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# Back Movement Monitor Field Testing: Summary Report

by

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## Technical Report Documentation Page

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# BACK MOVEMENT MONITOR FIELD TESTING: SUMMARY REPORT

This project has been partially funded by matching grants from the Missouri Transportation Board. This project was completed during the doctoral research of Dr. Tristan H. Jones. The candidate graduated in May of 2008, which coincided with the completion of the project.

The project consisted of development of the HRTMM and laboratory and field testing of the designed movement monitor. Laboratory evaluation included verification of the theories developed for determining the monitor's maximum sensitivity and error as well developing procedures for using the monitor in various environmental conditions. Variables such as target surface roughness, laser incidence angle, lens focal length, lens filter color, digital camera parameters, and ambient lighting conditions were tested to determine their effect on the monitor's usability and functionality. Field evaluation of the movement monitor included installing the monitor in an active underground lead mine and testing its response to fog particles, vibration from nearby machinery and mine explosions, and its ability to properly function in that particular atmosphere.

During the project a number of publications were completed. In total the project resulted in three conference papers, three conference oral presentations and the research contributed to the publication of three journal articles with two additional articles currently in progress or in review. In addition to articles and presentations, the dissertation of Dr. Jones was based entirely on the work completed during this project.

## System Description

### HRTMM Components

The HRTMM consists of four main sections; the sensor, the target, the incidence laser(s), and a computer. Each of these sections is responsible for a particular aspect of the monitor's function. The sensor is responsible for capturing the light in the monitor's field of view, converting it to an image, and storing the data or routing it directly to the computer. The target is the focus at which the sensor and incidence laser(s) are aimed in order to monitor movement.

The incidence laser(s) are the coherent light source that moves across the target in response to target movement. The computer is responsible for setting and carrying out a data capturing program, operating the sensor, recording data, and running the HRTMM software which tracks the movement of the incidence laser across the target, ultimately allowing for measurement of movement sensed by the monitor.

One of the goals of this project has been to keep the build of the monitor both inexpensive and simple. Smaller mines with smaller budgets are more likely to use an inexpensive monitoring solution than an expensive one, thus making the permeation of this technology through the industry more likely. One of the easiest methods of keeping the price down is to utilize parts and equipment that are easily purchased "off-the-shelf" and to refrain from having too many specialized components produced exclusively for the monitor. This has been a large factor in the decision to use many of the components of the monitor.

**The Sensor.** The HRTMM is designed to primarily utilize a digital camera as a sensor, though other methods of recording digital image data are available. A mounting platform has been designed to firmly hold the digital camera and a targeting laser. The platform consists of a one ½ inch thick piece of aluminum approximately 9 inches square. An upright sheet of the same aluminum is bolted perpendicular to the platform and is drilled to accept the mounting threads of a high quality video tripod head. In this configuration the camera is oriented in a horizontal position. The video tripod head allows the entire sensor to be rotated along three axes, giving complete control over the aim of the sensor.

The mounting platform has been drilled to accept the standard quarter-twenty bolts used in the camera industry for mounting cameras to tripods. A locking pin has also been installed to match the locking hole provided on the base of many cameras. The location of this hole will need to be altered depending on what model of camera is used, but locating and drilling the hole is a simple matter. When attached to the platform, the imaging plane of the camera is parallel to the upright sheet of aluminum. The camera is aligned with the locking pin and mounting bolt and a ¾ inch long bolt attaches the camera firmly to the mount.

Next to the camera a targeting laser is attached to facilitate faster alignment of the sensor portion of the monitor with the target, helping to assure quick and simple installation. The targeting laser is a simple pen laser that operates on two AAA batteries. The targeting laser is a

635 ±10 nm class IIIA red laser with not more than 5 mW of output power. The range of the targeting laser is significantly longer than the current practical range of the monitor with the setup used in this research. A more powerful laser could easily be substituted if necessary. Substitution of a more powerful laser would require precautionary measures be taken by the user to ensure that no eye damage could occur.

