24-083

Testing of Ground Truth Instruments for Use in Evaluating Haul Truck Collision Warning and Avoidance Systems

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ABSTRACT

Between 2005 and 2021, surface mining haul trucks were involved in 54 fatal incidents in the United States [1]. Collision warning and avoidance systems (CXS) can help haul truck operators navigate their route safely. The evaluation of CXS object detection performance for surface mining haul trucks relies on the positional accuracy of the ground truth instrument. As part of a holistic approach, researchers from the National Institute for Occupational Safety and Health (NIOSH) characterized the accuracy of a global navigation satellite system (GNSS) that serves as the ground truth instrument to determine object position and velocity in CXS object detection performance testing. We used precision surveying equipment to establish ground truth points for comparison with GNSS data collected for static positional measurements and reduced-scale straight-line vehicle dynamic tests. We conducted these tests with real-time kinematics (RTK) and then satellite-based augmentation systems (SBAS). For the dynamic tests, we measured a distance error of 1.34 m (4.40 ft) using RTK and 1.50 m (4.92 ft) using an SBAS. This research will provide CXS manufacturers and CXS researchers a basis for evaluating the positional accuracy of CXS. Note that we did not evaluate any CXS in this experiment.

INTRODUCTION

Background

For surface mine haul trucks, the main function of collision warning and avoidance systems (CXS) is to assist drivers at avoiding accidents in their travel that can lead to collateral damages, injuries, or fatalities. Because detection performance is critical, the ground truth instrument (GTI) used to assess positional accuracy of CXS must be reliable. Modern GNSS receivers can be considered as a GTI because of their reported centimeter level of accuracy, under static condition [2]. Researchers from the National Institute for Occupational Safety and Health (NIOSH) designed an experiment to validate the positional accuracy of GNSS receivers for our intended purpose which is to use GNSS receivers as ground truth to assess detection of CXS, specifically while GNSS receivers are in motion.

Limited literature exists describing dynamic test measurements of GNSS receivers. However, two relevant standards exist that discuss the accuracy of GNSS receivers for static measurements or testing methods for GNSS while in motion. These are ISO 12188-1 and ISO 12188-2. These standards provide detailed instructions on how to test the positional accuracy of GNSS receivers in the agricultural industry. ISO 12188-1 specifies common parameters to assess and compare different GNSS receivers in dynamic conditions [3]. ISO 12188-2 covers how to assess automated guidance systems based on GNSS technologies for agricultural vehicles [4]. NIOSH researchers modified the static and dynamic test methods described in these standards to make them more suitable to our application. Our test method differed in terms of test course requirement, test procedure and test report and calculations.

Approach in the Current Study

Using ISO 12188-1 and ISO 12188-2 as reference, we took measurements to evaluate the positional accuracy of GNSS receivers we used in a separate experiment to assess detection performance of CXS designed for surface mining haul trucks. Note that we did not evaluate any CXS in this experiment. We collected measurements while the GNSS was not in motion—static, and then dynamic while the GNSS was in motion. Under static conditions, these measurements included positional data such as latitude, longitude, and elevation. Under dynamic conditions, these measurements included latitude, longitude, elevation, speed, and timestamp. For both conditions, a combination of sensors is used to validate the measurements. The following section describes the test method.

