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Signal Lights-Based Light Vehicle Safe Movement on Underground Mine Ramps

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A B S T R A C T

The safe movement of Light Vehicles (LVs) is jeopardised on underground mine ramps due to the single lane nature of ramp and the use of ramp by Heavy Vehicles (HVs). Two-way traffic flow dynamics in single-lane underground mine haulage ramps do affect productivity of ramp in times of ore transportation from underground to the surface for processing. In this research, we made use of traffic signal lights, Radio Frequency (RF) Transmitters (Tx) and Receivers (Rx) and a traffic signal lights module to safeguard LV motion on underground ramp. Simulation outcomes confirm safe movement of LV in the midst of HV and other LV on the haulage ramp. This development assures of safety of LV and stands to minimise the incidents occurrences rate in mine ramp haulage systems.

INTRODUCTION

Haul-truck-related accidents and injuries constitute 6 of 28 and 6 of 27 fatal accidents occurring in the mining industry in 2017 and 2018, respectively and are related to vehicle control and hazard recognition [1]. Safety 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 [2]. According to authors of [3], 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. Out of all vehicles that use a typical underground mine ramp, the light vehicle is the most disposed to accidents and incidences as well as possible "bullying" from the much heavier haul truck vehicles. To minimise occurrence of these fatal accidents in underground environments, notable researches strongly recommend use of Light Fidelity (Li-Fi) technology which is known to be faster, has high data density, unregulated large bandwidth and more cost and energy efficient than the RF-based technology. Without the light source however, data transfer becomes problematic [4]. Vigorous research regarding effective communication in underground mining environments were conducted using LEDs and photodiodes [5], [6], ZigBee network-based Wireless Sensor Networks (WSNs) [7] and magnetic induction [8], [9].

A number of research on underground mine safety and anti-collision of vehicles were duly reported. Authors in [10] improved mine trucks-related safety using a novel Information Technology (IT) assisted driving system, but, only for surface mining operations. They developed a conceptual model and framework of the integrated IT assisted system. Researchers in [11] improved underground mine safety using Bluetooth beacon and helmet-based wearable personnel proximity warning system to prevent equipment-pedestrian collisions in underground limestone mines. Topological navigation and localisation to autonomous Load-Haul-Dump (LHD) vehicles operating in underground mines was applied to achieve precision and safe movement of the vehicles [12]. However, the system lacked a wireless communication infrastructure. Hitherto occurring haul truck fatal accidents in the mining industry were investigated by authors of [1]. They stated loss of situational awareness, poor design and operational controls that lead to lack of hazard recognition as the causes. In [13], authors reviewed anti-collision systems used to improve effectiveness and safety in civil and underground mine sites for possible introduction of innovative techniques to reduce the occurrences and consequencies of shared spaces. Eight such spaces were identified but, they are of limited application for example, on underground mine ramps. Authors of [14] used Human Factors Analysis and Classificatioon system (HFACS) to analyse 508 mining incidents and accidents from Queensland, Australia to conclude that skill-based and decision errors of humans are responsible for the happenings. Horberry (2011) [15] strongly advocated operator-centred safe design of

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traffic management system for mobile equipment such as haul trucks and road vehicles. Akkas (2016) [16] recommended use of Wireless Sensor Networks (WSN) for underground coal mine and miner safety monitoring in real-time to enable early warning of hazards. Authors of [17] by a review of 57 studies in the period 2015 to 2019 for a better understanding, investigated the trends in research regarding mining accidents. They identified mechanical failure as the main cause of mining accidents and software utilisation or safety models to predict the potential hazards or risks of accidents are considered as the most promising method of accidents prevention. Safer working environment for all workers is to be provided by mine owners.

Traffic signal lights are mostly used to moderate vehicle traffic at road intersections as well as for illumination of the surroundings. To date, their use on underground mine ramps for the safe movement of light vehicles has not been reported. In this paper, we extend the research domain by deploying traffic signal lights, Radio Frequency (RF) Transmitters (Tx) and Receivers (Rx) for the purpose of safe movement of the light vehicle in an underground mine ramp environment. We validated the developed system by simulation with regard to movement of Light Vehicle (LV) and Heavy Vehicle (HV) on the mine ramp. The rest of the paper is structured as follows: In Section 2, we present the research method which comprises design concept, traffic signal lights, traffic signal module, RF transmitter and receiver units, and the computer simulations. Section 3 provides the simulation results with the discussion and Section 4 gives the conclusions.

