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Research Article

Intelligent Drilling Depth Monitoring System for Geotechnical Site Investigation

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The drillhole depth is an indispensable parameter in the exploration process of drilling and coring engineering, but it is mainly calculated by manually counting the number of drill pipes. This highly subjective measurement method can easily lead to artificially misreporting borehole drillhole depth data, making the geological information mismatch. This study presents the overall scheme design of intelligent drillhole depth monitoring and designs real-time acquisition equipment and an installation device. The designed drillhole depth monitoring system is applied in the engineering investigation of a school laboratory expansion. In accordance with the collected data on site, the variation law of the drilling rig in the soil layer and the calculation formula of the drillhole depth are obtained. In addition, it is validated that the monitoring system can also be used well in the rock layer geology. Therefore, the proposed monitoring method is more reliable and convenient than the traditional calculation method of drillhole depth, which could serve as a reference for the intelligent drilling field management.

1. Introduction

Conducting geological surveys before project construction can help to gain more information about geological conditions. This information can better help us understand the impact of unfavorable geological conditions, which make effective treatment measures to ensure the development of the project. The drilling and coring method is an effective method used to obtain geological information, which is very extensive in engineering applications [1–4]. The key to the method is to get the accurate drillhole depth [5–7]. At present, the drillhole depth is obtained by calculating the number of drill pipes under the supervision of the operator. The drillhole depth obtained by this traditional method of counting the number of drill pipes is greatly affected by some subjective factors [8, 9]. Hence, this traditional method of calculating the number of drill pipes needs to be further optimized [10].

With the development of technology, some researchers have proposed intelligent methods to monitor drillhole depth [11–14]. Among them, the use of waveforms (e.g., sound waves, low-voltage pulses, and electromagnetic waves) to monitor the drillhole depth is a common intelligent monitoring method [15–18]. However, using waveforms to monitor the drillhole depth has some disadvantages. The waveform will reflect during the propagation, resulting in the gradual attenuation of the energy during the propagation. In this case, the information received will be inaccurate. For energy attenuation, some scholars use the secondary curve or index curve to make digital compensation, and some even calibrate the drill rod on site, but this increases the workload [19, 20]. In this case, the use of wired sensor monitoring can greatly reduce the problems encountered in the signal transmission process [21–23]. The wired sensor monitoring method is less affected by the surroundings, which can reflect the real on-site monitoring situation in real time. Some scholars applied wired sensor monitoring to logging while drilling (LWD) [24–26]. The LWD is mainly used in drilling, but few monitoring fields are related to the drillhole depth of drilling core in engineering investigation. Yue et al. [27] conducted a more in-depth study on the whole process of monitoring the drilling with wired sensors. On this basis, the authors of [28–30] proposed a system for drilling process monitoring (DPM), which can obtain the mechanical strength of the underground rock and soil. It also provides a reference for us to build a drillhole depth monitoring system with wired sensors.

This study proposes a drillhole depth monitoring system with wired sensors. The monitoring system is easy to install and suitable for hydraulic drilling rigs that are widely used in China. According to the oil pressure data and laser displacement data collected by the monitoring system, the drillhole depth calculation formula for the soil layer geology is proposed. The calculated drillhole depth is close to the drillhole depth obtained by calculating the number of drill pipes. Additionally, the monitoring system is also successfully applied in the rock layer geology.

2. Method

2.1. Traditional Manual Calculation Method. The engineering core drilling rigs commonly used in inland China are hydraulic, and the drillhole depth of onsite is generally calculated by counting the number of drill pipes. The main calculation formula is as follows:

$$L = NH, \tag{1}$$

where L is the total length of drill pipes, N is the number of drill pipes, and H is the length of a single drill pipe. This is greatly affected by the subjective factors because the drilling construction is mostly paid for by footage and different people have different standards when calculating the drillhole depth. On the other hand, in order to obtain the benefits, there is a phenomenon of falsely reporting the number of drill rods. If a special person is arranged to supervise, it will waste human resources and increase management costs. Accordingly, this study proposes a drillhole depth monitoring system to better serve the hydraulic core drilling rig commonly used in public works.