TEST METHOD

Test Course Setup

NIOSH researchers conducted static and dynamic tests to evaluate the positional accuracies of GNSS receivers in a parking lot area at the NIOSH campus in Bruceton, PA. This area has a relatively flat surface area about 80-m (260-ft) long and 15-m (49-ft) wide. To set up for the tests, we used surveying equipment to establish known ground truth or "benchmark" points to compare with measurements of the GNSS receivers. We used two geodetic points on the NIOSH campus to localize two types of surveying equipment. One item of our surveying equipment was GNSS based and the other was a robotic total station (RTS) that used an optical laser and a prism to collect positional data. Using the RTS, we surveyed a point for the base station. During the test, we positioned the base station on that point to transmit real-time kinematics (RTK) corrections to the to the receiver or GTI Away from the base station point, we also surveyed two 64-m (210-ft) parallel lines spaced about 0.61 m (24 inches) apart. Along the lines, we surveyed and marked 10 points on each line from one end to the next using nails and marking paint. We placed 10 metal strips covered with reflective tape (reflectors) perpendicular to the two lines (as shown in Figure 1). We designated the most westbound reflector as reflector #1. Reflectors #2 through #10 were placed with respect to reflector #1 about 9.14 m (30 ft), 15.24 m (50 ft), 21.34 m (70 ft), 27.43 m (90 ft), 39.62 m (130 ft), 47.72 m (150 ft), 51.82 m (170 ft), 60.96 m (200 ft), and 64.00 m (210 ft) away from point 1—respectively. These 10 reflectors and 21 points constituted the ground setup for our static and dynamic tests described in the following paragraphs.

Static Test Setup, Data Acquisition, Instrumentation, and Test Procedures

NIOSH researchers collected static measurements to evaluate the positional accuracy of the GNSS receivers. We used commercially available GNSS receivers. These receivers have RTK using a base station and satellite-based augmentation system (SBAS) capabilities when the base station is not in use. Using these receivers, we recorded real-time positional measurements such as longitude, latitude, and altitude. For the static tests, we recorded measurements from 20 physical points to compare them to the ground truth points collected using the robotic total station. These points were recorded at the two longitudinal ends of the 10 reflectors.

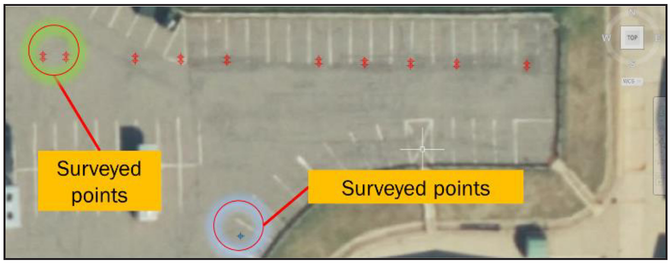

Figure 1. Test setup for static and dynamic tests. Starting from the top left, the two rows of points represent the ground truth marked by the RTS and the point on the bottom is the point surveyed for the base station

To collect ground truth test points for the static tests, we used two items of surveying equipment: 1) An RTS with a 2.4 GHz RC-4 radio mounted on top of one prism and a field controller to log and store data. At this mode, the RTS had range of 3,000 m (9840 ft) with a coarse accuracy of ± (10 mm + 2 ppmxD) mean square error. 2) A GNSS-based surveying system which was comprised of two receivers to collect data with a data collector to store the collected data. We used one receiver as a base station to provide RTK correction and the other as a rover to collect data. This equipment had a 25-cm baseline precision of a differential code solution for static and kinematic surveys.

During the static test, we placed the GNSS receiver on the desired location and collected data for about 60 seconds and recorded the average latitude, longitude, and altitude for 20 points from 10 reflectors. The points were in the middle center edges of each reflector as illustrated in Figure 2. Because we already surveyed the ground truth points using the RTS during the general set-up, we retained these points as ground truth data for a total of 20 points, knowing that the locations surveyed were offset about 25.4 mm (1 inch) from the center edges of the reflectors. We then used the GNSS-based surveying equipment and our GNSS receiver to collect measurements from the same 20 points. In addition, we surveyed 10 points in the middle center of each reflector. However, we only used the center points as ground truth for the dynamic tests.

