Identification and location of steel coils using the GNSS system with RTK correction

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Abstract.

The precision, repeatability, and accuracy of the system were measured in order to verify if it is possible to identify a coil stored in the yard through its geospatial position. To obtain the desired result, it was necessary to develop a hardware that allows tracking the forklift using real-time kinematic correction, also known as GNSS-RTK. The proposed system had a base station communicating directly with one or more rovers, sending data through the RTCM protocol to perform correction calculations based on the received information. After the development of the hardware and validation tests in the laboratory, the hardware was installed on forklifts with load capacity of 40 tons that operate in a real coil production and storage environment. The average weight of the coils operated by forklift machinery was 20 tons. This manuscript communicate the real results of the identification and location of steel coils procedures by using GNSS-RTK. The tests were carried out in a large-company producer of steel coils. Our data analysis and results confirm the efficiency of the proposed system in an open-sky yards environment.

Keywords: GNSS, RTK, GNSS-RTK, Precision, Identification

1 Introduction

The metallurgy sector is of utmost importance to the market worldwide. In 2019 it produced more than 1.8 trillion tons of crude steel, where Brazil was in the 9th position of world producers and first in Latin America (Brasil [1]). To ensure the evolution of processes and improve the quality of products, new methods of control, production and storage become a necessity for this sector. Numbers in this sector are impressing and data point out that a given company produced more than one billion tons of steel in 2016 (ARCELORMITTAL [2]). Based on this trend, it is estimated that the amount of steel coils produced by Arcelormittal Tubarão (AMT) in 2016 was around 160 thousand steel coils, which represents almost 18 steel coils of 25 tons per hour.

The logistical demand for accommodation, storage, movement and transport of these items is intense, which requires strict logistical control over the time that these coils are accommodated in *"pátios de Bobinas Quentes"* (BQ) (hot coil yard from Portuguese). The BQ7, which is an open sky hot coil yard, where the coils do not have fixed positions on the floor, only demarcated sub-areas, where they are grouped. To carry out the movement of these items, ram pin-type forklifts are needed, with a load capacity of around 40 tons. The operation carried out in this yard is carried out by four forklifts that can work simultaneously in several handling operations, whether carried out simultaneously with different coils, or sequentially on the same coil with different forklifts. The time from the coil's arrival at the yard to its departure can take months, a coil may undergo several handling operations throughout its existence in the yard. The last movement of the coil in the yard consists of taking the coil from its resting place with a forklift and moving it to the transport truck or train wagon for delivery to the customer. What at first appears to be a simple operation, although the process of searching for the specific coil is laborious and may require moving intermediate coils with the forklift to make way for the desired coil.

In order to identify the exact location of each coil in the yard, an intelligent system was proposed to indirectly track the coils by means of global precision georeferencing. The system worked with available database able to cross operating information about the site where the coil was taken to its placement, analysis of historical data, forklift movement, time and method of forklifts operation, in addition to precision analysis of georeferencing and other information. Paper such as Zhang et al. [3] and Odolinski and Teunissen [4] demonstrate and compare the accuracy of Global Navigation Satellite System (GNSS) and Global Navigation Satellite System - Real-Time

Kinematic (GNSS-RTK) equipment, and the paper [5] demonstrates the use of this technology applied in other areas.

2 Development

For the development of Proof Of Concept (POC), we adopted an approach to test the efficiency and accuracy of the GNSS-RTK. The results were verified and then compared with the equipment operating in a covered area versus the operation in open sky. After data analysis and reports, we confirmed our hypothesis of the design phase of the study. Our proposed monitoring system with position correction features built into the forklifts, makes it possible to obtain accuracies in the hundredths of meters.

A forklift hydraulic line pressure monitoring system was also installed within the equipment. The forklift equipment called Rover, has the ability to capture information related to: 1- date and time; 2- communication with the base; 3- base operational status; 3- latitude and longitude and relative precision; 4- distances relative to base and rover in meters on the North and South axis; 5- East West axis; 6- the height of the rover; 7- the precision linked to these measurements; 8- hydraulic line pressure; 9- orientation in degrees relative to north using an electronic compass; 10- using the compass of the system GNSS; 11- the speed of rover. All these measurements were stored in embedded MultiMediaCard (eMMC) memory every second (1Hz) and collected later to be post-processed and generate information and reports regarding the system.