METHOD

Design Concept

The conceptual diagram of the underground mine ramp haulage system is as depicted in Figure 1. Figure 2 shows the functional block diagram of the proposed system. The design made use of RF Tx and Rx, traffic signal lights, LV and HV vehicles. In Figure 1, the red and white boxes represent fans at the 1925 vicinity. The traffic signal lights are installed on the roof of the decline or underground ramp at pre-determined intervals of 40 m to alert drivers of vehicles on the status of the 1925 level about vehicle movement. The RF transmitters are installed on the Heavy Vehicles (HVs) 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 HV triggers red warning lights mounted on the backs of ramp within 70 - 80 meters 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, being 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. Figure 3 gives the flowchart of safe movement of light vehicle.

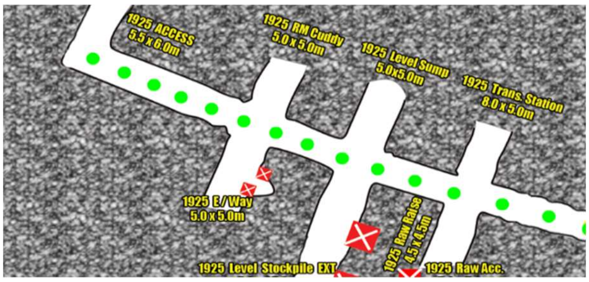

Figure 1. Conceptual Diagram of System

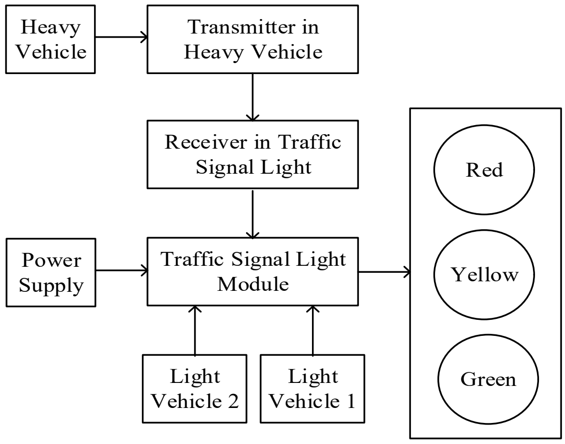

Figure 2. Functional Block Diagram of Proposed System

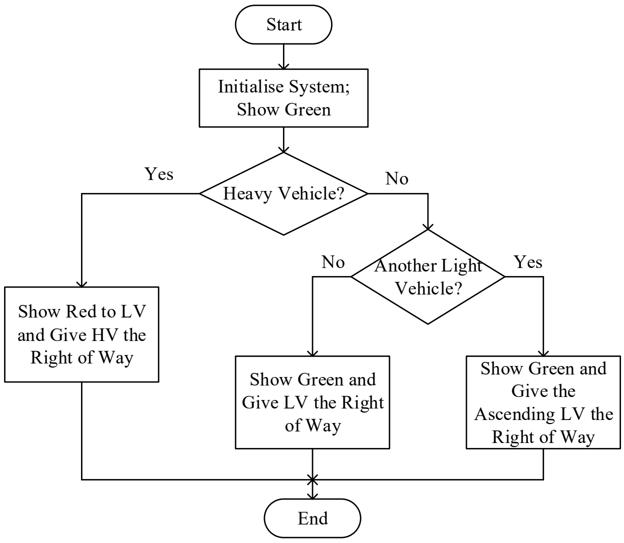

Figure 3. Flowchart for Safe Movement of Light Vehicle on Underground Mine Ramp

Steps of the flowchart are as follows:

Step 1: Start by initialising the control of underground mine ramp system and show green signal light.

Step 2: Request whether there is an HV on the ramp.

Step 3: If there is HV on ramp, show red signal light to LV and give HV the right of way.