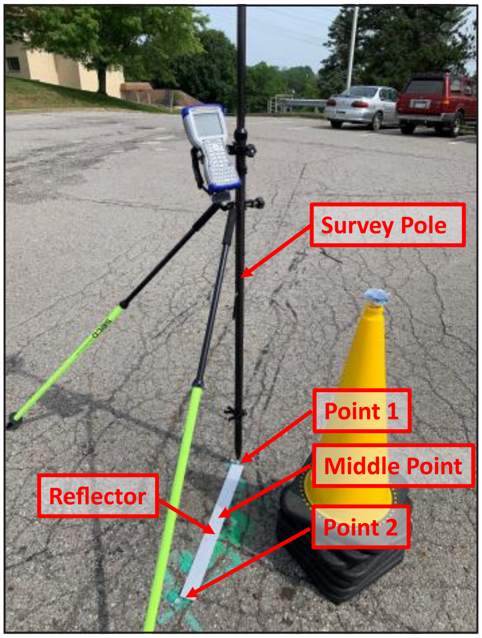

Figure 2. An illustration of the points on one of the surveyed reflectors

Dynamic Test Setup for GTI Test Using an Electric Truck

To evaluate the positional accuracy of the GNSS receivers while in motion, NIOSH researchers conducted dynamic tests using two reduced-scale vehicles. We used an unmanned ground vehicle (UGV) and an electric pick-up truck (e-truck) as reduced-scale vehicles. The UGV measured 0.99-m (39-in) long, 0.67-m (26.4-in) wide, and 0.39-m (14.6-in) high, and the e-truck measured about 4.52-m (178-in) long, 1.47-m (58-in) wide, and 1.84-m (72.25-in) high. Using the manufacturer's specifications, each reduced-scale vehicle was equipped with GNSS To measure the time at which the UGV or e-truck crossed the reflector, NIOSH researchers used a remote optical laser sensor (ROLS) pointed at the ground that is capable of measuring rotation speed from 1–250,000 rpm or pulse per minute from a reflective tape with an operating range of 0.9 m (36 in). Using the ground facing ROLS, we collected time-stamped signals triggered by the vehicles crossing over any of the ten reflectors. Aiming for the center, we drove each vehicle over each reflector to enable the ROLS to trigger a signal and use that time-stamped signal to select the position (latitude and longitude) where the signal change occurred. Because the ROLS and the receivers capable of producing time-stamped positional data and speed. The UGV had two pre-installed GNSS receivers located on opposite corners, on top of the UGV, about 0.39-m (14.6-in) high from the top surface of the UGV.

We installed one GNSS receiver on the top of the e-truck about 1.85 m (73 in) from the bumper along its length, 0.74 m from the driver side along its width, and 1.84-m (72.25- in) high. For the dynamic tests, we collected data from the GNSS and from additional ground truth devices, such as a wheel tachometer and a remote optical laser sensor (ROLS), to one central data acquisition system (DAS).

Dynamic Data Acquisition and Instrumentation

NIOSH researchers used a rugged data recorder or data acquisition system (DAS), a universal amplifier, and a DAS software to record and visualize data in real time. The DAS was mounted on the e-truck or UGV during the test. The DAQ was capable of recording data from 16 channels. We used 11 channels. Nine channels were used to record data for the GNSS receivers such as timestamp, latitude, longitude, altitude, speed, satellite time, satellite date, satellite status, true heading, etc. We used two channels to record a voltage output from the wheel tachometer and a ground-facing optical laser sensor. We set the sampling rate on the DAQ at 200 Hz, although the sampling rate for the receivers was limited to 10 Hz.

To measure the speed of the rotating tire of the UGV or e- truck, we used a laser tachometer. This wheel tachometer could sense the speed of tire rotation up to 30,000 rpm at a max range of 0.51 m (20 in). Using the wheel tachometer, we collected time-stamped voltage output related to tire rotations that were later processed into speed. For that reason, we measured the average circumference of the tires to extract the radius for both the UGV and e-truck—prior to the installation of the wheel tachometer. On the UGV, we installed the wheel tachometer about 50.8 mm (2 in) from the outside left-front tire. On the UGV tire, we placed four strips of reflective tape about 90° offset to trigger a change in voltage output during motion. On the rear driver side tire of the e-truck, we installed the wheel tachometer and one strip of reflective tape to trigger the signal during motion.

