Real Time Tracking and Sensing Systems for Improved Safety and Security in Mines

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Abstract

The production of any mine is heavily dependent on safe interface between mining equipments and human beings. Protecting these resources against possible collision and maximizing their utilization through real time location monitoring and control can improve the mine safety and productivity to a great extent. Wireless Sensor Network has evolved to be one of the most effective means of creating communication mechanism between these enterprise objects to improve overall control, visibility and cumulative utilization through real time location awareness. In this paper, we explain the underlying technology behind three mining applications developed by us, e.g.

DumperShield - an active dual alarm collision avoidance system based on GPS and radio frequency proximity sensing that provides a secure virtual shield surrounding a dumper protecting against possible collision with other vehicle / human being .

DumperTrace – an integrated and automated dumper utilization management system capable of counting the number of trips made by each dumper through analysis of their movement patterns and improving the cumulative efficiency and overall production of a mine site.

WirelessUnderground – for enhancing the visibility and safety of the underground mines in terms of locating the miners, equipments and sensing the underground mining environment parameters such as temperature, humidity, and air quality and taking precautionary actions in case of imminent disaster.

1. INTRODUCTION

The mines are usually high risk regions. Various research works in wireless communication can be applied to the mines to enhance their safety measures and also promote utilization of their assets [1]. Widespread attention to research and development in this field of wireless sensor network has contributed to the creation of small and low-power wireless devices, which can be used to create an environment of ubiquitous computing spread across huge industrial area. A more specific flavor of this technology, active radio frequency identification (RFID) is an automatic identification method, used for remotely retrieving data through radio transmission using RF devices. Active RFID technology coupled with sensing devices provides a reliable, low-cost and effective means of collecting data from the tagged enterprise objects and from the environment through what is known as wireless sensor networks, connected to a central control station for enhanced viewing and control the enterprise objects [2.3].

The use of wireless network in mines as a Real time Locating System have been tried out in various mines of Australia and USA as an enhancer of safety as well as efficiency. In underground mines, the miners are fitted with a RF tag in their caps. The position of the miners can be easily read now

from a control room by the installation of software. Usually in case of any accident, the deaths of miners are caused because rescue team does not reach them in time. If the last position before accident of the trapped miners is known, then the rescue forces can be sent immediately and many lives can be saved. Sensing devices can be attached to the workers so that the level of poisonous gases can be detected. In open cast mines, a more rigorous use of this technology is in the anti-collision system of heavy vehicles (dumpers, etc) that can be deployed in various mines. The vehicles used in open cast mines for hauling, transporting and other related operations are usually vehicles having a very high gross vehicle weight (GVW). The GVW indicates that there is a very high risk of run over owing to the difficulty in visibility range of the operators. In spite of all efforts taken we often encounter accidents of these vehicles. Moreover the vehicles used are expensive and the damage caused due to collision is usually very high. Some mines are in the process of deploying various systems in order to set up an anti-collision system, but till now the success is limited. Moreover, the efficiency of production can also be increased by proper tracking and hence utilization of all assets.

In this paper, we explain the work done by us in three mining applications and illustrate the application of state-of-the-art wireless technology in the following areas:
Dumper Collision Avoidance System: We have developed an active dual alarm collision avoidance system based on GPS and radio frequency proximity sensing that provides a secure virtual shield surrounding a dumper, protecting against possible collision with other vehicle / human being .
Dumper Utilization Management System – We have developed an integrated and automated dumper utilization management system capable of counting the number of trips made by each dumper through analysis of their movement patterns and improving the cumulative efficiency and overall production of a mine site.
Tracking Underground Miners / Machineries: We have developed an integrated and automated wireless mesh network system for enhancing the visibility and safety of the underground mines in terms of locating the miners, equipments and sensing the underground mining environment parameters such as temperature, humidity, and air quality and taking precautionary actions in case of imminent disaster.