The targeting laser is aligned so that it is parallel to the line-of-sight of the digital camera. This was accomplished by first measuring the offset of the targeting laser aperture from the center of the digital camera lens. Next the complete sensor mount was placed on a tripod at one end of a hallway and aimed at a marked target point the other end of the hallway approximately 75 m away. The center crosshairs viewed through the camera were placed directly on a target point. Next the previously measured laser offset was measured from the target point on the opposing wall and marked, showing where the targeting laser should intersect the opposite end of the hallway if it were aligned parallel to the camera line-of-sight. Finally the targeting laser attached to the camera mount was aligned to intersect the point. This method is sufficiently accurate for the purpose of aiming the sensor at the HRTMM target due to the long distance between the mount on the tripod and the point of measurement on the opposing wall. Also, the distance at which the alignment was made is further than what is currently considered practical for the monitor. While one purpose of the targeting laser is aiming the sensor at the target, the primary use of the laser is for helping to align the camera and the target. This will be covered in more detail later.

The digital camera used in the HRTMM is not limited to a particular brand, make or model. The decision concerning which type of camera to employ with the monitor depends on the required accuracy and desired cost, as well as the maximum range at which the monitor will be used. The environment in which the sensor will be placed, the frequency of image capture, and the method of transferring data to the computer need also be considered.

During testing on this project two different types of digital cameras were tested. Initially and for a short period a Konica Minolta DiMAGE A2 digital camera was used. This camera is an 8.0 megapixel camera with a fixed lens capable of 8x zoom. The lens has a 35 mm. equivalent focal length of 28 - 200 mm. and is capable of apertures from F/2.8 – 3.5. Unfortunately, as of March 31$^{st}$, 2006 Konica Minolta has ceased production of all consumer cameras. This camera was used for initial testing and validation of the system as well as for all testing during software development.

When replacing the Konica Minolta DiMAGE A2 certain criteria were set forth for the digital camera. It was decided that the camera should be of the digital single lens reflex (DSLR) variety and should have a maximum resolution of at least 10 megapixels. This type of camera would provide greater flexibility in camera usage for research and would also allow for higher sensor sensitivity due to the enhanced resolution. The camera also needed to be capable of taking delayed images so that it could be set to allow for vibrations to be eliminated. The camera was also required to use interchangeable lenses in order to allow for greater flexibility and the use of a telephoto lens.

The search for a more suitable camera led to the Nikon D200. The D200 is already incorporated into a number of other geotechnical monitors. It met every criteria set forth in the search and had dozens of additional features that made it an ideal choice for this research.

The Nikon D200 is easily available off-the-shelf to anyone. It is a 10.2 megapixel DSLR with interchangeable lenses and a crop factor of 1.5. It has great flexibility in its usage options with respect to sensitivity, shutter control, focus options and image control. It is capable of outputting data in both compressed .jpg format and in a proprietary and lossless .nef format as well.

The D200 is very easy to interface with a computer system. It provides a regular USB interface as well as an option for interfacing over the wireless 802.11b/g standard. Every option on the camera can be completely controlled via computer when it is used in conjunction with the computer program Nikon Capture Control 4.4.0.

The camera control program allows a user to make a predefined program to remotely activate and use the camera. It has very flexible time-lapse photography routines allowing for images to be taken repeatedly for as long or as short a time as necessary and it is capable of directing the camera to take images in bursts of any desired number of images at a given time. The data is automatically transferred and named according to user definition and can be stored on any computer hard drive. Batch routines can also be used to automatically perform certain modifications to the images such as file type conversions and automatic white balance corrections. The camera is also capable of operating independently of this computer control program and stores its data on a compact flash memory card.