2.2. Monitoring Equipment. The hardware of the monitoring system is divided into four modules in accordance with their function, including the data acquisition module, the transmission module, the power supply module, and the terminal display module. The data acquisition module includes the laser displacement sensor and the oil pressure sensor (Figure 1). The transmission module transmits the obtained data to the display terminal in a wired manner. The power supply module provides electricity to other modules to ensure normal operation. The terminal display module can display the changes of monitoring data in real time and save them.

The software of the monitoring system includes four major functional modules, as shown in Figure 2. The parameter setting module can set the serial port, save path, etc. The functions of the real-time monitoring module include real-time data acquisition, statistics, and output functions. The database management module includes data backup and viewing of historical data. The system setting module can set the background color, grid color, and coordinate axis color of the graph curve.

2.3. Installation of Equipment. The drilling rig widely used in China is the GXY-1C hydraulic drilling rig, which includes hydraulic jacks, drill pipes, drill bits, racks, diesel hydraulic presses, and others, as shown in Figure 3. The main power source of the drill is a hydraulic jack, which is supplemented by the rotation and propulsion force of the drill bit. When the drilling rig is working, hydraulic oil flows through the tubing in the following manner: it flows in four different directions to power the rig's different operations after flowing out of the main pipe. The oil pressure and laser displacement sensors are installed in a reasonable position in accordance with the working principle of the on-site drilling rig. The oil pressure sensor is mounted on one of the pipes which provides downward power to the power head. According to the designed installation equipment, the laser displacement sensor is installed under the drilling rig power head. The schematic diagram of the installation of the sensing device is shown in Figure 4.

3. Application

3.1. Project Overview. The designed drillhole depth monitoring system is applied in the engineering investigation of a school laboratory expansion (Shaoxing, Zhejiang). Four holes are drilled on the site. The drillhole depth of the soil core holes (denoted as ZK1–ZK4) is about 30 m. The soil core obtained onsite is mainly clay (Figure 5), and the installation of the site sensing equipment is shown in Figure 6.

3.2. Result Analysis. Under the geological condition that the drilling stratum is soil, the working stages of the drilling rig during the process can be roughly divided into four stages (a, *b*, c, and d). Stage a (installing the casing). It indicates that the drilling rig reaches the specified hole location and prepares to install the casing. First of all, a core rod with a height of 0.8 m and a diameter of 108 mm is used to drill down until about 3 m. Then, a casing with a length of 3-4 m is placed, which is for subsequent convenience to connect or remove the thin rod to ensure the fluency of the drilling work. The drilling depth of this section is recorded as Ha. Stage *b* (drilling into the core sample). This stage indicates that the power head moves up and down and the core rod begins to fill the core sample. This process takes about 3 min from start to finish. During this process, the oil pressure and

(a) (b)

Figure 1: Two types of sensors. (a) Laser displacement sensor. (b) Oil pressure sensor.

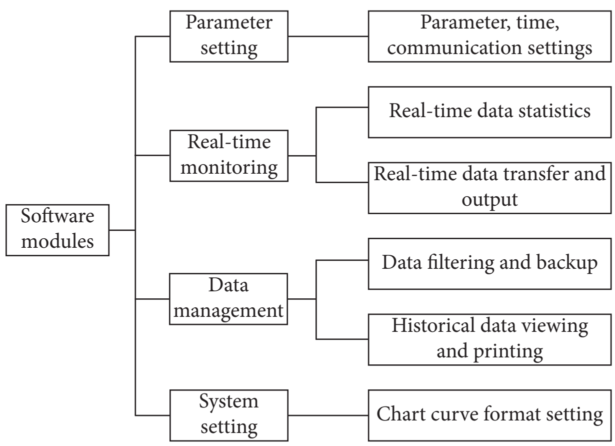

Figure 2: Modular design of software.

