

Memorandum for the Record – MEMS-based Inertial Navigation Systems for Mining Applications.

Inertial navigation is an established technology in guidance systems for aircraft, marine vessels, and other vehicles. The introduction of Micro-Electro-Mechanical Systems (MEMS) has allowed the miniaturization of the sensors that provide the position tracking functions of Inertial Navigation Units (INUs). MEMS-based INUs are now sufficiently small and power efficient to be worn by a person. These devices use accelerometers and gyroscopes to monitor a person's velocity and heading as they walk. This technology has been proposed by several organizations for coal miner tracking applications.

Miner tracking systems that are based on INU technology may have advantages over other tracking methodologies. The INU tracking functions are not dependent on mine infrastructure over limited distances and provide miner location even when mine power is lost. Because the miner's location can be determined on-board, tracking information can be sent to the surface via a low-bandwidth communications link. Low data rates are important because limited bandwidth is available on current communications systems that could survive a disaster, such as through-the-earth or medium-frequency systems.

The use of MEMS-based INUs is relatively new, and there are considerable technical challenges in implementing this technology. This has been confirmed in a recent NIOSH contract to develop a miner tracking system using an INU and in articles from a recent navigation conference (GNSS 2007). The following quotes provide examples of the challenges associated with this technology:

- "...in a more realistic environment where an operator's dynamics changes from walking to running, to climbing stairs, etc., a more complex approach to the DR [dead reckoning] navigation task must be developed..."
- "In general, DR navigation has good short-term error performance, but insufficient long-term accuracy."
- "However, these [INU] states have errors that drift over time and the Inertial Measurement Unit (IMU) has to be integrated with other techniques, sensors or systems to constrain its drift error."
- "The quality of the MEMS inertial sensors is, however, conspicuously low. So, a new algorithm is required to enhance the performance of the portable navigation system implemented using the MEMS inertial sensors."

In addition to these findings, a recent NIOSH contract to develop an INU to be worn by coal miners was not successful (Contract Report 200-2007-21249). Position errors accumulated too quickly as the test person walked through the mine. Also, as in most pedestrian INU applications, the tracking algorithm depended on cues associated with the person's stepping motion. Thus, if the person kneeled, crawled, or rode a vehicle, the INU would not provide useful velocity or heading information. Significant errors were also introduced when the test person was standing near noisy, vibrating machinery.

Finally, the durability of MEMS-based INUs for use in the mining environment is in question due to the failure of two prototypes during initial tests.

While there is considerable research in this area, there are still significant issues that must be overcome before INUs can be reliably used for tracking workers in an underground coal mining environment. These include:

- Computer algorithms that can resolve a miner's location during all types of possible movement including walking, crawling, duck walking, and riding in vehicles.
- Wearable computer processors that are small and power efficient.
- Safe batteries that can power a miner's system for at least 24 hours.
- Methods to provide correction data to the INU, which accumulates significant errors over time and distance traveled.
- Low-power and low-bandwidth communications schemes compatible with mine communications systems.
- Electronics design and packaging that is comfortable, tough, and meets MSHA approval criteria for underground coal mines.

It is anticipated that some of these issues will be resolved as military and civilian applications mature, but underground mining will require further development to optimize trade-offs between accuracy, power requirements, physical size, data link requirements, and survivability.

Due to the technical risks and projected costs of arriving at a cost effective, reliable, and MSHA-approved INU-based solution, and due to the limited timeframe of the MINER Act, NIOSH has decided not to pursue the development of INU-based personal tracking systems at this time. NIOSH will instead monitor research sponsored by other agencies within the government that have budgets more suitable to fund such cutting-edge technology. NIOSH will also conduct research as necessary to analyze issues specific to the mining environment that are pertinent to future use of INU-based tracking.