Global Navigation Satellite System(GNSS) based Machine Guidance System for Improving Surface Mining Efficiency

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Key words: Digital Terrain Model (DTM), Machine Guidance System, GNSS/GPS, Mine surveying

SUMMARY

The operational efficiency of surface drill rigs is critical to overall productivity in mining operations. However, this efficiency is increasingly compromised by a growing shortage of skilled operators and surveyors. To address this challenge, this paper presents the development of a high-precision machine guidance system for mining drill rigs. The system integrates a Global Navigation Satellite System (GNSS) with an Inertial Measurement Unit (IMU) and an Encoder sensor, utilizing a Digital Terrain Model (DTM) for spatial reference. It provides real-time positioning of the drill bit relative to design specifications, presenting this information to the operator through an intuitive, color-rendered visualization interface for trajectory tracking and quality assessment. Furthermore, the system enables remote monitoring via wireless connectivity, allowing simultaneous oversight from multiple locations. This capability supports real-time data transmission, informed decision-making, and swift response to operational issues, thereby significantly reducing downtime. The implementation of this system demonstrates a substantial improvement in drilling accuracy, operational safety, and overall productivity.

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1. INTRODUCTION

Surface drilling is a fundamental yet costly and precision-critical operation in mining. Traditional methods depend heavily on manual surveying for staking, operator skill for alignment, and physical monitoring, leading to inconsistencies, safety risks, and high labor overhead. The advent of Machine Guidance (MG) and remote monitoring offers a transformative solution. By fusing Global Navigation Satellite Systems (GNSS) with Inertial Measurement Units (IMU), robust communication networks, navigation algorithm, and cloud data analytics, as shown in Figure 1, these systems enable high-precision drilling. Using MG and machine control (MC) systems, the productivity was improved compared to the traditional work method[1][2].

This paper examines a comprehensive MG solution, as implemented in real-world mining scenarios. The system goes beyond basic positional guidance to offer a remote monitoring suite. All processes are monitored and managed through an industrial in-cab interface and a centralized cloud platform. The following sections detail the system's technological foundations, hardware and software components, workflow, and the resulting benefits in operational metrics, culminating in a validation through practical application.

The results represent a significant leap in both construction efficiency and accuracy.
-Real-time monitoring and recording of borehole horizontal positioning — Down-to-Earth drill accuracy: 3–5 cm
-Real-time monitoring and recording of borehole depth — Accuracy: 5–10 cm
-Real-time monitoring and recording of drill tower inclination — Dynamic accuracy: 0.3°
-Construction efficiency improved 35%

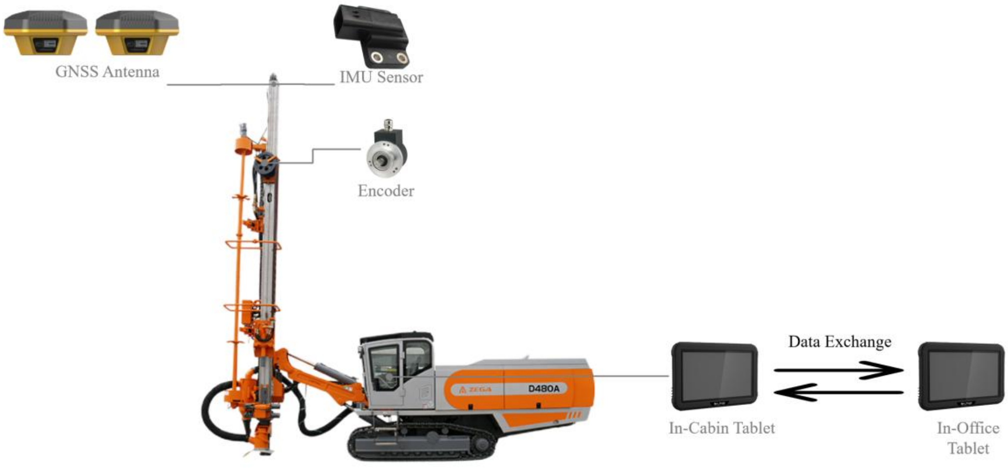

Figure 1-MG Installation Structure

2. MG-WORKFLOW

Traditional workflow involves multiple specialized roles: a designer provides precise hole coordinates to the construction company, a surveyor conducts the site layout and staking, and a machine operator follows the surveyor's guidance to complete the drilling tasks. In contrast, the Machine Guidance (MG) system streamlines this process, enabling a single operator to execute the entire construction workflow while ensuring high precision compliance, as illustrated in Figure 2.