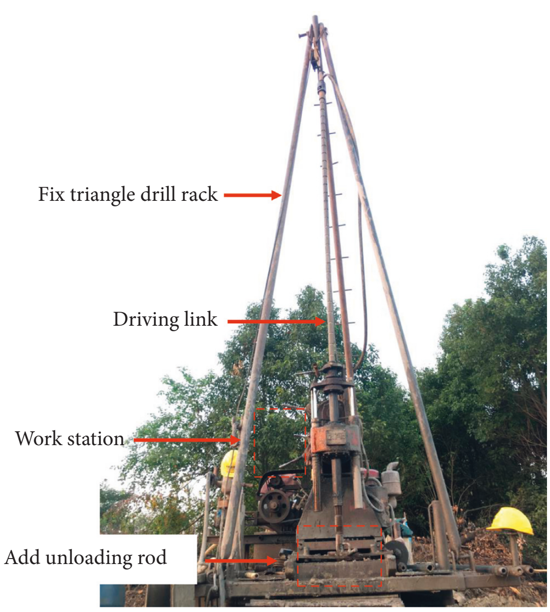

Figure 3: GXY-1C hydraulic drilling rig.

laser displacement change considerably, and the drillhole depth can be monitored by calculating the effective displacement. Stage c (taking out the drill pipe). This stage indicates that the mandrel is filled and the process of extracting core samples by oil pressure. The process can be divided into the process of raising the core rod, lifting the drilling rig, moving the power head back, removing the thin rod, raising the core rod, passing the core sample out of the core rod, putting back the core rod, and connecting the thin rod. Stage d (hole washing). There are two types of hole washing, one is that of the downward hole washing by the active drill pipe with self-weight plus drilling speed. The other is that of the hole washing by way of the power head going up and down.

The time points of each stage were recorded and are shown in Figure 7 along with the monitored oil pressure and laser displacement. In Figure 7(a), the whole drilling process includes the four stages (a, *b*, c, and d) of the above-mentioned core soil sample, but it is mainly a cycle of (b, c, and d) three stages. The cycle of the three stages expresses the complete operation from putting in the core rod to drilling into the core sample and then to extracting the core sample. The displacement of taking out the drill pipe in stage c is invalid for the calculation of the drillhole depth. For stage d, the displacements produced by the two washing methods correspond to the second d and the third d in Figure 7(a). During the up and down displacement of the power head, no core sample enters the mandrel, and the displacement in this process is invalid. Moreover, the oil pressure in the two cleaning methods is extremely small, and the oil pressure changes in a similar pattern. The stage *b* can be well distinguished from the three stages, and the drillhole depth is mainly calculated from it.

The oil pressure and laser displacement data of the part surrounded by the dotted line in Figure 7(a) are analyzed, as shown in Figure 7(b). In Figure 7(b)), when the laser displacement starts to fall from the maximum value, the power head applies pressure through the jack. The oil pressure rapidly and abruptly changes from approximately 0.02 MPa to 1.8 MPa or even 3.5 MPa. Subsequently, when the power head is lowered to the lowest point, it needs to be lifted. The oil pressure value rapidly drops to approximately 0 MPa when the displacement increases (i.e., the power head lifts upward), showing the same pattern as rock drilling in the following. This process expresses the complete process of the drilling power head being drilled down once and then lifted up again. We define the interval of the power head dropping from the highest point to the lowest point as i. The effective drilling into the core sample displacement can be well distinguished and counted. Let the oil pressure be M, the rate of change per second is ΔM, when $M \geq 1.5$ and $\Delta M \geq 1$, there are m drilled core sample

