Theory and Practice of Science and Technology
2025, VOL. 6, NO. 10, 33-36
DOI: 10.47297/taposatWSP2633-456907.20250610

Design of an Automatic Hole-Spotting System for Drilling Rigs

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ABSTRACT
To address the issues of low precision, inefficiency, and high safety risks associated with manual hole-searching in traditional drilling rigs, this study proposes an automatic hole-searching system based on GPS inertial navigation and Siemens PLC. The system integrates multi-sensor data, achieves closed-loop control via PLC, and features a human-machine interface for real-time monitoring and parameter configuration. Tests conducted in a simulated mining environment demonstrate that the system achieves a positioning accuracy of ±5 cm, reduces hole-searching time by over 60%, and effectively enhances operational safety and efficiency, indicating broad engineering application value.

KEYWORDS
Integrated navigation system; Siemens PLC; Drilling rig; Automatic hole-spotting

1 Introduction

In engineering fields such as geological exploration, mining, and building foundation piling, the drilling rig is a core piece of equipment. Its operational efficiency and accuracy directly impact project quality and cost. Hole positioning, as the primary step in drilling operations, traditionally relies on manual methods. This involves surveying personnel setting up total stations or GPS receivers to stake out the hole location, followed by the driller manually adjusting the rig's attitude and advance direction based on experience [1]. However, as engineering scenarios become more complex and precision requirements increase(geological exploration often requires hole position errors to be controlled within ±5cm), the limitations of traditional manual hole-spotting are becoming increasingly evident:Low Positioning Efficiency:Single-hole staking can take as long as 30 to 60 minutes and is significantly affected by weather and terrain [2]. Poor Accuracy Stability: Manual measurements are susceptible to instrument operation errors, terrain judgment deviations, and differences in driller experience. In complex terrain, the success rate of hitting the intended hole position is only about 70% to 80%.High Safety Risk: Surveying personnel and drillers frequently need to enter the drilling rig's working radius, increasing the risk of mechanical collision or collapse accidents.Therefore, breaking through the bottlenecks of traditional hole-spotting technology to achieve autonomous, precise, and safe automatic hole-spotting has become a critical requirement for the intelligent upgrading of drilling rigs [3].

In recent years, with the rapid development of multi-sensor fusion technology and intelligent control theory, the automation of drilling rig operations has become a research hotspot [4]. Furthermore, existing path planning algorithms are mostly designed for static environments and lack the adaptive adjustment capability required for real-time rig attitude (inclination, yaw angle) and operational constraints (minimum ground clearance, hydraulic system response delay), making them difficult to meet the dynamic hole-spotting demands of engineering sites [5]. To address the aforementioned issues, this paper proposes a design scheme for a multi-source perception and cooperative control automatic hole-spotting system for drilling rigs. The system is centered on the core objectives of high-precision positioning and real-time precise control.It determines the optimal hole-spotting path based on multiple automatic hole-spotting tests, balancing global efficiency with local obstacle avoidance, and utilizes servo execution mechanisms to achieve millimeter-level attitude correction. Concurrently, a Human-Machine Interface (HMI) is developed to support monitoring of operational status and anomaly alarms.Experimental verification demonstrates that this system can improve hole position accuracy to ±5cm (static) and ±10cm (dynamic) in complex terrain, increase hole-spotting efficiency by over 60% compared to manual operation, and effectively mitigate the risk of personnel entering hazardous areas. It provides key technical support for the intelligent operation of drilling rigs and holds significant engineering application value for promoting the efficiency and safety of geological exploration, mining, and infrastructure projects.

2 Scheme Design

The system adopts the classic Sense-Decide-Act control architecture and is further subdivided into the following three layers, ensuring system modularity, ease of maintenance, and scalability.Sensing Layer (Data Acquisition and Fusion): As the eyes and ears of the system, this layer is responsible for comprehensive environment and self-state perception.Global Positioning: The GNSS/INS integrated navigation system is adopted as the core absolute positioning unit, providing the drilling rig's geodetic coordinates (latitude, longitude, altitude) and real-time attitude (roll, pitch, heading). Local Perception and Visual Assistance:High-definition, wide-angle cameras are installed on the front and rear of the drilling rig body, providing a 360°panoramic view. This is not only used to assist remote operation but can be expanded in the future for vision-based secondary borehole position verification or obstacle recognition.Vehicle Body Attitude Monitoring:High-precision inclination sensors are installed at key positions on the drill rig's main beam and chassis to monitor the verticality of the drill mast and the stability of the vehicle body in real time, which is crucial for achieving high-precision vertical drilling.Decision Layer (Brain and Interaction): As the system's brain, this layer is responsible for data processing, path planning, and command generation. Upper Computer (Industrial PC): Runs the core control algorithms and the Human-Machine Interface (HMI).Data Fusion: Receives and fuses position/attitude data from the GNSS/INS, and data from the inclination sensors.Path Planning:Automatically calculates the optimal path for the drill rig's movement and drill arm adjustment based on the preset borehole coordinates.Visualization (HMI): Displays the drill rig's real-time position, target borehole position, vehicle body attitude, sensor status, system alarms, and provides operation interfaces such as one-button hole search.Execution Layer (Precise Control): As the system's hands and feet, this layer is responsible for precisely executing motion commands. Main Controller: Adopts the high-reliability Siemens S7-1500 series PLC as the lower computer, which receives motion commands sent by the upper computer. Actuators: The PLC controls the drill rig's hydraulic servo valve group, motors, etc., through the control box, driving movements such as track advancement, drill arm lifting/lowering, and extension/retraction, ultimately completing the alignment of the drill bit.Working Process: The operator imports the borehole coordinates on the upper computer HMI to The GNSS/INS guides the drill rig to move to the general area of the borehole position to The system combines inclination sensors and visual assistance, using the PLC to precisely control the hydraulic system to fine-tune the drill arm attitude, ensuring the drill bit center accurately coincides with the target borehole center to The drilling command is issued.The scheme design is shown in Figure 1.