GNSS receivers were in different locations on each vehicle, we measured their vertical and horizontal positions relative to the 2D area of the vehicles. We designated the vertical to be the axis along the length of the vehicle and the horizontal axis along the width of the vehicle. Knowing these measurements, we calculated the center location of the ROLS from the center location of the GNSS receivers. On the UGV, we installed the ROLS with an offset from the GNSS receivers of 0.7 m (27.44 in) on the vertical axis,

0.27 m (10.69 in) on the horizontal axis, and 0.18 m (7.25 in) high. On the e-truck, we installed the ROLS with an offset of 0.62 m (24.53 in) on the vertical axis, 0.71 m (27.6 in) from the horizontal axis, and 0.52 m (20.5 in) high.

Dynamic Test Procedures

The main objective of the dynamic tests was to assess the accuracy of the GNSS receivers while in motion using two vehicles (UGV and e-truck) depending on their speed, direction of travel, and GNSS status through RTK or the satellite-based augmentation system (SBAS). At the beginning of each UGV test, NIOSH researchers cleared the testing area of unneeded participants, excluding the three researchers conducting the task. Near the testing area, researchers maintained the remote connection with the DAQ throughout the test using a laptop. Inside the testing area, a designated driver of the reduced-scale vehicle drove the vehicle to the starting position. From that point, the driver signaled to a spotter to press the record button on the camera, and the spotter signaled to the researcher with the laptop to start data collection. Once data collection had begun, the driver accelerated the vehicle and drove over each of the ten reflective strips in the forward direction of travel—from west to east. Data collection ended after the vehicle had passed the final strip and came to a stop. The researcher checked the data to make sure that all ten reflectors had been picked up by the ROLS sensor. The file was saved, and the test was repeated in reverse or the return direction—from east to west. The e-truck tests were conducted like those using the UGV, only with a researcher physically driving the e-truck. The e-truck tests were conducted at three speeds (5, 10, and 15 mph), while the UGV tests were conducted at two speeds: low speed (1.27 mph) and high speed (2.59 mph).

The NIOSH researchers could make more progress to improve the testing reliability of the ROLS passing over the center of each reflector and at top speed because during the dynamic tests, we could not ensure that the ROLS went over the center of each reflector on every trial. Therefore, the consistency of our measurement could be more reliable. In addition, we could also improve the consistency of driving at consistent speeds because of human error.

DATA ANALYSIS

Static Data Processing and Analysis

To better represent the data collected for the GTI test, NIOSH researchers subjected the static and the dynamic data to different data analysis processes. Because the static tests had less variables that could affect the results, the processing for the statistical analysis was simpler than the dynamic tests. For the static tests, the data analysis process included two steps. First, we performed a coordinate transformation of the GNSS positional data collected and the surveyed RTS ground truth test points in the same X and Y coordinates. Next, we calculated the errors in the X coordinates and Y coordinates relative to the ground truth test points collected using both sets of surveying equipment.

Dynamic Data Processing

After verifying the accuracy of the static measurement between the RTS and GNSS surveying equipment, NIOSH researchers processed the dynamic data to estimate the positional errors of the GNSS receivers relative to the ground truth points using the following four steps. First, because the positional data recorded from the GNSS and the signal from the ROLS were on the same timestamp, we wrote an algorithm to select the 10 time-events. These events were characterized as when the ROLS went over a reflector. Second, using these times, we selected the longitude and latitude associated with each time. Next, we performed a coordinate transformation to convert the latitude and longitude data from the GNSS receiver into the same local coordinate system (X and Y) as the ground truth test points. We then calculated the errors in both the X and Y directions for each of the 10 reflectors for each trial. Lastly, the calculated errors were submitted for statistical analysis. Note that in Figure 3, there were 10 additional standalone points measured by the GNSS equipment that were used to assess the dynamic test results.