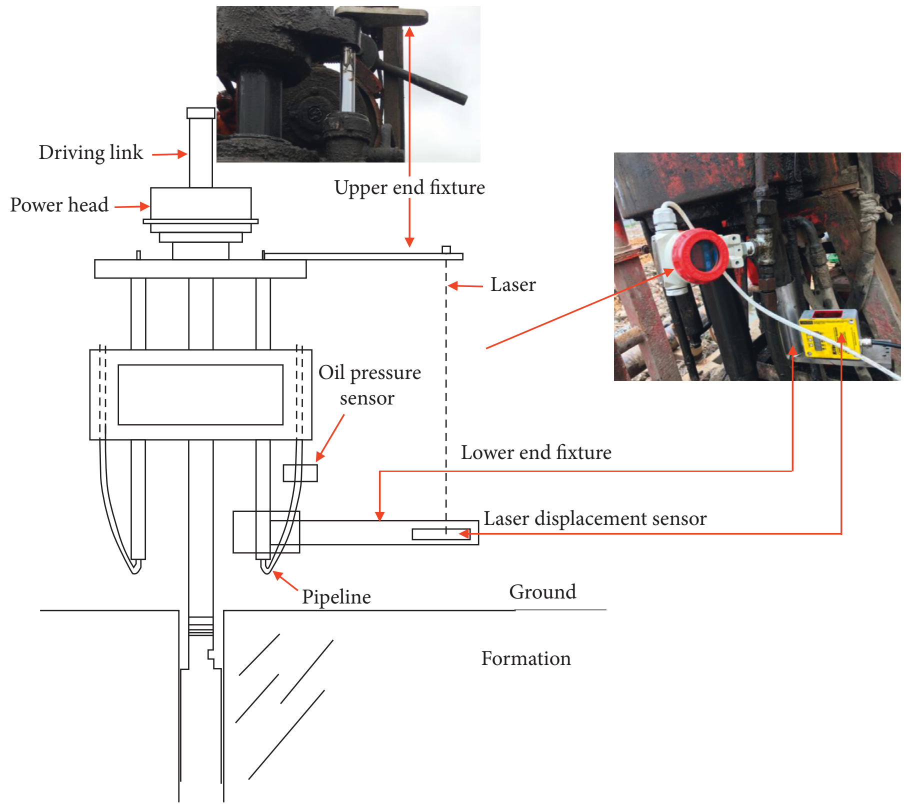

Figure 4: Schematic diagram of sensing device installation.

Figure 5: Core sample of soil on site.

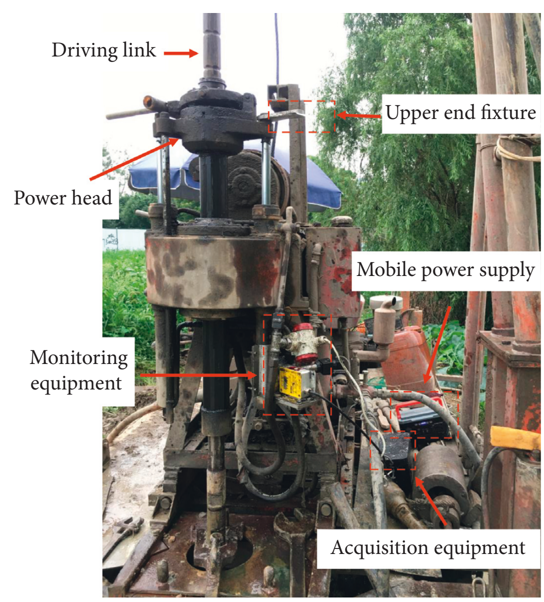

Figure 6: Device installation on site.

stages b, as shown in Figure 7(a). There are n intervals in each stage b, as shown in Figure 7(b). The maximum laser displacement value in the ith effective interval is recorded as Himax, the minimum laser displacement recorded value is Himin. The difference between the Himax and the Himin in ith interval is recorded as the effective laser displacement. The sum of the effective laser displacement in one stage b is denoted as l. The total laser displacement (drillhole depth) L is obtained by the sum of the l in each stage b and Ha. The calculation flowchart of the drillhole depth is shown in Figure 8, and the specific formulas are as follows:

