Wireless Tracking and Sensing Systems for Mine Safety, Security and Productivity Management

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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 and workers against possible accidents and maximizing their utilization through real time location monitoring and control can improve the mine safety and productivity to a great extent. At the same time, the sensitive areas of mining premises must be automatically protected against unauthorized intrusion to cope up with possible security hazards. Since identification of any forthcoming crisis requires current information and such information must be communicated in real-time, therefore the need arises for a wireless communication framework for mine safety, security and its management that provides efficient, reliable, secure exchange and processing of relevant information.

The objective of our proposed work is to showcase the impact of using our Real-Time Tracking, Sensing and Management System using Active RFID, Sensors and Wireless Mesh Network for improving mine safety, security and productivity management. **W**e explain the underlying technology and system solutions behind four 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 dumpers / light vehicles / 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 System is a completely wireless and automatic system for real-time tracking of miners & mining equipments and real-time monitoring of underground environmental condition (i.e., emission of toxic gasses such as, Methane, Carbon Monoxide) inside the mine. It provides audible warning to prevent collision between miners & mining vehicles and sends warning to alert the miner approaching unsafe areas. It also enables the miner to send emergency message to control station on the surface.

WIID: Wireless Infrared Intrusion Detection System: Breach of physical security can result in not only theft of expensive equipments but also put severe threat to the safety of the enterprise and the people working inside. Our Wireless Infrared Intrusion Detection (WIID) System is a IR-based wireless perimeter fencing system that automatically detects any attempt of physical intrusion in the organization premise and sends real-time alert (Buzzer/ SMS) wirelessly to the central security office along with the location details of the event for immediate actions.

1. Introduction

The existing safety and security management systems are mostly manually triggered and reactive. Since real time on-line data about the safety and security parameters are usually not available, there is minimal scope to take any prior preventive measure to avoid any kind of safety & security hazards. Since identification of any forthcoming crisis requires current information, and such information must be communicated in real-time, therefore the need arises for an wireless communication framework for mine safety, security and its management that provides efficient, reliable, secure exchange and processing of relevant information.

In this paper, a framework has been proposed using our Real-Time Tracking, Sensing and Management System with Active RFID, Sensors and Wireless Mesh Network for improving mine safety & security. This will enable the mine management to improve both object visibility and environment visibility of a mine through real-time tracking and monitoring of enterprise objects using the Internet. It also allows controlling the objects and the environment by triggering actuators, which are also part of the enterprise objects. **W**e explain the underlying technology and system solutions behind four mining applications developed by us, e.g.

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2. Proposed framework for enterprise visibility

Our framework for “Enterprise visibility” essentially creates a wireless communication environment by attaching intelligent wireless devices, sensors and actuators to the industrial objects and environment so that each and every object, human being and the environment of any enterprise can be made visible and controlled (actuated) in real-time from anywhere in the world at any point of time [1].

The building blocks of this framework are

a) active RF tags and sensors for tracking status and location of enterprise resources and environment
b) Wireless routers and gateway for creating a self-forming wireless mesh network with tags and sensors in their vicinity to transmit tag/ sensor data from field to a control station for remote real-time monitoring.

This wireless network, thus formed, is also known as LR-WPAN since it uses low power and low data rate short range wireless communications suitable for tracking and monitoring applications. Low data rate protocols have been designed specifically for these needs lately, which is a significant deviation from the trends of building high-bandwidth networks. The protocol ratified by IEEE is 804.15.4 in 2003 and updated in 2006. The 802.15.4 standard provides specifications for the Physical and Medium Access Layer. The upper layers (Network to Application) have been developed by a consortium of wireless device manufacturers and enthusiasts called ZigBee [2].

We have developed an end to end architecture for such remote visibility of enterprise "objects" and remote actuation necessary for controlling these "objects" using the basic building blocks described above. The architecture comprises of three basic components: (a) the wireless mesh network, consisting of RFID tags, sensors and/or actuators (b) the gateway and the central server and (c) the Internet [3].