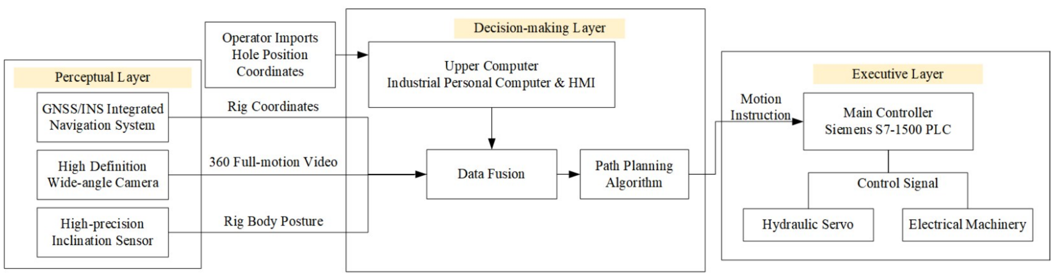

Figure 1 Block Diagram of Scheme Design

3 Systematized Design

3.1 Hardware System Design

Hardware selection is governed by the primary principle of ensuring stability, precision, and anti-interference capability under harsh working conditions.Positioning and Sensing Units:GNSS/INS Integrated Navigation System: A GNSS receiver supporting RTK (Real-Time Kinematic) technology is selected, deeply coupled with an IMU (Inertial Measurement Unit) to ensure continuous, reliable high-precision positioning and orientation even during momentary satellite signal loss.The integrated navigation system is shown in Figure 2.

Inclination Sensors: Industrial-grade dual-axis digital inclination sensors are selected, with a measurement range of ±90°and an accuracy of ±0.1°. They are installed on the rigid structure of the drilling rig to avoid vibration interference. Cameras: Ultra-low illumination industrial cameras with IP67 protection rating and wide dynamic range support are

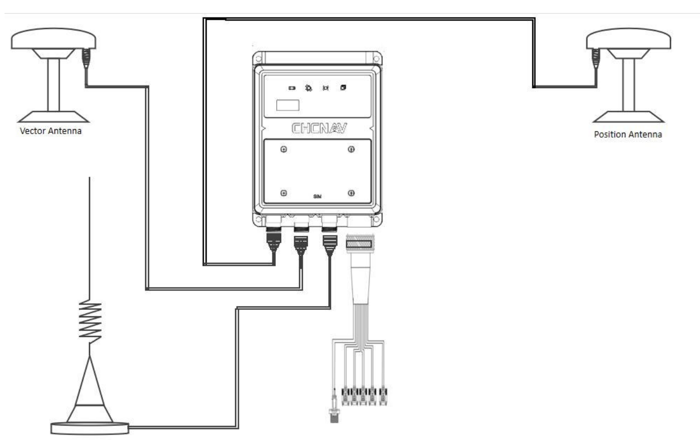

Figure 2 GNSS/INS integrated navigation system

chosen to ensure clear images day and night. Control and Execution Units: Upper Computer (Industrial PC): A fanless embedded industrial PC with multiple serial ports and network ports is selected to meet the requirements for multi-device access. PLC: The Siemens S7-1500 series is chosen for its powerful computing capability and rich communication interfaces, allowing it to efficiently process multiple digital signals and precisely control proportional valves. Communication Network: GNSS/INS, Inclination Sensors to Upper Computer: RS232 serial communication is adopted for its transparent protocol, stability, and reliability. The data received from the RS232 serial port is shown in table 1. Upper Computer to Siemens PLC: Industrial Ethernet communication is used for its high speed and real-time performance, for transmitting control commands and status data.