Step 4: If no HV is on ramp, and there is only one LV, show green signal light and give the LV the right of way.

Step 5: If there are two LVs on the ramp, and there is no HV, show green and give right of way to the ascending LV.

Step 6: End.

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Traffic Signal Lights

Figure 4 depicts the traffic signal 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 changes. They are powered from a 240 V AC, 50 Hz supply and have annual consumption of 876 kW/hr. Operating temperatures are in the range from negative 40 ^oC to positive 60 ^oC [18].

Figure 4. A Picture of the Traffic Signal Lights

Traffic Signal Light Module

The electrical schematics of the traffic signal light module is presented in Figure 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 protections.

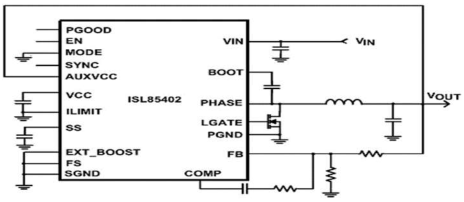

Figure 5. Schematic Diagram of Traffic Signal Light Module

Radio Frequency Transmitter Unit

The block diagram of the RF transmitter unit is presented in Figure 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 pin14 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. Figure 7 shows the electrical schematic diagram of the RF transmitter unit. In the transmitter part of Figure 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, SW3 are used to input data to the decoder. These switches are pushbutton switches with active low states and the default state is '1'.

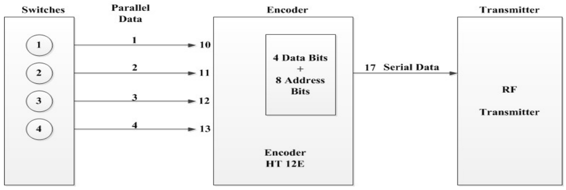

Figure 6. Block Diagram of the Radio Frequency Transmitter Unit

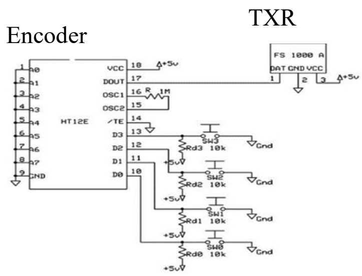

Figure 7. Schematic Diagram of the Radio Frequency Transmitter Unit

Radio Frequency Receiver Unit

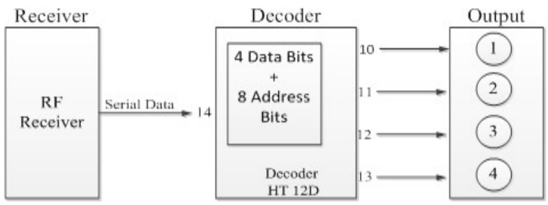

Figure 8. Block Diagram of the RF Receiver Unit

In Figure 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

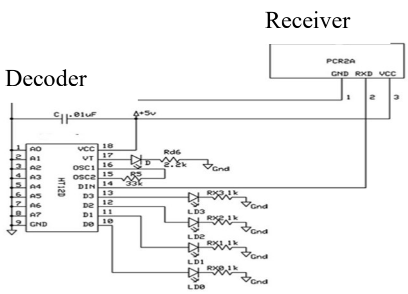

Figure 9. Schematic Diagram of the RF Receiver Unit

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. Figure 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.

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: Heavy Vehicle (HV) moving at the underground mine, and HV ascending and 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 packs at the nearest stockpile to give way to the one ascending.

RESULTS AND DISCUSSION

Results

Light Vehicle Ascending and Another Light Vehicle Descending

At the beginning of simulation, two light vehicles converged (Figure 10). LV nearest to 1925 Raw Access packed to give the other LV the right of way (Figure 11). Given the right of way, descending LV continued its motion and passed by (Figure 12). Packed LV moved out of the 1925 Raw Access and continued its motion (Figure 13).

Light Vehicle Ascending and a Heavy Vehicle Descending

Launching of the simulation, operator of descending HV detected an ascending LV approaching (Figure 14). LV ascending reversed and packed at the nearest available stockpile (Figure 15). Descending HV then passed after the ascending LV had packed (Figure 16). Lastly, LV started moving out of the stockpile upon seeing the green light of the traffic light (Figure 17).