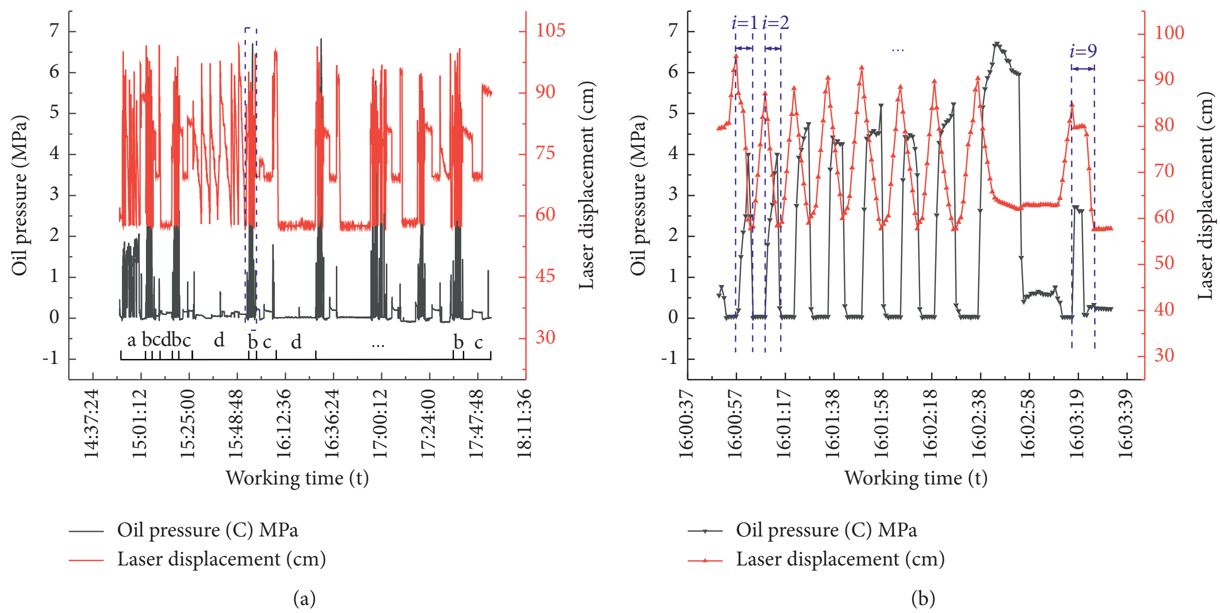

Figure 7: Distribution law of oil pressure and laser displacement with time during ZK 1 drilling. (a) ZK 1 (soil sample). (b) Dashed box part in ZK 1.