2. Dumper Collision Avoidance System (DumperShield)

Protecting huge-sized dumpers against collision with other mining equipments or workers is a critical problem in opencast mining operations. Lots of fatal accidents occur due to:

- Poor visibility
- Lack of concentration of driver
- Failure to detect approaching vehicles at the blind spots of a dumper
- Failure to protect the vehicle against fall while dumping waste at the boundary region

These potentially dangerous occurrences can result in extensive and costly damage to equipment or even fatalities. While some systems use ultrasonic and/or CCTV to try to combat this problem, this can be expensive to install and maintain and usually have a limited operating range. Anti-collision mechanisms based on CCTV or video camera have the following limitations:

- Range of operation gets affected by harsh weather condition and poor visibility
- Do not take into account the surrounding vehicles navigation parameters (speed, direction etc.)
- These systems are stand alone as they do not interact with other vehicles in the vicinity

Some research has been done in the area of GPS based collision avoidance system [4,5]. This section introduces **DumperShield** [6], an active alarming system for predicting a collision between two or

more vehicles using GPS and IEEE 802.15.4 MAC/PHY specification compatible system on chip (SOC). We develop a generic estimation mechanism for the safety coordinates of a vehicle based on its orientation, size, current speed, acceleration and its braking potential. Such safety coordinates are communicated among all vehicles in proximity and is used to determine overlaps thus detecting a possible collision. Additionally, RF proximity sensors around the dumpers will also give alarm against possible collision.

DumperShield offers a Dual-alarm Dumper Collision Avoidance System for mining vehicles. It creates a secured virtual shield surrounding a vehicle such that any other vehicle / human entering its coverage area would create an automatic alarm to the dumper driver. It not only provides alarm for the impending collision between dumpers, but also for the collision of approaching dumpers with miners and other fixed hazards like coned off areas, dump stations, crib huts within its vicinity.

The working principal of DumperShield system is explained below.

- Each dumper is fitted with **wireless dumper collision detection unit** comprising of positioning device, display unit and proximity sensors.
- Position device of each vehicle captures the location, direction & speed of its own movement and exchanges the information with other dumpers in its vicinity**. Driver of a dumper gets constant visual updates on the cabin display unit** about the location of the approaching vehicles, workers and fixed hazards present within its 300m vicinity using GPS. Figure 1 shows a typical visual display at the driver's cabin where "yellow" dumper visualizes the relative position of other dumpers in the vicinity of 300 meters.
- **Collision detection unit** of each dumper creates **a virtual alert zone (safety shield)** surrounding a dumper which is shown in the fig 1 as gray colored region surrounding a dumper. It enables the driver to get an **early warning** as soon as the contours of two safety shields overlap due to movement of approaching vehicles, workers and fixed hazards. If any vehicle or worker is found entering that virtual safety shield of a dumper, it will **generate an immediate audio and visual alarm** in the driver's cabin.

Fig. 1. *The visual display at the driver's cabin of "yellow" dumper where relative position of other dumpers in the vicinity of 300 meters are shown. The red dumper is in the collision range, as indicated by overlapping dumper shield (Early warning) and also two red dots on yellow dumper (proximity warning)*

- **Radio Frequency based proximity sensors** are also attached at four sides of the dumper (shown as green dots) to control impending collision. If a dumper gets into further close proximity even after getting early warning then the direction from which the collision is expected is informed to the driver by turning on the color of the corresponding green dot to red. Figure 1 shows that the red dumper is in the collision range, as indicated by overlapping dumper contour (Early warning) and also two red dots on yellow dumper indicates proximity warning caused by the red dumper. Thus, DumperShield automatically safeguards a dumper around 360 degrees.

Figure 2 shows the calculation of the four safety coordinates of a vehicle. The front (*F*) and back (*L)* and width *(W)* would be different for vehicles of different sizes.

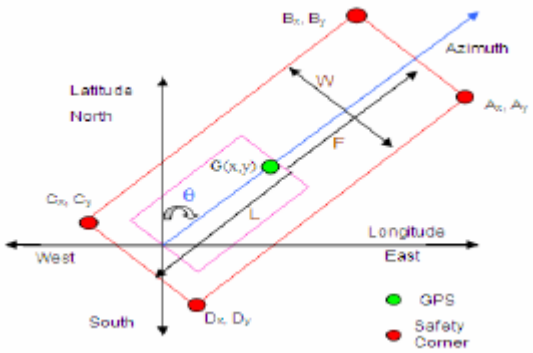

Figure 2: Schematic diagram for calculating the four safety-coordinate of a vehicle.