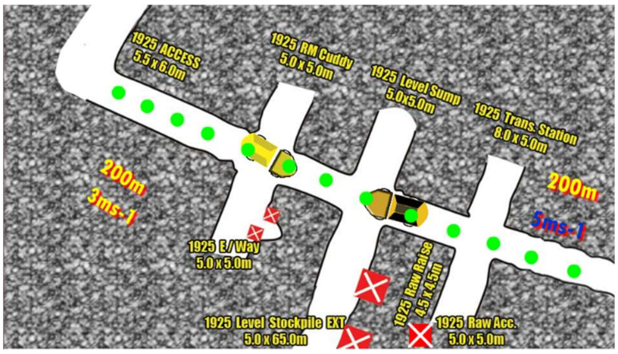

Figure 10. Convergence of the Two Light Vehicles

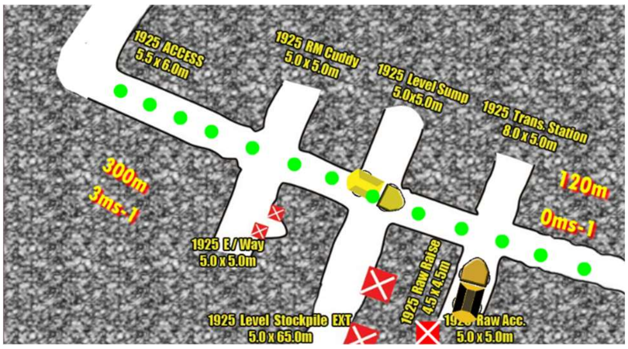

Figure 11. Light Vehicle Nearest to 1925 Raw Access Packed to Give Way to the other Light Vehicle

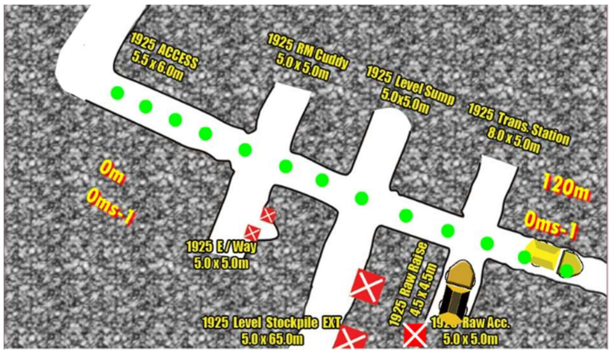

Figure 12. Light Vehicle Descending Passed by the Packed Light Vehicle

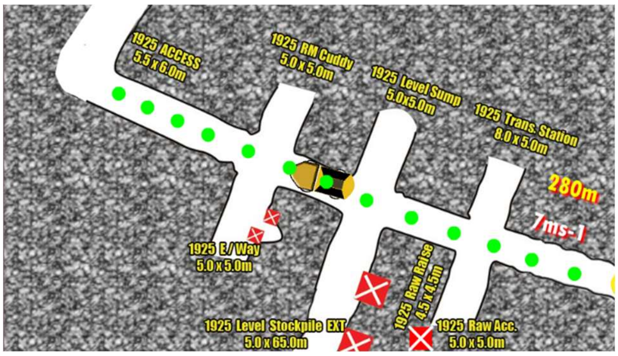

Figure 13. Packed Ascending Light Vehicle Moved out of 1925 Raw Access and Continued Motion Up the 1925 Level Stockpile

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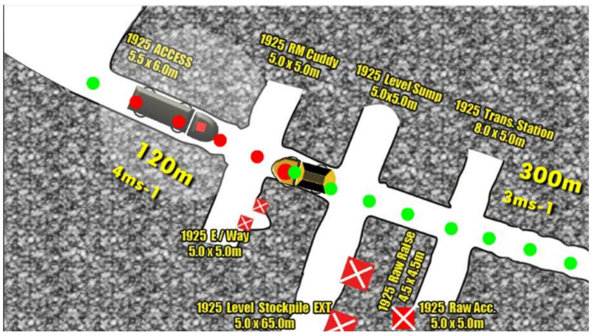