The BASE station (module with GNSS-RTK signal correction station and energy management Uninterruptible Power Supply (UPS)) was installed in a high place to expand the coverage area, and with the least possible interference by shields, capturing the signals from the satellites and the other facing towards the yard, aiming to communicate with the rover. Figure 1 shows the proposed function block diagram for the POC and the location of installation. The UPS is necessary because, when energized, the base position identification system is composed of an algorithm that needs 24 hours of observation of the satellite constellations, and only after this period, and the convergence of precision below to 5m the base station starts sending information packets to the rover correct its positions, increasing precision using the Real-Time Kinematic (RTK) method.

Figure 1. Block diagram of the base station used in the POC and installation, and RTK correction system.

The ROVER module installed on the forklift is responsible for receiving and identifying its geospatial position on the globe, along with the information sent by the Base module. Rover performs the real-time processing of both information, reaching centimeter precision to achieve the objective of identifying the coil in the yard by its position described in latitude and longitude. To make this possible, it is necessary to inform the Rover's position (latitude and longitude) with up to the seventh decimal place of both coordinates. The developed device for the POC, without internet connection, or any other device. Some modules have been integrated for this purpose in order to validate the chosen hardware and provide remote diagnostics, communication and configuration.

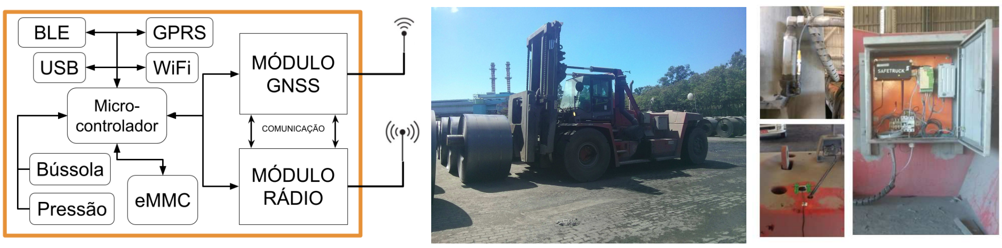

Figure 2. Block diagram of the Rover used in the POC, and forklift rover module installation.

The Rover and Base module work together as shown in the image on the right of Figure 1, the Base has a communication radio that sends the information in multicast to all Rovers of the Radio Technical Comittee for Maritime Service (RTCM) protocol. The Rover receives the information and the system performs the kinematic correction in real time increasing the accuracy of the georeferenced position of the GNSS system. Unlike the Base, the Rover module does not have the UPS in its block diagram, since its initialization takes only a few seconds.

3 Field testing

The installation of the equipment on the forklift can be seen in the right image onFigure 2. In order to facilitate the handling of the stored records, files are segmented into groups of 30 minutes to ease the transfer of data from the rover module to the computer, therefore if a file is corrupted, there is no loss of large volume of data. When a new file is generated, a control message is sent to a telephone number pre-configured in the firmware, thus it is possible to register crashes during the operation of the equipment.

With the beginning of the field tests using the forklift, from time to time an assisted operation was performed in order to record some specific positions to ensure the location and repeatability of the movements together with the forklift operator as seen in Figure 3. These operations were used for the elaboration of repeatability analysis, daily average precision, standard deviation, operating time, etc. These points in question are called Garage Control Point (CP-GR), Transfer Area Control Point (CP-AT) and Walking Beam Control Point (CP-WB) respectively.

Figure 3. Test with assisted operation in controlled positions.

The transfer area position is located inside the shed and has a metal roof, this covered point was chosen to evaluate the performance of the system in indoor operation, while the other two points were outdoors. These three points were evaluated to study the repeatability of the system, however the equipment was constantly monitored and evaluated according to other parameters such as average and median precision of the equipment in internal and external areas, communication with the base and its effects.