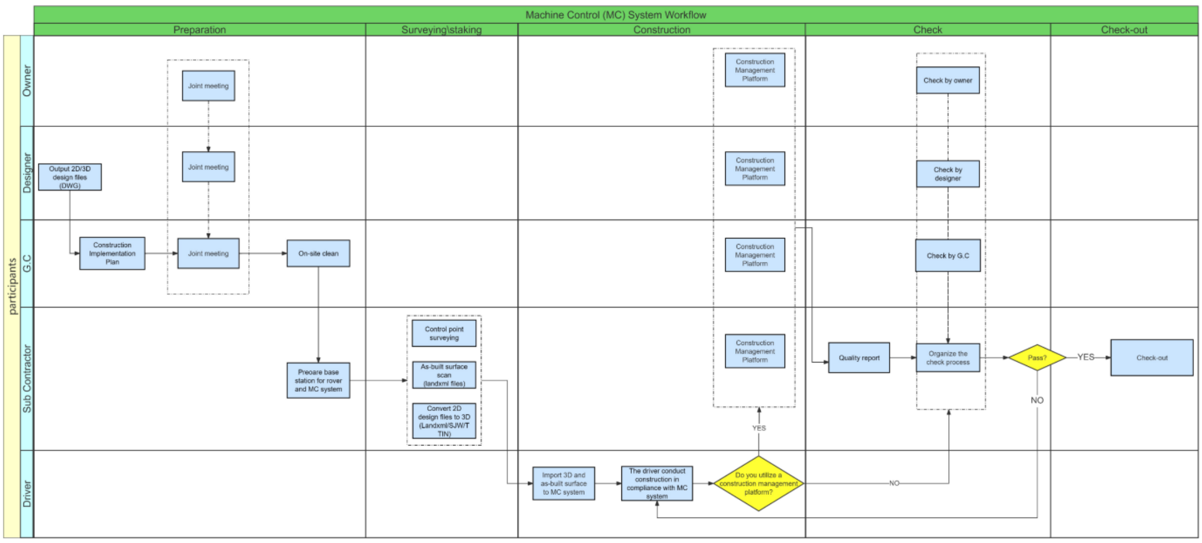

Figure 2-MG Workflow

2.1 Development of expressing work information for Down-The-Hole (DTH) Drilling Machines

By applying the angular data from the IMU to the baseline established by GNSS1 (coordinates) and GNSS2 (direction), the system calculates the relative coordinates of the drill bit location (Point G) at the bottom of the DTH drilling rig, as illustrated in Figure 3.

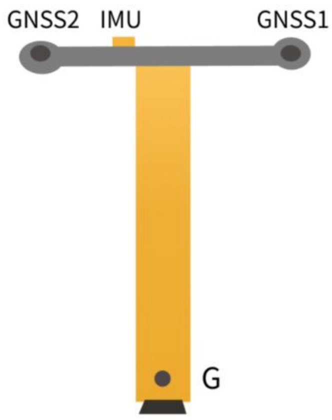

Figure 3-Installation View

The heading of the machine is derived by calculating the vector between the coordinates of the two GNSS antennas, as shown in Figure 4. This calculation provides the Machine Guidance (MG) system with the necessary directional information.

$$L_{PD}^{n} = L_{D}^{n} - L_{P}^{n}$$

$$heading = \arctan 2\left(L_{PD}^{n}\left(e\right), L_{PD}^{n}\left(n\right)\right)$$

Figure 4-Expression Work for Heading

2.2 Drilling Guidance

After import the design files into MG system, according the algorithm of guidance system, the system automatically calculates out the distance between point G and target hole. The system provides the guidance command on the screen while the driver in compliance with the instruction to arrive the target location and the horizontal accuracy achieve in 3 centimeters, as shown in Figure 5.

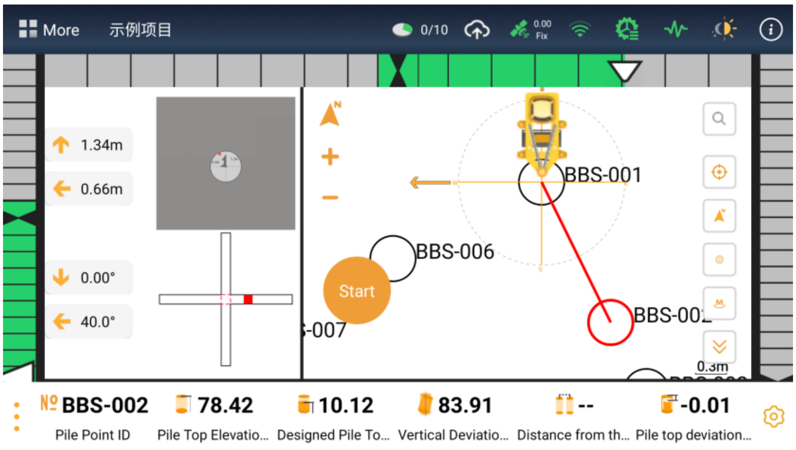

Figure 5-Guidance View

The encoder sensor measures the wire length variation on the Down-The-Hole (DTH) drilling machine. The MG system supports both automatic and manual operational modes for the drilling process.

