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Design of optical and wireless sensors for underground mining monitoring system

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Miner'health and safety is now considered as a major challenge, hence novel technologies such as optical sensors and wireless sensors networks (WSN) have been adopted to monitor underground mining. In this paper we propose a real time system for underground mining monitoring based on optical sensors and WSN. We treat the sensor deployment in underground tunnels and its impacts on underground mining monitoring system (UMMS). The dilemma of wireless and optical node deployment, efficient coverage and sensing in underground mining is detailed. Therefore, we are interested on the case of optical sensors use in UMMS. The introduced architecture may detect and localize damages such as strain vibration, temperature and humidity change. In this work, the suggested optical sensors (Raman, Brillouin, Fabery–Perot and Bragg) are used in UMMS.

1. Introduction

Ensuring safety of mining has a great importance in modern societies. In underground mining, several components exist including for example mining machinery, ventilation system, sensors, etc. Thus, by the use of monitoring systems our aim is to protect mine workers and managers. Today, structural health monitoring and control technologies attracted a lot of attention because of their great potential to monitor and maintain the safety of civil engineering structures [6]. Wireless sensor network (WSN) is spatially distributed sensors in an autonomous manner to monitor physical environmental conditions. The appearance of optical fiber sensors (OFS) had facilitated the control of various infrastructures. These sensors make it possible to understand the structural behavior of any structure, they promote the detection of anomalies and risks, and they ensure the evaluation of the structural safety status by using a certain diagnosis of damage. Environmental monitoring applications had mainly a crucial importance for various companies as a whole. WSN and OFS are adopted to reach this goal. Thus, underground monitoring systems should provide at real time any data concerning the physical phenomena occurring in its environment. Underground Mining Monitoring Systems (UMMS) aims to achieve the safety of working and the maximum of productivity [1,9]. UMMS systems use sensors networks to ensure control and damage detection at real time, especially wireless sensor networks which combine wireless communication, distributed processing, micro electromechanical systems, machine vision, embedded computing, and sensor technology has attracted a lot of attention. WSN has been applied in health monitoring for mines (underground and open-pit), infrastructure and equipment, such as bridges and tunnels. Monitoring technologies, especially wireless technology, had becoming one of the hotspots research [4]. SHM systems offer a real

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time vibration profiles in special hazardous zones and obviously tunnels. Therefore, it offers automatically triggered alarms when strain exceeds a certain hop. Verma et al. (2017) present a study of safety of workers in Indian mines. They highlight the significance and the importance of UMMS, their work provides a detailed analysis of underground mining accidents [10] and Zrelli et al [7]. Henriques et al. [8,11] describe in theirs works [11,12] a design and construction of a mine safety system prototype using a WSN. Their objective is to build a safety system to monitor the ambient characteristics of the mining environment. The constructed system may measure ambient characteristics underground mining and communicate between nodes sensors using ZigBee module. In this paper, we propose a novel architecture of safety underground mining monitoring systems based on optical sensors (SOFO, FBGS, Brillouin and Raman sensors). Our objective is to build a safety system which can monitor divers characteristics of the mining environment (humidity, temperature, strain, vibration and pressure). Thus, the hardware consists of optical fiber sensors electrical sensors (DHT11, DHT22, ADXL432, etc.) and electronic circuitry (microcontroller such as raspberry and arduino). Therefore, we will explain, in the first section, significance of node deployment in underground mines. Then, we propose a novel design of our own UMMS system used to monitor various parameters in underground mining.

2. Deployment of optical and wireless sensors in mines

Deployment of optical and wireless sensors had a great impact on Qos of WSN especially when we treat the case of underground mining monitoring. Today, sensor node deployment in mines can affect hugely the performances of wireless sensor networks [1]. To improve lifetime of wireless sensor networks and then UMMS, the choice of adequate routing protocol in the work of [22] for health monitoring system based on WSN. Moreover, deployment of optical sensors and wireless nodes in WSN has a major role in prolonging the network life-time, efficient reliability and routing, well preserving of network energy, ensuring connectivity, increasing throughput of the network [2]. Optical sensors deployment strategy especially depends on the structure of the monitoring environment, in our case we treat coal underground mines. Monitoring of locating miners must ensure safety of workers. Thus, working conditions in coal mines should be monitoring at real time and many environmental factors gas, humidity, temperature, vibration, water level need to be checked constantly. Chen et al. have proposed a topology of chain-type wireless underground mine sensor network called 'CWUMSN' [1]. Various deployment techniques and strategies have been reported in the literature like random deployment or a controlled deployment. Controlled deployment nodes sensors proposed in [3] is usually pursued for indoor applications of WSN such as underground mines monitoring. ZHU et al. [5] have used a 2D band-type to deploy nodes in coalmine. Comparing to the random deployment technique, this strategy proposed in [5] may prolong the lifetime of WSN.

According to the conditions of monitoring task in underground mining, such as gas, temperature and humidity monitoring, optical sensors and nodes should be deployed uniformly.

2.1. Efficient coverage

To achieve the optimal coverage capabilities of WSN in underground mining, the deployment of nodes in WSN need to be discussed. To provide a high quality of collected data, we should assure efficient coverage in underground mining.

Kumar et al. show that the maximum coverage must be target in surveillance of mines [12]. They define the efficient coverage as following:

$$C(N) = \frac{Np\pi {r_s}^2}{\mathrm{Log}(Np)} \tag{1}$$

where N is the number of nodes and p is the probability of active sensors, r_s sensing radius. Efficient coverage problems evolved in three stages: simple coverage, k-coverage and Q-coverage [13]. K-coverage is used in literature to refer to the minimum coverage. A WSN is called k-coverage if every point in this network is covered by at least k sensors [12]. Monitoring region (M) in underground mining [2] is given by (2). Each M area contains n_M sensor nodes where $n_M = \frac{N}{K}$ and M is mathematically:

$$M = \frac{L \times W}{K} \tag{2}$$

where K is the number of region in monitoring region (M). Since the sensnodes are independently and uniformly distributed in the underground mining then the probability of optimal coverage is given by :

$$\mathrm{P_{cov}} = 1\text{-}\exp(\text{-}p \times \pi \times R_s) \tag{3}$$

Using the simple coverage, each region (see Fig. 1a) should be monitored by at least one sensor node [13]. The regions (I)–(VIII) are considered as coverage area of the node sensor. Many analysis and simulation results indicate and show that optimal deployment strategies may achieve a certain degree of coverage sensing results with less number of sensors. In underground mining a sensor node may cover up to four regions (I,II,III,IV), monitoring region (M) is presented in Fig. 2 (a) and (b).