Table 1 data received from the RS232 serial port

byte segment	name	explanation	format	e.g
1	Heading	Yaw angle	hhh.hh	289.19
2	Pitch	Pitch angle	+/-pp.pp	-0.42
3	Roll	Roll Angle	+/-rr.rr	0.21
4	Latitude	Latitude(-90,90)	+/-ll.lllllll	28.8594969
5	Longitude	Longitude(-180,180)	+/-ll.lllllll	121.5150073

3.2 Software and Control Logic Design

Software, especially the core control algorithms, is key to realizing intelligent automatic hole-seeking. Upper Computer Software (Developed in C#): Communication Module: Parses data packets from the GNSS/INS and sensors via the serial port library; exchanges data with the Siemens PLC using the S7 protocol. Data Fusion and Positioning Solution Module: Implements the Kalman filter algorithm to fuse the absolute position from GNSS and the relative attitude from the IMU/inclination sensors, outputting the precise pose (position and orientation) of the drill bit end. The results of the automatic hole-seeking error test are shown in Table 2.

Table 2 Automatic Hole-seeking Test Error

Number	1	2	3	4	5	6	7	8	9	10	Average
Error/mm	80	82	59	80	96	72	79	75	82	70	77.5

Path Planning Module: Adopts a two-stage Coarse Positioning + Fine Alignment strategy. The GNSS/INS first guides the rig to the vicinity of the target point, followed by micrometer-level precise alignment using vision. The path planing is shown in Figure 3. Visualization Interface (HMI): Developed based on the Qt framework, it displays the drill rig and borehole locations on a 2D map background, and includes functions for parameter settings, manual/automatic mode switching, and historical data querying.

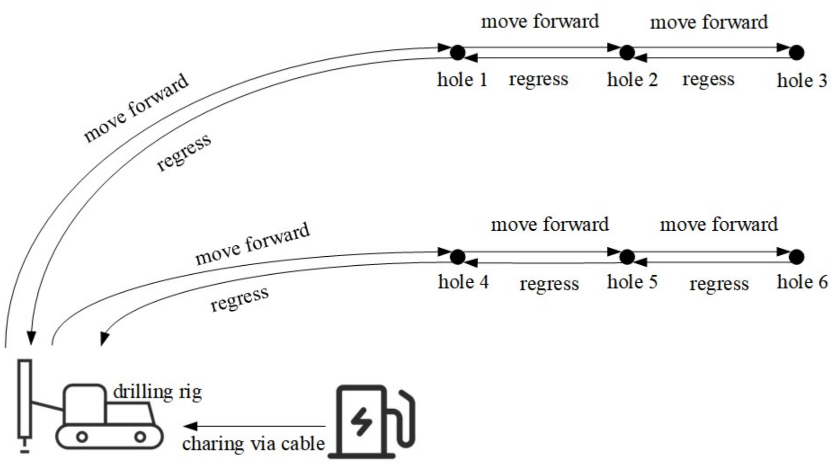

Figure 3 path planning schematic

PLC Control Program (Developed using the TIA Portal Platform): Sequential Function Chart (SFC): Designs the automated process flow: Approach to Outrigger Leveling to Drill Arm Positioning to Fine Alignment to Drilling. Closed-Loop Control Algorithm: During the fine alignment stage, the PLC receives the pose deviation ($\Delta X, \Delta Y, \Delta Z$) sent by the upper computer. A PID control algorithm is used to continuously adjust the extension/retraction amount of each hydraulic cylinder in real-time, progressively reducing the deviation until it reaches the permissible error range (±2 cm). Safety Interlocks and Fault Handling: Comprehensive safety logic is programmed, such as: prohibiting drill arm movement if outriggers are not fully grounded, prohibiting drilling if the drill mast inclination exceeds the limit, and immediately pausing and alarming upon sensor communication interruption, ensuring system safety. This systematized design scheme establishes an efficient, reliable, and safe automatic hole-seeking system through multi-source sensing (GNSS/INS+ Inclination Sensors+Vision) and the coordinated decision-making and control of the upper computer and Siemens PLC. The modular architecture not only meets current automation needs but also reserves upgrade potential for future integration of advanced technologies like AI visual recognition and digital twins.

4 Conclusion

This paper completes the overall design of an automatic hole-seeking system for a drilling rig. The research proposes a sensing solution centered on GNSS/INS integrated navigation, supplemented by inclination sensors and visual assistance, and constructs a cross-layer collaborative control architecture of Upper Computer intelligent decision-making + Siemens PLC reliable execution. This system design aims to achieve high-precision, automated borehole alignment for the drilling rig in complex environments. It is expected to significantly improve the efficiency and safety of drilling operations, providing a viable solution for the intelligent upgrade of engineering equipment. Future work will focus on system implementation, algorithm optimization, and field testing and verification.

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