The mesh networks house local information which is communicated through a gateway to the central server. The gateway handles the messages to and from the mesh network. The gateway is expected to be mains powered while the individual nodes (sensors/actuators) are battery driven. The information is then transported to a web endpoint by the Central Server. The central server essentially does the job of protocol conversion from the Internet to the sensor network and vice-versa. The information is displayed in the requisite format and provides an interface for object management. The web end point application can be a simple hosted page viewed on a personal computer or a message transmitted to a mobile device. We could think of supporting both push based and pull based systems. A push based system updates the status of the devices automatically, either periodically or when a status changes. In a pull based system, the latest information is provided when the user asks for it.

The conceptual framework is pictorially depicted in figure 1.

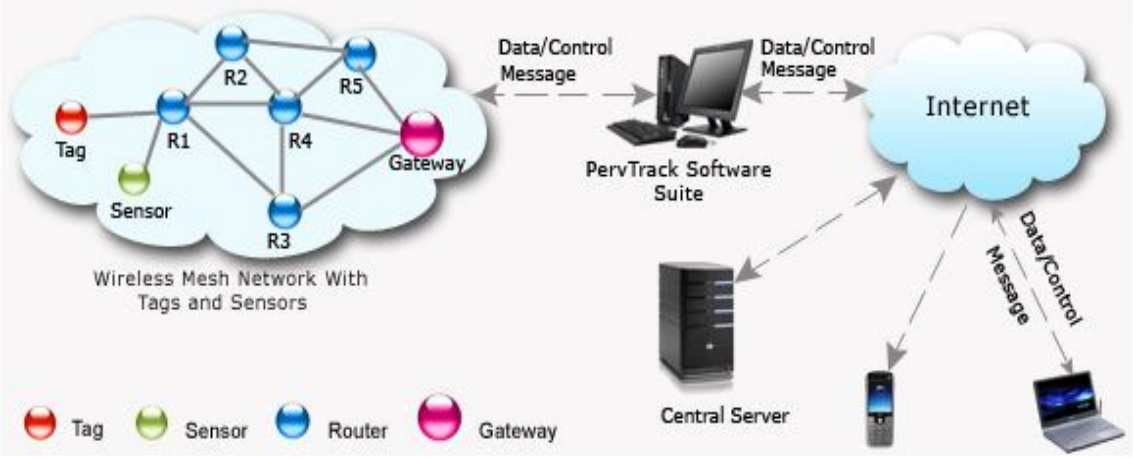

Figure 1. *A conceptual framework for Monitoring and Actuation of objects and environment through the Internet*

3. **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.

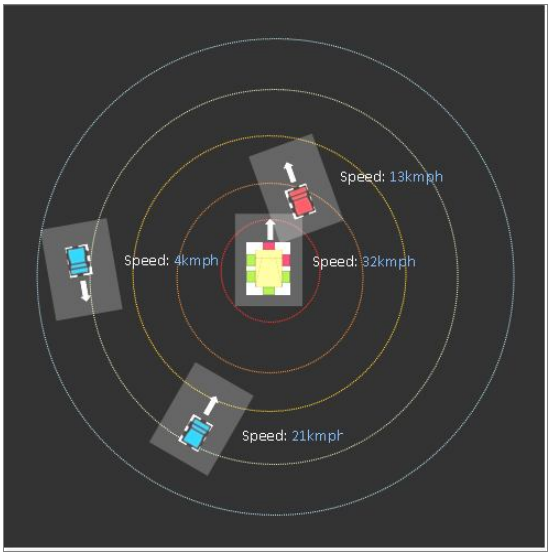

Fig. 2. *The visual display at the driver's cabin of "yellow" dumper where relative position of other dumpers in the vicinity of 300 meters are shown. The red dumper is in the collision range, as indicated by overlapping dumper shield (Early warning) and also two red dots on yellow dumper (proximity 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.

4. 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.

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 3: Sample mining site with Wireless Mesh Network, 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].

5. Tracking miners and mining environment in underground mines

The physical and geographical complexity of tunnels in underground mines impairs the visibility of environment and operating assets, including human beings. Irrespective of the acuteness of locating mineral though proper mining design and planning, the hazards of the sub-terrestrial world remains unpredictable. This increases the vulnerability of the miners. Most of the available technologies are restricted in being reactive rather than proactive, which means that it can not predict an imminent disaster situation. And, once the disaster strikes sub-terrestrially, it leaves very little window of opportunity to control the disaster from getting worse.

