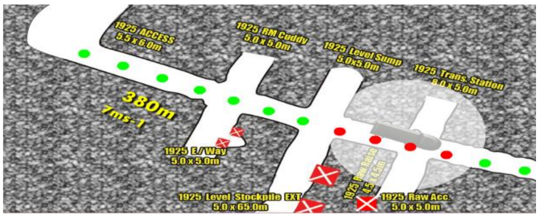

Fig. 12 Heavy Vehicle Moving at the Underground Mine and at the 1925 Raw Access

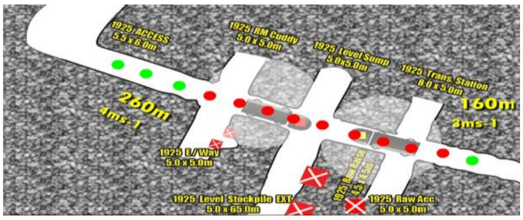

Fig. 13 Ascending Heavy Vehicle is Detected by the Descending Heavy Vehicle

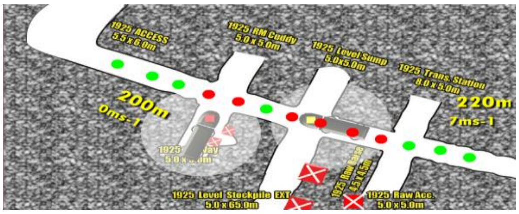

Fig. 14 Descending Heavy Vehicle Packed at the 1925 E/Way

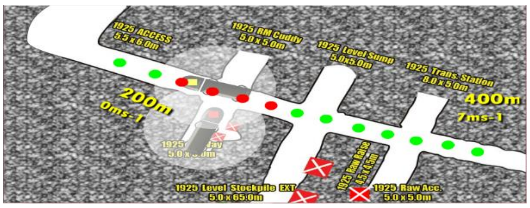

Fig. 15 Ascending Heavy Vehicle Passed by the Heavy Vehicle Located in 1925 E/Way

3.2 Discussion

From Figs. 10, 11 and 12, it can be seen that an HV was moving at the underground mine from the 1925 level access to the main decline. The traffic signal lights lit red when the HV was within the transmitting range of radius 80 m. Conflicts between vehicles can then be prevented as well as congestion at the ramp, because of the orderly movement of vehicles. From Figs. 13, 14 and 15, the reaction of two HV, one ascending and the other descending at the 1925 level are well illustrated. It can be seen that the traffic lights switched into the red mode when the vehicles were within the transmitting range. When the individual vehicle operators detected themselves at a distance of about 60 m between them, descending HV parked at the 1925 E/Way nearby to give the right of way to the ascending HV since, it was assumed to be carrying load. After ascending HV passed, descending HV moved into the main decline and continued its journey.

4 Conclusion

The incidents rate and noise level at an underground mine necessitate the need to implement traffic signal lights based underground communications system to augment the existing leaky feeder system. The cycle time situation at the underground mine requires a system, such as traffic signal lights-based communication that assures of orderly movement of vehicles. A traffic signal light-based communication system capable of surviving the rigours of the underground mine environment assures of orderly movement of vehicles on a decline. Success of system hinges mainly on correct RF Tx-Rx functionality. Incident occurrences of HVs, therefore, stand to be minimised by this system that can coexist effectively with an existing typical leaky feeder communication system with the assurance of an effective V2V communication.

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