Statistical Method for Dynamic Data

The objective of this statistical analysis was to create a statistical model that could yield Euclidean error estimates and 95% confidence intervals in instrument measurements for the dynamic tests conducted using a commercially available statistical tool. The main variables in this analysis were the vehicles—e-Truck and UGV. NIOSH researchers performed this analysis using all possible combinations and levels of the fixed effects. The fixed effects, for example, were GNSS status such as RTK or SBAS, the different speeds of the e-truck or UGV, and direction of travel. We summarized the results of the dynamic tests conducted with RTK and then SBAS for each day. Also, we divided the statistical analysis in terms of days, GNSS status for that day, and each speed and direction of travel of the vehicles. We computed the Euclidian error for both vehicles by squaring the X and Y errors, summing them, and taking the square root of that sum. We used these errors as the response variable in our model. A repeated measures mixed model was created separately for both vehicles. In the models, we ran the analysis separately for each date, and both test numbers and the dates were random effects. In the model with data from all dates combined, an autoregressive correlation matrix was used to model the correlation between the repeated measures at the 10 reflectors. The autoregressive correlation assumes pairs of measurements closer together in time will be more highly correlated than pairs of measurements farther apart in time. For this analysis, the P-values were less than 0.05 and therefore considered to be statistically significant. The outcomes for the static and dynamic data analyses are discussed in the Results section below.

RESULTS

Static Test Results

Figure 3 shows a comparison of the coordinates measured by the two different systems for the 20 points on the 10 reflectors. It can be found seen in Figure 3 that the coordinates measured by the GNSS system agree well with the coordinates measured by the RTS system. Figure 4 shows the difference (i.e., the error shown in Figure 4) between the coordinates measured by the two different systems for all 10 reflectors. The average error in the X coordinates was less than 0.5 cm, and the average error in the Y coordinates was less than 0.8 cm. The median errors in the X and Y coordinates were less than 0.5 cm and less than 0.8 cm, respectively.

Dynamic Test Results

The results showed the estimated distance error in positional accuracy of the GNSS receivers for all variables such as day of testing, GNSS status, direction of travel (forward or return/reverse), and vehicles, independently. As shown in Table 1, NIOSH researchers estimated a distance error of 1.34 m (4.40 ft) with a 95% confidence interval (0.99 m, 1.69 m) (3.2 4 ft, 5.54 ft) using RTK and 1.50 m (4.92 ft) with a 95% confidence interval (1.15 m, 1.85 m) (3.77 ft, 6.07 ft) using SBAS. These error estimates were independent of vehicles, the different date of testing, the directions of travel, and the different speed. Independent of the date of testing, GNSS status, speed, and vehicles we estimated distance errors of 1.09 m (3.57 ft) in the forward direction and 1.75 m (5.74 ft) in the reverse or return direction. Independent of GNSS status and date of testing direction of travel, our model yielded results for all the speed categories of both vehicles. For the UGV, we estimated a distance error of 1.38 m (4.52 ft) at 1.27 mph or low speed (L) and a distance error of 1.41 m (4.63 ft) at 2.59 mph or high speed (H). For the e-truck, we estimated distance errors of 1.34 m (4.5 ft) for 5-mph tests, 1.43 m (4.69 ft) for the 10-mph tests, and 1.55 (5.09 ft) for 15-mph tests.

DISCUSSION

Independent of the date of testing, GNSS status only influenced the distance errors for tests conducted using a UGV and not the results for the e-truck. For the UGV, the distance errors in positional accuracy were less for tests that were run with RTK corrections than those with SBAS—for all variables independently and in combination (see Table 2). Independent of speed, NIOSH researchers measured distance errors of 1.25 m (4.10 ft) moving forward and 1.11 m (3.64 ft) moving in reverse. With SBAS, we measured distance errors of 1.71 m (5.61 ft) moving forward and 1.49 m (4.89 ft) moving in reverse. Independent of direction of travel, at high speed (H), we measured distance errors of 1.15 m (3.77 ft) using RTK and 1.66 m (5.45 ft)