In manual mode (Figure 6), depth recording is initiated only after the operator manually activates the start command. The system then calculates the depth by integrating the real-time GNSS-derived coordinates with the wire length change measured by the encoder.
In automatic mode, which requires a pre-loaded Digital Terrain Model (DTM), the MG system autonomously determines when to begin depth recording based on whether the drill bit reaches a predefined distance threshold relative to the DTM surface. During operation, the depth is continuously computed as the vertical difference between the real-time coordinates of the drill bit tip and the DTM surface.

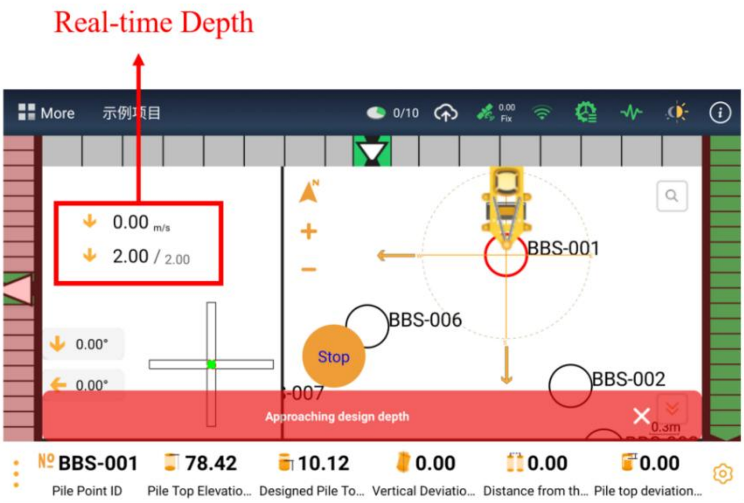

Figure 6-Real-time Depth

2.3 Remote Monitoring and Operating

The in-office tablet displays all real-time construction data process instantly, which is same view as in-cabin tablet, communication flow as shown in Figure 7.1. Driver controls the in-cabin tablet remotely by operating in-office tablet. All of commands conducted on the in-office tablet and automatically being done on the in-cabin tablet. Operator can collect all the construction quality and trajectory data sit inside office, as shown in Figure 7.2, obtaining a clearer understanding about the construction performance on job-site.

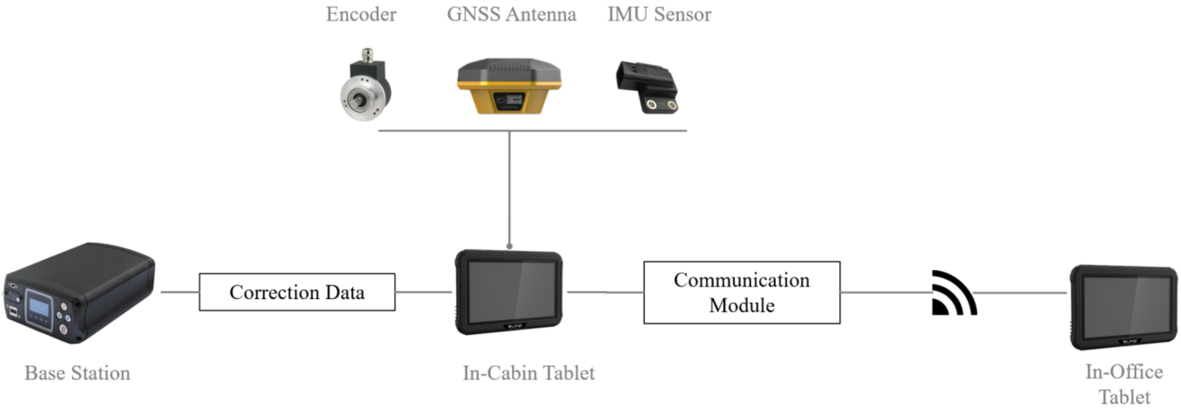

Figure 7.1-Communication Flow

Figure 7.2-Remote Monitoring

2.4 Work Quality Rendering

MG system automatically logs and categorizes operations as [Qualified/Unqualified] in real-time, the quality rendering is shown in Figure 8. Operator sets up qualification indicators before working. During construction process, driver adjust machine position and heading to achieve design requirements more precisely. At same, completed zones by other equipment are highlighted with dedicated colors (Only on Cloud Construction Management), all data are shareable between different machines.