Figure 14. Light Vehicle Ascending is Detected by Operator of Descending Heavy Vehicle

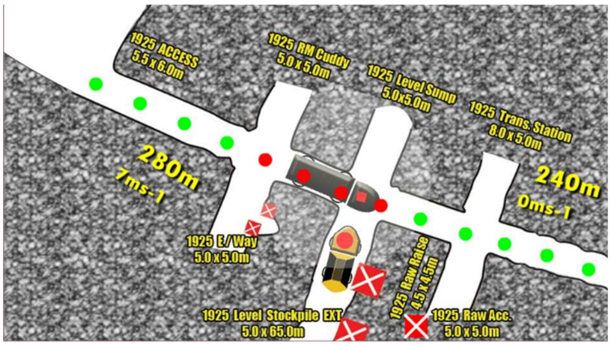

Figure 15. Light Vehicle Reversed and Packed at the Nearest Available Stockpile

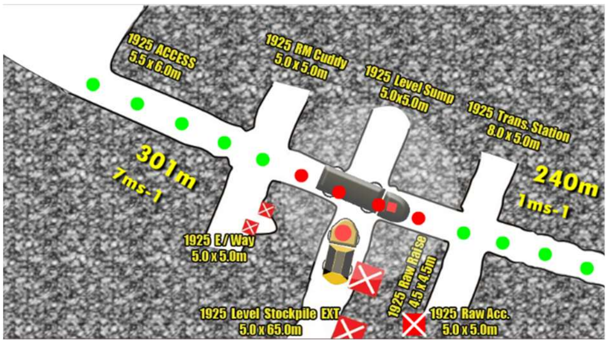

Figure 16. The Packed Light Vehicle is Passed by Descending Heavy Vehicle

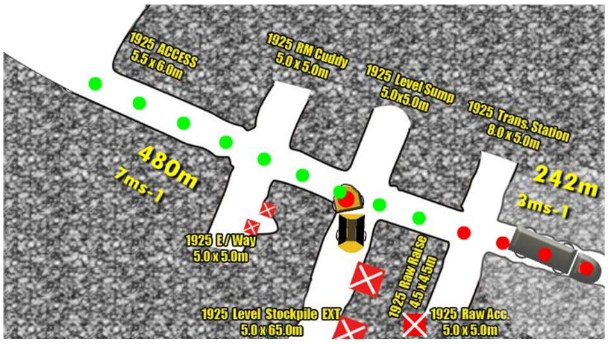

Figure 17. Light Vehicle Moving out of Stockpile after Passage of Descending Heavy Vehicle

Discussion

From Figures 10 to 13 can be seen the setting of an LV ascending and another LV descending at the 1925 level of an underground mine area. Operators of the LVs saw each other at a distance of 80 m between them. They all had the same right of way. Here, the LV nearer to the 1925 Raw Access packed (Figure 11) to give way to the other LV. The traffic lights at the roof of the ramp and visible to the operators turned green, that is for the normal mode since LV had no transmitters on them. From Figures 14 to 17, the scenarios of an LV ascending and an HV descending are depicted. For these, the HV is always given the right of way (Figures 15 and 16) whether descending or ascending when it met the LV. Furthermore, HV is heavier than the LV and it was comparatively easier for the LV to maneuver its way than the HV.

Conclusions

The incidents rate and noise level at underground mines necessitate the need to implement the traffic lights based underground communications system to augment an 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. The purpose of this paper was to design a traffic signal light-based underground mine communication system. The outcome of the research was a successful design of an underground mine communication system capable of minimising vehicular accidents occurrences rate in some parts of an underground mine environment. More importantly, the results of the research have shown that traffic signal light-based underground mine communication is applicable to underground mines. A traffic signal lights-based system assures of orderly movement of vehicles. Success of implementation of the designed system hinges mainly on correct functionality of the transmitter-receiver system of the design. An effective underground mine communication system can be developed based on the use of traffic signal lights to minimise human accidents and incidence occurrences at the underground mine environment. The design can coexist effectively without conflicting with an existing leaky feeder system. The designed communication system can be implemented by both large and small-scale underground mines.

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