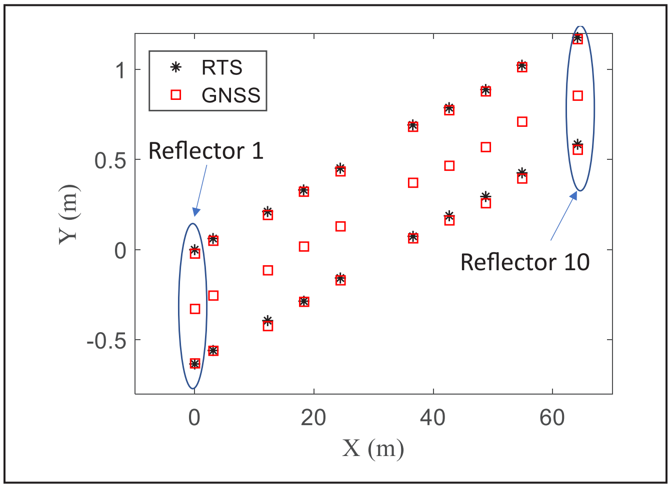

Figure 3. A comparison of the measured coordinates for the ten reflectors mounted on the ground using two systems: the RTS (serving as the ground truth) and the GNSS receivers

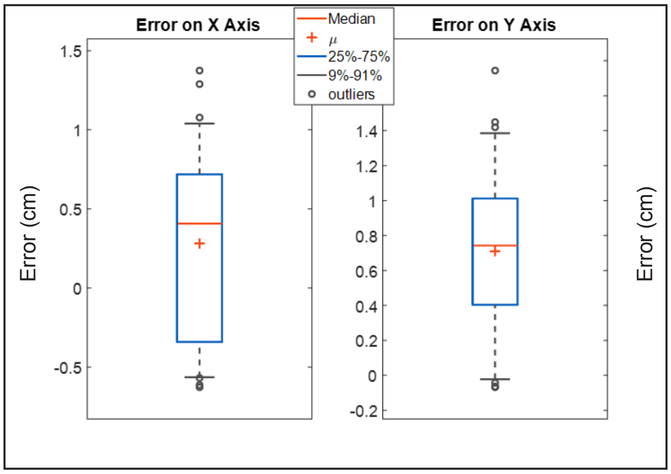

Figure 4. Static results comparing the GNSS receivers to our RTS-based surveying equipment

Table 1. Aggregate results for both vehicle accounts for GNSS status, direction of travel, and speed

GNSS Status	F or R	Speed	Estimate (m)	Lower 95 CI (m)	Upper 95 CI (m)
RTK			1.34	0.99	1.69
SBAS			1.50	1.15	1.85
	F		1.09	0.74	1.44
	R		1.75	1.4	2.1
		15 mph	1.55	1.04	2.05
		10 mph	1.43	0.92	1.93
		5 mph	1.34	0.83	1.84
		H (2.59 mph)	1.41	0.97	1.85
		L (1.27 mph)	1.38	0.94	1.82

Table 2. 95% confidence interval (CI) test results for UGV

GNSS Status	Direction	Speed	Estimate (m)	Lower 95 CI (m)	Upper 95 CI (m)
RTK			1.18	0.65	1.72
SBAS			1.60	1.06	2.14
RTK	F		1.25	0.71	1.78
RTK	R		1.11	0.58	1.65
SBAS	F		1.71	1.17	2.25
SBAS	R		1.49	0.95	2.03
RTK		2.59 mph (H)	1.15	0.61	1.68
RTK		1.27 mph (L)	1.22	0.68	1.75
SBAS		2.59 mph (H)	1.66	1.13	2.20
SBAS		1.27 mph (L)	1.54	1.00	2.07
RTK	F	2.59 mph (H)	1.23	0.69	1.77
RTK	F	1.27 mph (L)	1.27	0.73	1.80
RTK	R	2.59 mph (H)	1.06	0.53	1.60
RTK	R	1.27 mph (L)	1.16	0.63	1.70
SBAS	F	2.59 mph (H)	1.81	1.28	2.35
SBAS	F	1.27 mph (L)	1.60	1.06	2.14
SBAS	R	2.59 mph (H)	1.51	0.98	2.05
SBAS	R	1.27 mph (L)	1.47	0.93	2.01