The determination of the overlap between two perimeters is simplified by working on the coordinates of the four safety corners, thus reducing the complexity of computation. We focus on two possibilities – either vehicle A's coordinate(s) is inside the perimeter of vehicle B, or the other way around. Referring to figure 3, vehicle A would sound the alarm since its upper right coordinate is inside the perimeter of vehicle B. Vehicle C would buzz since the coordinate of B is inside its perimeter [7].

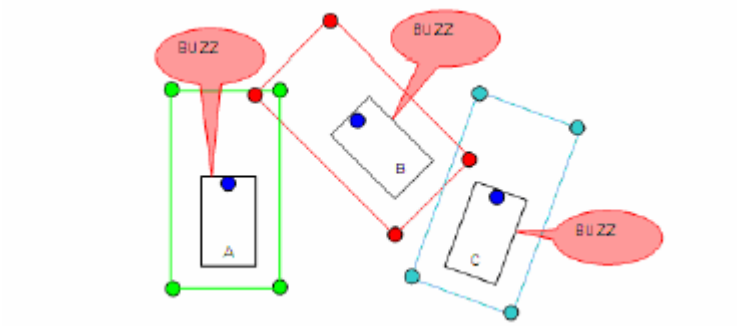

Figure 3: Schematic diagram for alarm generation in vehicles with overlapping safety zones

3. Dumper Utilization Management System (DumperTrace)

Real time visibility of mining assets, such as dumpers, dozer, shovel, etc. and their performance are of cardinal importance for operational efficiency in any open cast mine. In the current scenario, most of the dumpers operating in the open cast mine are paid by the trips they make to and from the mine carrying waste earth material or ore. It is also assumed that the dumpers are carrying the load with its full capacity. However, currently the whole trip counting procedure is handled manually, and very much prone to deliberate human error for obvious business benefits. Because of the heavy load carrying capacity of the dumpers and precarious geographical nature of the open cast mines, installation of weigh bridges are not feasible to measure the accurate loads being carried by the dumpers in each trip. Irrespective of the actual utilization rates of the dumpers, the organizations are obligated to pay them per manual trip count. This results in higher operational cost for the mining industries. As there are no mechanisms available to automatically count the number of trips made by each dumper and also the loads being carried by each dumper, the organization drains huge investment without yielding desired productivity. The problem of accurately measuring the performance of the dumpers can be solved using our active RFID based wireless mesh networking technology. The operation of dumpers can be monitored in the mining area using the wireless mesh network technology on a real time basis and also their past activity status can be generated for future analysis. Thus the operation and performance of the mine can be made visible and accountable to the complete organization, hence improving the utilization of those costly assets.

In the solution each dumper will be equipped with Active RFID tag, capable of sending continuous beacons upon sensing the proximity of Active RFID Routers. The locator tags will carry the ID of the dumper and the also the time stamp which will eventually be stored at the enterprise database. As depicted with the red dots in the following figure 4, a sample open cast mine, Routers are placed along the four different exit points from the mine, capable of sensing the direction and ID of the dumpers in real time. The direction of the dumpers will let the system, at the central control station, determine if the dumpers are exiting the mine or entering the mine. The Routers are capable of forming a wireless mesh network between them to propagate the network information to a central control station, as depicted in the green box area of figure 4.

Figure 4: Sample mining site with Wireless Mesh Network deployment, depicted by red dots

Thus, the management can have an automated mechanism to track the activity status of a particular dumper over a period of time. Also, the manual trip counting mechanism can be validated accordingly. This will lead to an efficient operation of the dumpers and possibly reduce human error resulting lower operational cost for the dumpers [6].