Very limited work is done to remotely monitor the location and activity status of miners and mining environment in real-time from the surface. Real-time data about mining environment i.e., emission of poisonous gases in underground mines is also not available currently at the mine office on the surface. Wireless communication inside the underground mine is one of the most promising and effective technique that is being used in number of solutions. The limited infrastructure required as compared to the legacy wired communication technology, which is very much susceptible to the disaster itself, has paved the way for ingenious solution development to tackle the mining disaster issue.

Proposed Solution using Active RFID and wireless sensor based tracking and monitoring system

Active RFID technology integrated with sensors for real time location monitoring and sensing emerges to be the obvious solution which has the capability to address the mining disaster handling issue competently.

The RFID tags attached to the miners or assets are capable forming a network between them even under constant mobility. This smart active RFID tags are capable of communicating in both directions, so the miners can also communicate with the control station on the surface and vice versa. 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 to carry miners' tag data to control station on the surface [6].

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 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 [6]. 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 imminent 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.

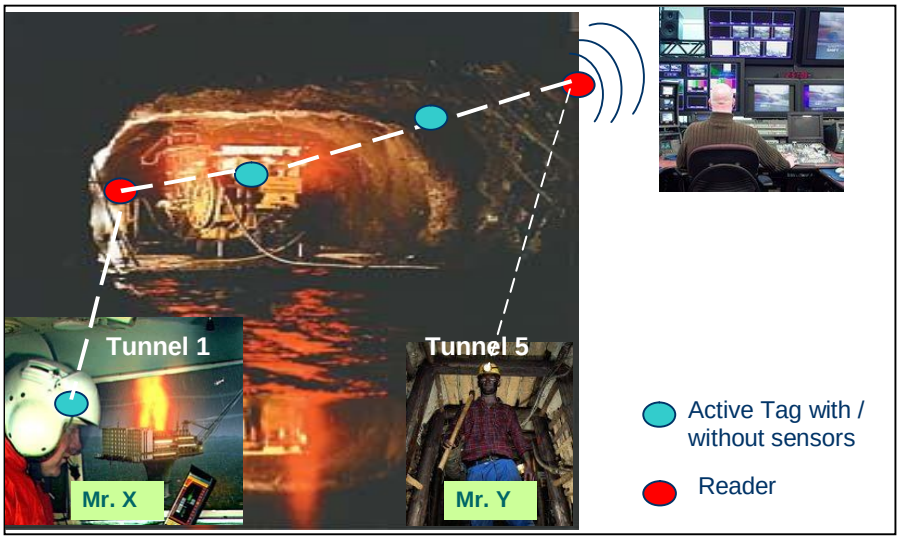

Figure. 4*. Conceptual framework for Underground Miners' Tracking & Poisonous Gas Detection System: Coursey: Pervcom Consulting Pvt. Ltd.*

6. Securing the explosive magazine premise against intrusion in opencast mines

Securing the explosive magazine premises in an opencast mine against un-wanted intrusion is critical. Breach of physical security can result in not only theft of expensive equipments but also put severe threat to the safety of the plant and the people working inside. Traditional ways of securing the perimeters of factories, plants and mines only consists of barbed wire fencing with limited number of security personnel patrolling the entry gates. These methods are nowhere close to being full-proof against intrusion, simply because of the huge size of the perimeters, which is physically impossible to monitor through limited number of human eyes. Most of the plant uses barbed wire fencing and electronic power fencing. Barbed wire fencing can be easily broken down, whereas, power fencing security can be broken by making hidden underground passes. Common fencing solutions do not provide location of breach. So, reaction time for counteraction is quite significant. Killing of security guards in recent maoist attack at one of the blue-chip aluminum company has once again raised the need of exploring new technology option to improve perimeter security that can autonomously track the actual location of breach in real time and take preventive measures immediately.