using SBAS. At low speed (L), we measured distance errors of 1.22 m (4.00 ft) using RTK and 1.54 m (5.05 ft) using SBAS. Combining speed and direction of travel, for moving forward at high speed (H) we measured distance errors of 1.23 m (4.04 ft) with RTK and 1.81 m (5.94 ft) using SBAS, and at low speed, we measured distance errors of 1.27 m (4.17 ft) with RTK and 1.6 m (5.25 ft) using SBAS. Moving in reverse at high speed (H), we measured distance errors of 1.06 m (3.48 ft) with RTK and 1.51 m (4.95 ft) using SBAS, and distance errors of 1.16 m (3.81 ft) with RTK and 1.47 m (4.82 ft) using SBAS at low speed (L). For the e-truck, GNSS status had virtually no effect on the measured distance error in positional accuracy. As shown in Table 3, independent of speed and direction of travel, we estimated a Euclidian error of 1.45 m (4.78 ft) using RTK and 1.43 m (4.69 ft) using SBAS.

The speed of the vehicles affected the distance errors independent of the date of testing and other variables. For the UGV, as the speed increased, the estimated errors generally increased independent of and in combination with other variables (see Table 2). It was a similar case for the e-truck, independent of and in combination with other variables. Except for the return tests with RTK combination (see Table 3), NIOSH researchers measured distance errors that ranged from 0.66–1.92 m (2.17–6.30 ft) for the 5-mph tests, 0.81–2.03 m (2.66–6.66 ft) for the 10-mph tests, and 0.97–2.14 m (3.18–7.02 ft) for the 15-mph tests.

For either vehicle, the direction of travel had zero effect on the results. Independent of testing dates, GNSS status, and speed, the results showed a higher estimate in distance errors in positional accuracies for the tests going forward than the tests moving in reverse travel for the UGV or moving in return travel for the e-truck (see Table 1). It also seemed to be the case for the UGV test results in combination with other variables (see Table 2). However, this seems to be misleading. The results are different upon closer

Table 3. 95% confidence interval (CI) test results for e-truck

GNSS Status	F or R	Speed	Estimate (m)	Lower 95 CI (m)	Upper 95 CI (m)
RTK			1.45	1.18	1.73
SBAS			1.43	1.15	1.70
RTK	F		0.83	0.55	1.10
RTK	R		2.08	1.80	2.35
SBAS	F		0.83	0.55	1.10
SBAS	R		2.03	1.75	2.30
RTK		10 mph	1.43	1.15	1.71
RTK		15 mph	1.54	1.26	1.81
RTK		5 mph	1.39	1.12	1.67
SBAS		10 mph	1.43	1.16	1.71
SBAS		15 mph	1.56	1.29	1.84
SBAS		5 mph	1.29	1.01	1.56
RTK	F	10 mph	0.81	0.53	1.09
RTK	F	15 mph	0.97	0.69	1.25
RTK	F	5 mph	0.70	0.42	0.97
RTK	**R**	**10 mph**	**2.05**	**1.77**	**2.33**
RTK	**R**	**15 mph**	**2.1**	**1.82**	**2.38**
RTK	**R**	**5 mph**	**2.09**	**1.81**	**2.37**
SBAS	F	10 mph	0.83	0.55	1.11
SBAS	F	15 mph	0.99	0.71	1.27
SBAS	F	5 mph	0.66	0.38	0.94
SBAS	R	10 mph	2.03	1.75	2.31
SBAS	R	15 mph	2.14	1.86	2.42
SBAS	R	5 mph	1.92	1.64	2.2

inspection for the UGV and the e-truck in combination with other variables. Independent of speed, the estimated distance errors for the UGV moving forward were 1.25 m (4.10 ft) using RTK and 1.71 m (5.61 ft) using SBAS. Moving in return travel, NIOSH researchers measured a distance error of 1.11 m (3.64 ft) using RTK and 1.49 m (4.89 ft) using SBAS. Independent of speed, the estimated distance errors for the e-truck moving forward were 0.83 m (2.72 ft) using RTK or SBAS. Moving in reverse travel, we measured a distance error of 2.08 m (6.82 ft) using RTK and 2.03 m (6.66 ft) using SBAS. It seemed that these results followed the same trend as the results where all variables are combined. For the UGV, the range in distance errors were 1.23–1.81 m (4.03– 5.94 ft) moving forward and 1.06–1.51 m (3.48–4.95 ft) moving in reverse travel. For the e-truck, the distance error estimates were 0.66–0.99 m (2.17–3.25 ft) moving forward and 1.92–2.14 m (6.30–7.02 ft) moving in return travel.