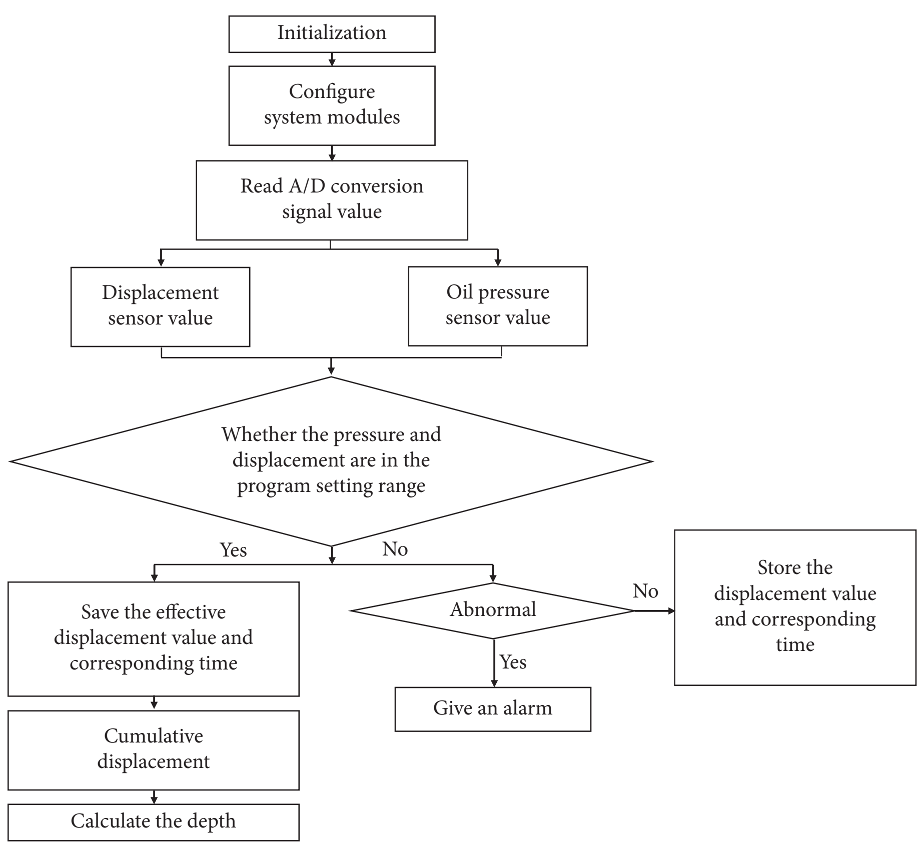

Figure 8: Flowchart of cumulative drillhole depth calculation.

Table 1: Comparison of drillhole depth calculation in two methods.

Coring category	Drilling serial number	Test monitoring depth (m)	Number of drill pipes calculated depth (m)
Soil sample	ZK 1	29.63	29.91
	ZK 2	31.13	31.39
	ZK 3	29.64	29.89
	ZK 4	34.70	34.96

Figure 9: Core sample of rock on-site.

$$l = \sum_{i=1}^{n} H_{i\max} - H_{i\min}, \quad (2)$$

$$L = \sum_{j=1}^{m} lj + H_a. \quad (3)$$

The drillhole depth of the four measuring points is calculated by monitoring the system and is recorded in Table 1. It is close to the drillhole depth obtained by calculating the number of drill pipes. The relative errors of the two are 0.94%, 0.83%, 0.84%, and 0.74%, indicating that the proposed method is feasible in the calculation of drillhole depth. The results show that it can detect the drillhole depth conveniently and quickly, which is better than the traditional manual calculation method and has great importance for reducing the falsification of the drillhole depth.

4. Discussion

Under the condition of the rock layer, three holes are drilled on the site. The obtained core is mainly tuff (Figure 9) and the depth of the rock core holes (denoted as ZK5–ZK7) is about 5 m. The drilling stages in the rock layer are different from that of the soil layer, which are divided in the following categories. Stage a (idling drilling). This stage indicates that the drilling rig imitates normal drilling, and the core rod is drilled in the hole with the highest oil pressure and the fastest drilling rate. The drillhole depth of this section is recorded as Ha, but this section is generated by empty drilling and is invalid displacement. Stage *b* (drilling into the core sample). This stage indicates that the power head moves up and down and the core rod begins to fill the core sample. In this process, the oil pressure is kept at a certain value, and the core rod bit keeps wearing the rock to achieve the effect of core entry, thereby increasing the displacement slowly. Stage c (unclogging hole). This stage indicates that the drilling rig performs high-frequency drilling, and the laser displacement under the drill head and the size of oil pressure keep changing. This process is to unclog holes and prevent sticking for better subsequent drilling. Stage d (taking out the drill pipe). This stage refers to the process of further compaction of the core rod. After the compaction is complete, the mandrel is pulled out and then connected to the water pump pipe, and the core sample is extruded by water pressure.