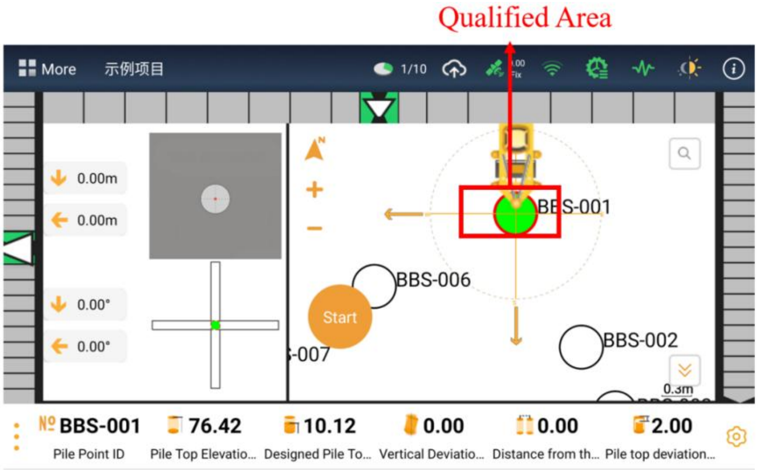

Figure 8-Work Quality Rendering

2.5 Cloud Construction Management (CCM) platform

Operational data from the in-cabin tablet is transmitted in real-time to the CCM platform (Figure 9), where it is recorded and visualized. Key parameters displayed include drilling depth, perpendicularity, current, actual hole/pile depth, and the corresponding top and bottom elevations (Figure 10).

Simultaneously, CCM platform supports to send updated design files remotely, to the in-cabin tablet. This bidirectional communication allows for on-the-fly design modifications, with the in-cabin tablet receiving all new files in real time, thereby minimizing construction downtime for DTH machines.

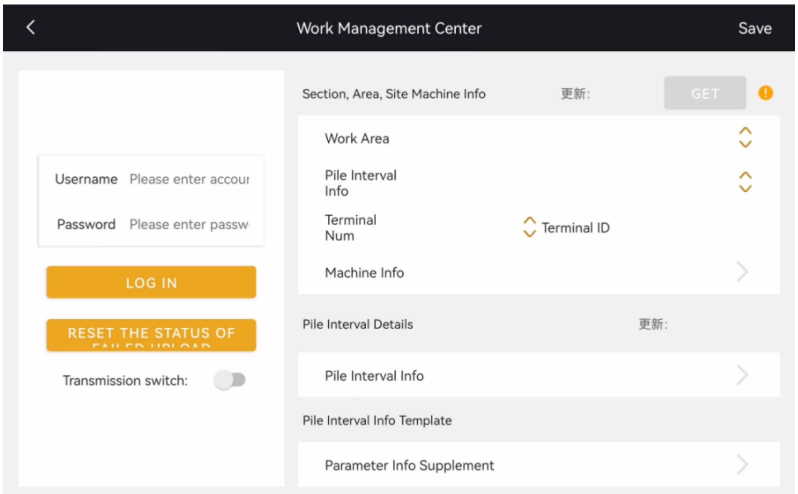

Figure 9-Uploading View

Figure10-CCM Platform Data

3. CONCLUSION

This paper presents a comprehensive GNSS-based Machine Guidance (MG) system designed to significantly enhance the efficiency and precision of surface mining operations, specifically for Down-The-Hole (DTH) drilling rigs. The system integrates GNSS, an Inertial Measurement Unit (IMU), and an encoder, utilizing a Digital Terrain Model (DTM) for spatial reference. It provides real-time, high-precision positioning of the drill bit (achieving horizontal accuracy of 3-5 cm for DTH drills) and offers intuitive visual guidance to the operator via an in-cab interface.

Key functionalities include automated drilling guidance, real-time depth monitoring (with 5-10 cm accuracy), and remote operation and monitoring through a wireless-connected tablet and a centralized Cloud Construction Management (CCM) platform. The system enables real-time data logging, quality assessment (with visual rendering of qualified/unqualified holes), and bidirectional data flow for on-the-fly design updates.

The implementation results on real drilling work site (Figure 11), MG system demonstrate a 35% improvement in construction efficiency, a 90% reduction in manual surveying work, and enhanced drilling accuracy and safety. By streamlining the workflow from multiple specialized roles to a single operator-led process, this MG system represents a transformative solution for modern, data-driven mining operations. To achieve the objective of full autonomous driving, the next step entails mastering comprehensive MG and dynamic route planning.

Figure 11-Application at Job Site

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