CONCLUSIONS

NIOSH researchers conducted static and dynamic tests to describe the positional accuracy of GNSS receivers that we later used as GTIs to assess the detection of CXS intended for surface mining haul trucks. For static tests, we collected data from 20 points. We used RTS-based survey equipment to collect data from those same 20 points for comparison. We calculated the Euclidian errors for both the static and dynamic tests. Results of the static tests showed that positions measured by GNSS receivers match well to the positions measured by the RTS-based surveying equipment. After conducting the static tests, we conducted the dynamic tests using a combination of the variables such as GNSS status, direction of travel, and speed. Among all the variables, the dynamic test results show that only the GNSS status and speed affected the estimated errors. Note that we did not evaluate any CXS.

LIMITATIONS

NIOSH researchers evaluated the accuracy of three GNSS receivers under a specific set of conditions. We selected the receiver mounted on the e-truck and the one for the static tests based on the same brand and model as the ones integrated in the UGV that we used to collect CXS detection performance data. The performance of the receivers tested may not be representative of the performance of all GNSS receivers. In addition, we conducted these tests at a single location under relatively consistent conditions in which satellite visibility remained high which is not a typical environment of mine sites with steep highwalls where the number of available satellites might be fewer than number of satellites that we had during our experiment. The performance under these conditions may not be fully representative of the range of performance that may occur under less ideal conditions.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

ACKNOWLEDGMENTS

The authors wish to thank former NIOSH employee John Homer for his support in installing instrumentation, setting up the data acquisition system, data acquisition, and executing the experiment.

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Testing, Design, Commissioning and Operation— A Disc Filter Life Experience on a Backfill Plant

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ABSTRACT

The paper reports on both, the design and decision making for the filters in a backfill plant in Europe as well as more then 10 years of operation and maintenance experience of the vacuum disc filters installed. It begins with the first step, the filter sizing based on a sample provided by the customer, followed by the commissioning of the filter units and reports on the development of the filter performance during the following 10 years of operation.

Based on the physical properties of the sample and the process targets of the client for the backfill plant, the paper shows the logic steps taken in the laboratory to ensure the target moisture, determine the required filtration area and filter size as well as the selection of the ancillary units and the formulation of the performance guarantee.

The paper discusses some issues with filter operation during the commissioning phase and the actions taken. Finally, the paper concludes by highlighting the gradual change over the more than 10 years of operation and how this change affected filter performance and operating costs.

INTRODUCTION

The treatment of tailings has become an increasing attention in the discussion of proper mining operation as well as the decision-making for new operations. Safety hassards, environmental risks and a significant consumption of fresh water are only the main topics to be considered. However, most, if not all, of these issues are solved, if mine backfill is used as the solution for tailing treatment and deposit. Although the main driver for this still expensive solution is the extra portion of valuable ore to be mined with this technology and not the safety and well being of the local communities and the environment. Generally, the earnings with the extra ore are far more than the extra cost for the backfill. In any way it requires a proper sizing of the backfill plant and its major components as well as the flexibility of these components as the mine operation is expected to last for decades.

Figure 1 is showing the general design of a backfill plant.

At the ground level of the building is the positive displacement pump which is feeding the pipeline that goes to the underground. Above this pump is the mixer which mixes the filtered solids with cement. The amount of cement required depends on the mineralogy and the particle size of the tailing solids. In most cases some water is added as well to get the right viscosity for pumping. And on top is the filter which is fed from the tailing thickener with feed solids typically in the range of 50–65 w/w%. The duty of the filter is to increase the solids content of the tailings to a good level for mixing in cement and pumping this slurry to the underground.