4. Managing Safety in Underground Mines

The inherent nature of underground mines and the working environment for the miners provide a daunting challenge to address the safety issue in the mines. The mining industry across the world suffers regular disasters, caused by toxic gas emission, fire or mud slides and other hazards. It takes catastrophic shape due to the fatal effects on the miners trapped inside the mine. Lack of availability of real time positional and environmental information inside the mining zone cripples the ability to react promptly and accurately in case of a mining disaster. In this section, we discuss various technology options available to mitigate the disasters in underground mines. The most significant of these options is the Active RFID-based wireless mesh networking technology that provides a sound foundation for establishing real time visibility of mining assets as well as miners that can significantly enhance disaster management capability. The active RFID devices, which support mobility and can be attached to miners, are capable of forming autonomous wireless mesh network and propagate the network information to a central control station in multi-hop, so that the entire network of devices can be viewed centrally. Thus the location of each miner (carrying an active RFID device) is known in real time [3]. The flexibility to attach gas sensors with active RFID devices allows safety monitoring center on the surface to view the poisonous gas level (such as methane, carbon monoxide, carbon dioxide etc) inside the mine on a real time basis. In this way, a combination of Real Time Locating System (RTLS) and Real Time Sensing System (RTSS) applications using active RFID technology in the mining industry will tremendously augment the capacity and effectiveness with which disasters can be foreseen and mitigated in underground mines.

Active RFID based Real Time Locating System (RTLS) and Real Time Sensing System (RTSS) [6], consists of small wearable active RFID tags, intelligent network of routers, a central coordinator and a system software suite which enable real time location and environment monitoring visually. If the central monitoring and control station, where the software suite runs, is internet enabled then the whole underground mining environment and operation can be viewed globally, giving anytime anywhere visibility as well control. The RFID tags attached to the miners or assets are capable forming a network between them even under constant mobility. Highly effective and small sensors can be integrated with these tags. The flexibility to attach gas sensors, capable of sensing toxic gasses such as carbon monoxide, carbon dioxide, methane, sulphur dioxide etc. and to subsequently transmit that information in real time to a monitoring station on the surface creates the absolute critical visibility of the sub-terrestrial mining world. This smart active RFID tags are capable of communicating in both directions, so the miners can also communicate with the control station and vice versa.

Figure 5 shows the complete system architecture of this active RFID based integrated real time locating and sensing solution. The routers are placed in strategic locations in the various mining tunnels and they are capable of forming autonomous, fault tolerant and robust wireless network. Specific sensors, such as vibration sensors, soil moisture sensor, smoke sensors for fire detection can be placed in critical locations and they can detect the environmental parameters continuously to predict immanent disasters. The integrated nature of the system enables the location tracking of every individual tagged object as well as miner in time of immenent disaster and subsequently sends

alarms to warn the miners to take necessary actions, such as evacuation. Even in case of disaster recovery, this real time location information is critical for prompt and effective rescue operation. Thus, we can see the completeness and effectiveness of such integrated real time location tracking and sensing system in improving the mine safety tremendously.

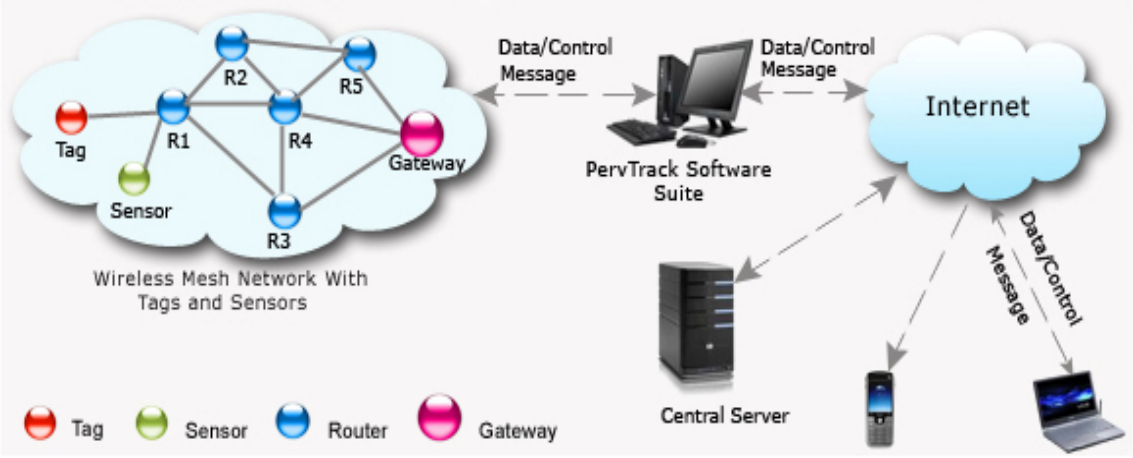

Figure 5: Architecture of Integrated Platform for Real Time Locating and Sensing System. (Courtesy PervCom Consulting, India)

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