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Future Challenges of Positioning in Underground Mines

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Abstract: The mining industry is facing a difficult challenge in the coming decades. High grade ore is becoming increasingly difficult to obtain and production in underground mines is constantly being carried out at deeper levels. This increases the production cost for the companies and a technology shift is needed to secure the production.

One solution often discussed is to introduce more autonomous machines and robots in the mine. This would improve personnel safety and also increase the productivity. Autonomous machines are already being used in mines, but often in restricted areas and they are typically not deployed on a large scale. Introducing unmanned machines on a large scale requires a completely new positioning solution compared to those being used today. Current solutions are primarily intended for personnel safety and emergency rescue, but these are not intended nor suited to be used for tracking and controlling unmanned vehicles.

The state of the art in positioning technologies has generally had a strong focus on consumer industry; this paper will describe a more challenging research topic, the underground mine. It will describe the state of the art in underground mining positioning applications as well as the foreseen future positioning applications. Taking the special mining requirements into account, the challenges of positioning in underground mines are thereafter identified and discussed.

The paper concludes that there are many challenges to solve in several areas, and that the research community has an important role to play.

Keywords: positioning systems, mining, control applications, requirements, localization, challenges, underground

1. INTRODUCTION

The ore production in underground mines is one industrial area which has not developed its automation methodologies as much as other industries in general. Automating the production is important since the ore is more costly to excavate at the deeper levels. The underground ore production is typically performed in several steps; drilling, charging, blasting, excavating and securing the rock. However, there are trials of using tunnel boring instead of traditional blasting (Atlas Copco 2010). Large and heavy machines are used to support the mine workers in all these steps mentioned above, but they consist of a large amount of manual tasks and contains rather few automation steps. Out of the ore production steps, it is only parts of the excavator step which has been automated (ABB 2013).

An extended use of automation, robots, autonomous operation as well as remote control of the underground mining vehicles and other equipment is a necessary step to continue to provide the required productivity and human safety in the future underground mines. Positioning is one of the key enabling technologies which the mining industry needs in order to reach this step.

2. STATE OF THE ART

The majority of positioning systems in underground mines today consist of access and entry systems which are used to identify people entering and leaving the mine at some key entrance and exit points. These systems keep track of who is in the mine, and potentially also their approximate position or depth level. Before every blast, it must be assured that all personnel is in a safe area or outside of the underground mine. In emergency and evacuation situations it is of key importance to know how many persons that still are in the mine. This type of mine safety application is in most countries regulated by law. The Mine improvement and new emergency response act of 2006 (US Department of labor, Mine safety and health administration 2006) is an amendment to the Federal mine safety and health act from 1977 with the aim to improve the safety of mines and mining. In general, the act regulates that each underground coal mine in the US need to develop and adopt a written accident response plan. The plan must include details on how to evacuate personnel in case of an emergency. The act also regulates the minimum requirements on communication and positioning in case of an emergency.

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Underground mine positioning systems are with few exceptions based on RFID, WLAN, UWB, INS or a combination thereof.

2.1 RFID

Radio-frequency identification (RFID) technology for use in real-time object identification is facing rapid adoption in several fields such as logistic, automotive, surveillance, automation systems, etc. (Chawla and Ha 2007). The cheapest RFID tags with the largest commercial potential are passive or semi-passive, where the energy is harvested from the reader's signal or the surrounding environment. Passive RFID tags are based on backscatter modulation where the antenna reflection properties are changed according to information data. A well-known location sensing system using the RFID technology is SpotON (Hightower, Want and Borriello 2000), which uses an aggregation algorithm for 3-D location sensing based on the RSS analysis. Another system is called LANDMARC (Ni et al. 2004) which uses active RFID.

Important requirement of future RFID systems will be accurate real-time localization at the sub-meter level, management of large number of tags, in addition to low power consumption, small size, and low cost. However, these requirements cannot be fulfilled by the current first- and second-generation RFID (Chon et al. 2004) or wireless sensor network technologies such as those based on ZigBee technology. Most available RFID sensors have insufficient range resolution to achieve accurate localization, affected by narrowband interference, and have an intrinsic low security.

2.2 WLAN

Using WLAN standards, operating in the 2.4 and 5 GHz ISM band, has become very popular in public hotspots and enterprise locations during the last decade and is now starting to appear in mining and other industrial automation plants. WLAN offers typically a gross bit rate in the range of 1-108 Mbps and a range of 50-150 m depending on the environment. It is appealing to use an existing WLAN infrastructure for indoor location as well, by adding a location server. The accuracy of typical WLAN positioning system using RSS is in the range from 2 m and upwards (depending on the environment), with an update rate in the range of a few seconds. The accuracy of location estimations based on the RSS of WLAN signals is affected by several elements in indoor environments such as movement and orientation, overlapping of access points (AP), walls, doors, etc. There is extensive literature available on using WLAN for localization (Bahl and Padmanabhan 2000), (Ekahau 2014), (Wang, Jia, and Lee 2003), (Kitasuka et al. 2005), (Lui et al. 2011) and (Haeberlen et al. 2004). Some available commercial systems are using Time Difference Of Arrival (TDOA) solutions (AeroScout 2014). TDOA requires synchronization of receivers and also requires the same radio signal to be received at three or more separate points to determine the location.

2.3 UWB

Ultra-wideband (UWB) is a relatively new and promising localization technology, especially for indoor applications. UWB technology offers various advantages over other positioning technologies, such as WLAN, with less interference and higher accuracy since the UWB pulses have short duration (less than 1 ns) (Ingram, Harmer and Quinlan 2004), (Zhang et al. 2006) and (Hancke and Allen 2006). This makes it possible to filter the reflected signals from the original signals. To date, several UWB localization systems are available (UbiSense 2014), (Time Domain 2014). The UbiSense platform is a unidirectional UWB location platform with TDMA control channel. Their triangulation locating technique, which takes advantages of both TDOA and Time Of Arrival (TOA) techniques, is employed to provide flexible capability of location sensing.

The principle of TOA is based on measuring the absolute travel time of a signal from a transmitter to a receiver. The Euclidean distance between two devices can be derived by the multiplication of the signal travel time by the wave speed. TOA relies on precise synchronization of transmitter and receiver clocks. TOA is particularly difficult to apply in indoor environments where multipath exists, because the autocorrelation peak in the signal referring to the Line Of Sight (LOS) beam may not be resolved.

Reported indoor position accuracies lie in the order of decimeters, but suffer from multipath effects and Non-Line Of Sight (NLOS) conditions (Eskildsen and Pedersen 2013). These effects are most prominent while tracking moving objects or persons and give rise to distorted and bumpy trajectories.

2.4 INS

Inertial navigation is a navigation technique where measurements of acceleration and angular velocity are used to track a mobile unit's position and orientation, given that the starting position and starting orientation is known. The acceleration and angular velocity are usually provided by an Inertial Measurement Unit (IMU) and the computations are performed by a computer, together forming a complete Inertial Navigation System (INS). This type of navigation is used in a wide range of applications such as ships, aircraft, missiles, spacecraft and robotics (Titterton and Weston 2004). The basic principle of an INS is to integrate the angular velocity and to double integrate the acceleration in order to compute the orientation and position of the mobile unit, respectively.

To improve the performance of an underground positioning system, based on, e.g., WLAN or UWB, an inertial navigation system can be added. Adding INS information to the positioning system can make it possible to compensate for directional dependent disturbances. Furthermore, it increases the dynamic range of the combined system and can also eliminate shadow areas (De Angelis et al. 2010).