Proposed solution on IR based perimeter fencing

Automating the whole security process through sophisticated sensors and wireless networking technology could be the answer to the age old security problems mentioned before. Infrared sensors can easily detect the breach of a security perimeter. These infra-red sensors can be electronically interfaced with tiny wireless devices. And, with the help of wireless networking technology the information from the infrared sensors can be spread across the enterprise and be aggregated at a central security station to generate a real time status of the fencing. To ensure reliability in data transmission, not only the wireless mesh networking infrastructure can be used, the public GSM service based SMS messages can also be sent to notify concerned person in real time. In case of a breach of

security, detected by the infrared sensors, real time alert notifications can also be generated through this kind of Wireless Infrared Intrusion Detection (WIID) system (figure 5).

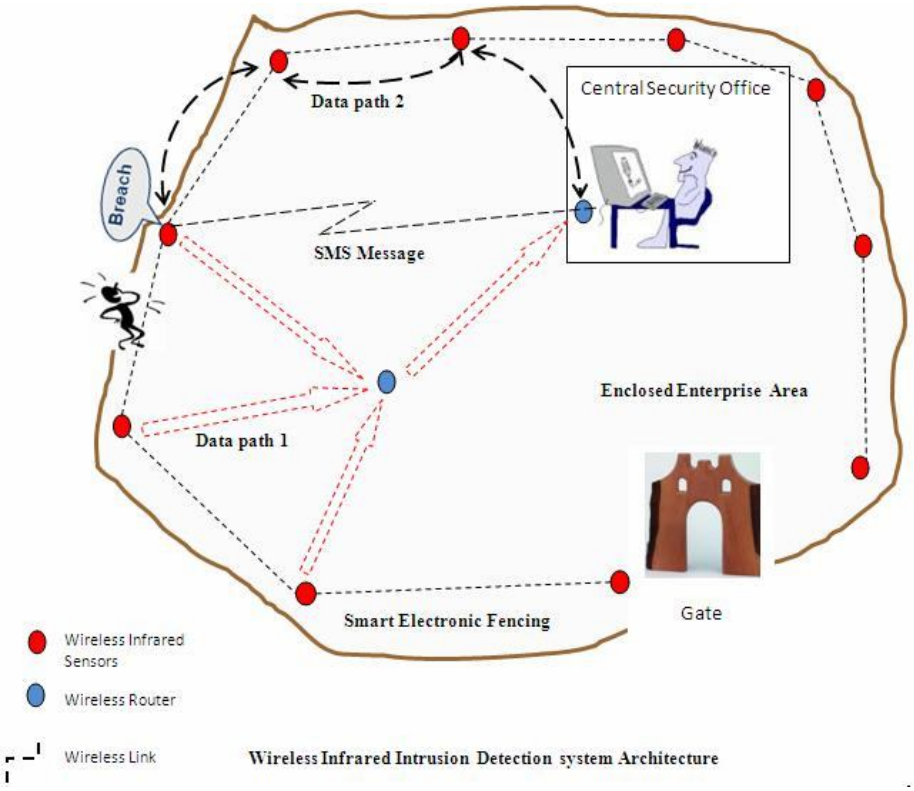

Figure 5. *Conceptual framework for Wireless Infrared Intrusion Detection (WIID) system*
Courtesey: PervCom Consulting Pvt. Ltd.

7. Conclusion

In this paper, we have discussed a framework for *Real-Time Tracking, Sensing and Management System* using Active RFID, Sensors combined with Wireless Mesh Networking technology that can be used to detect emergency events and safety threats and provides warning signals or other control signals to handle the emergency.

In the context of mine safety and security, the system offers real-time data about location and activity status of workers and equipments, level of pollutants in the industry premises, breach of security at mine perimeters. The real-time data helps to get early warning about a possible danger, even enables the authority to spot and alert their workers in case of emergency. The same framework is used along with IR sensors and other suitable sensors to automatically control and detect the unauthorized intrusion. The system allows view and control of enterprise objects, events "*anytime anywhere*" through the Internet. The proposed framework is generic and has a tremendous application potential to handle safety and security issues in different mine scenarios with necessary customization.

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