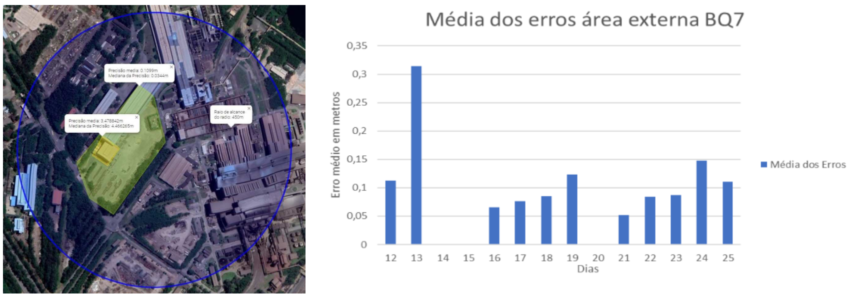

Figure 4. Base coverage area and accuracy per day outdoors.

The proposed coverage area for the GNSS-RTK system is shown on the left of the Figure 4. The obtained range of 450 m was sufficient to cover the entire length of the BQ7 for system evaluation. During this period of operation, encouraging values were found, the results in the area of the BQ7 had a median in open sky of 0.03 m and 4.47 m in a covered area. The data were obtained after processing the data stored in the Rover using computational tools, and analyzing historical data and segmented the areas of interest. Assisted operations of the forklift moving the coil is observed and the data obtained from this operation is analyzed Figure 5.

Compiling and analyzing the data during the entire period of the POC, we noticed that the GNSS system does not have enough precision to operate within covered areas with a metallic roof, with results superior to those desired by the AMT (30 cm). On the other hand, when observing the data in open sky for the BQ7, the median error was approximately 10 cm, one third of the limit desired by the contracting party. The mean and median value in the indoor area were respectively 2.0045 m and 1.7839 m, while the outdoor values were 0.2140 m of mean and 0.1074 for median.

Another analysis performed with the data obtained was the repeatability of assisted operations with known control points as shown in Figure 3 and called respectively CP-GR, CP-AT and CP-WB. The point CP-AT was allocated under the coverage and was considered an internal area, having values with low repeatability as expected. The precision results demonstrate that system is only suitable for operation in open areas, due to its better accuracy,

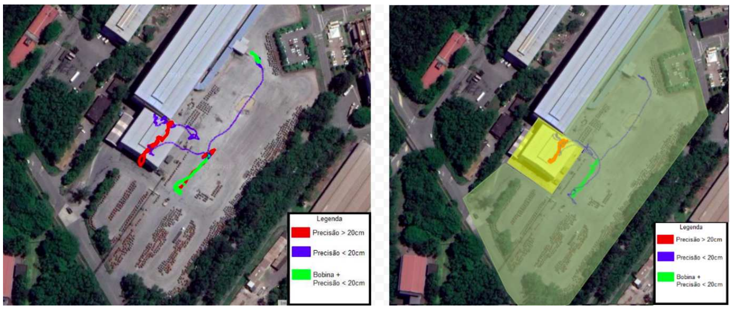

Figure 5. Tracking while moving between control points and continuous precision analysis.

acceptable for the application of coil identification by georeferencing. The operations tested in the open sky area CP-GR and CP-WB, demonstrate reliable repeatability with accuracies below 20cm. These points were plotted in Figure 6 using satellite images to visualization. Each circle represents the position measured by the system in each assisted operation and the radius of each circle is proportional to the precision value found. We verified that all measured points were superimposed. In the image on the left of Figure 6, the accuracy is found between 5 to 20 cm, due to a point known by the machine operator, this movement is done in a much more agile way than the operation described in the image on the right of Figure 6. This fact contributed to the GNSS-RTK system having more time to converge and correct the positioning stored in the equipment's memory to obtain precision of 4 to 8 cm.

Figure 6. Repeatability of assisted operations

4 Data processing

When performing the processing to present results, computational resources were used to filter, group, calculate, generate graphics and even create HTML files automatically in order to present the maps generated from the data collected by the equipment. Functions and routines were programmed to delimit the data of interest, which can be divided by period, area, points of acquisition and deposition of the coils, etc. With the segmented data, we performs processing to extract the relevant information for the performance analysis, and then save these data in html and/or csv files to enable viewing by a browser or compatible software. The information is saved in this way to facilitate the ordering of all the lines in the file, remembering that this table can be composed of several 30-minute log files.