Physically the Nikon D200 is one of the best consumer-grade cameras available for use in harsh environments such as mine sites. It has oversize controls that would make use with a gloved hand easier. Also, while most digital cameras are built with a plastic camera body, the D200 actually uses a magnesium alloy body covered in plastic and soft rubber coating and grips. The magnesium alloy increases the durability of the camera while the plastic and rubber help to deal with light bumps that the camera might take during use. It also helps to ensure a secure grip should the camera be damp from high humidity. As a consumer camera it is designed to be handled frequently, to travel via automobile and also to withstand trips on an airplane. This does give some stability to the camera with respect to its build, though like any consumer grade camera it is not designed to withstand being severely dropped or being struck by falling rock.

The camera does, however, provide an attractive option with respect to its use in mines. Most of the body seams, compartment doors and controls have either rubber seals or gaskets surrounding them in order to keep out moisture and dust. This is an essential feature in underground mines where there can be very high levels of both humidity and airborne particulates. The camera itself is not waterproof, but it is much more sealed than a normal DSLR camera. If the camera might come into direct contact with water a waterproof housing would be recommended of the sort used by underwater divers. None of these housings were actually used during the course of research, but the adaptation of the monitor to their use would be elementary.

Another positive attribute for the camera is that the screens are very large and bright, but have power-saving options that significantly reduce their drain on the battery. The camera operates on a 1500 mAh Nikon EN-EL3 lithium ion battery at 7.4 V. and is capable of up to 1800 shots per charge. During testing the camera was left turned on in a mine for approximately 12 hours with very little noticeable battery drain. From experience it is expected that the camera could easily be left on and used for a week without needing a battery recharge, though a DC power port is available if direct powering is desired from a standard 110 V AC power source. A supplemental battery pack is available that allows the use of either two EN-EL3 batteries or can be fitted with a cartridge holding six AA batteries. Since the beginning of this project Nikon has introduced the D300 DSLR camera. It has many improvements over the D200 and should be considered as a potential camera for this monitor. The price is similar to that of the price of the D200 when it was originally introduced, about $1,800.00. The introduction has decreased the price of the D200, making it more economical. This can now be found online for prices as low as $800.00.

During the project two interchangeable lenses were used. One was a Sigma 28-70 mm F2.8-4 DG standard lens while the other was a Sigma 70-300 mm F4-5.6 DG Macro telephoto lens. These lenses had 35 mm equivalent focal lengths of 42–105 and 105–450 mm respectively when the camera’s crop factor of 1.5 is taken into account. The increased performance of the camera and lenses over the DiMAGE A2 made them all very suitable for the project. The Nikon D200 and entire sensor section of the HRTMM can be seen in Figure 1.

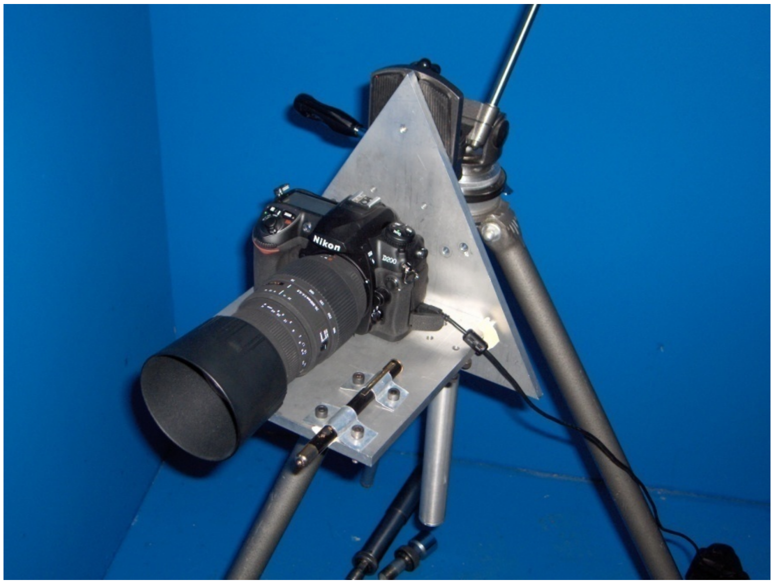


Figure 1: Sensor section of the HRTMM including the Nikon D200, Sigma lens, targeting laser, sensor platform, and video tripod head all mounted on a tripod.