Functions were also developed to create HTML pages to present data according to Figure 5. This type of visualization is of great value and easy to understand, since it consists of a map with a satellite view of the region of interest, being ideal to present to the target audience, both for the approval of the results, as for the understanding of the system behavior. The tracking data is generated from a set of information delimited by the date and time of the desired start and end of the operation, as well as the tracking referring to an assisted operation in the image on the left of Figure 5 , changing these input parameters, it is possible to generate a new map containing the tracking, automatically, as shown in the image to the right of Figure 5, these data refer to a second assisted operation, performed after a few days from the first one.

Other results generated from the information collected by the hardware, is regarding the crossing of weather information, based on the results obtained during a rainy day and a sunny day, the mean value for these condition ware 0.065881m and 0.08673m respectively, and for the day and night, the results were 0.1112m and 0.0827m. Using just the data of the outdoor area.

In addition to the error dispersion data, assisted operation tracking, repeatability at control points and errors inherent to the internal and external area, an algorithm was also developed to present only the places where the forklift picked up a coil and where it dropped it, these information is important to visually verify if there is an intersection between the places where the forklift carries out the beginning and end of moving each coil. In Figure 7 it is possible to visualize over a whole day of operation. The markings represented in green color refer to the places where the forklift picked up a coil, the markings in blue represent the places where the coil was left. This information will be the starting point for the recognition and tracking of the coil regarding its geospatial location.

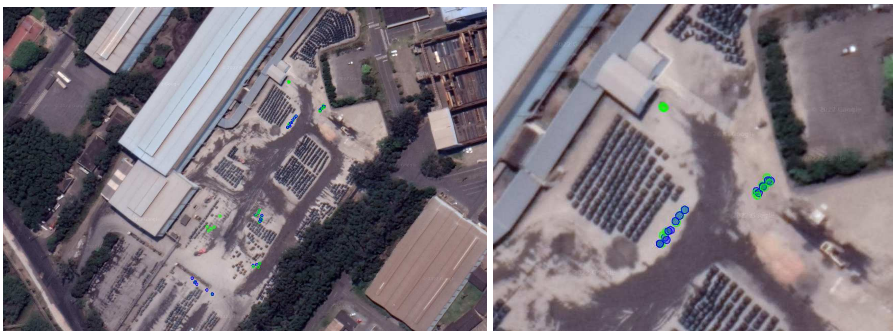

Figure 7. Points where the movement of a coil starts or ends.

A point of attention for this analysis is the WB, as it is the place where the coil is born in the BQ7 yard, this being the first movement and record of all the coils that are in the yard. Next to the WB it is possible to verify the concentration of these very grouped points, looking like a single green circle when the forklift picks up the coil. It is also possible to verify that there are blue and green circles in almost the same position, with a very small difference in values referring to their latitude and longitude.

5 Conclusions

This paper presents the development of a tracking system for the location of steel coils in a storage yard. The system is based on continuous and accurate monitoring of the position of the forklifts (tracking) during handling operations, starting with the acquisition of the coil and ending with its release. The tracking of the forklifts is done through the GNSS-RTK system and stored in memory. Through the sequential analysis of the handling operations, it is possible to estimate the location of any coil during its period of stay in the yard, thus eliminating the need for a person to walk around the yard in search of any coils. In the current phase of development, the POC of the proposed system was completed. It developed and tested all the hardware and software infrastructure necessary for the system to operate. The ROVER module, installed on forklifts to monitor and record movements; and the BASE station for GNSS-RTK correction needed to achieve location with high accuracy. The developed infrastructure was tested for several months and the results obtained demonstrated that the system has sufficient robustness, availability and precision to successfully achieve the proposed objective.

Authorship statement. All paper was designed and performed and the experimented by Mayer V.P., analyzed e compiled the data and results. Himself wrote the manuscript of the paper.

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