As shown in Figure 10(a), the main drilling process is the cycle of stages *b* and c. The displacement in stage c is generated by the simultaneous up-down movement of the power head and the active drill pipe. During the up and down displacement of the power head, no core sample enters the mandrel, and the displacement in this process is invalid. Therefore, the drillhole depth is still reflected by stage *b*.

Selecting a stage *b* (part of the dotted line surround) in Figure 10(a) for analysis, as shown in Figure 10(b). In Figure 10(b), it can be seen from the selection of the *i*th interval that this process expresses the complete process of the drilling head being drilled and lifted. It is characterized by keeping a certain oil pressure unchanged, and the core rod bit is constantly wearing the rock to achieve the effect of coring. The effective drilling into the core sample displacement can be well distinguished. Hence, the proposed calculation formula for the drillhole depth could also be used in the rock layer geology. The key is to identify the stage *b*. According to Figure 10(a), the conditions for identifying stage *b* are (1) $M \geq 1.5$, (2) $\Delta M \leq 3\%$ and the duration is greater than 10 s. The drillhole depth is then calculated by formulas (2) and (3). The calculation result is close to the drillhole depth calculated by the traditional manual calculation method (Figure 11). Therefore, the applicability of proposed monitoring methods in the rock layer geology is validated.

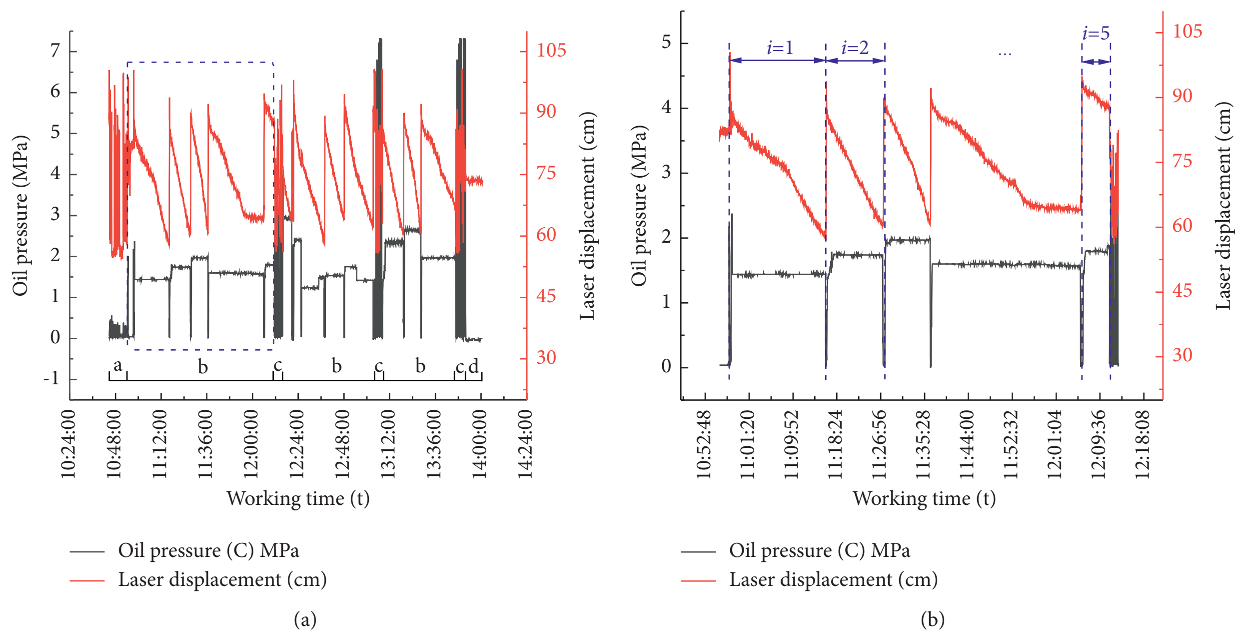

Figure 10: Distribution law of oil pressure and laser displacement with time during ZK 5 drilling. (a) ZK 5 (rock sample). (b) Dashed box part in ZK 5.

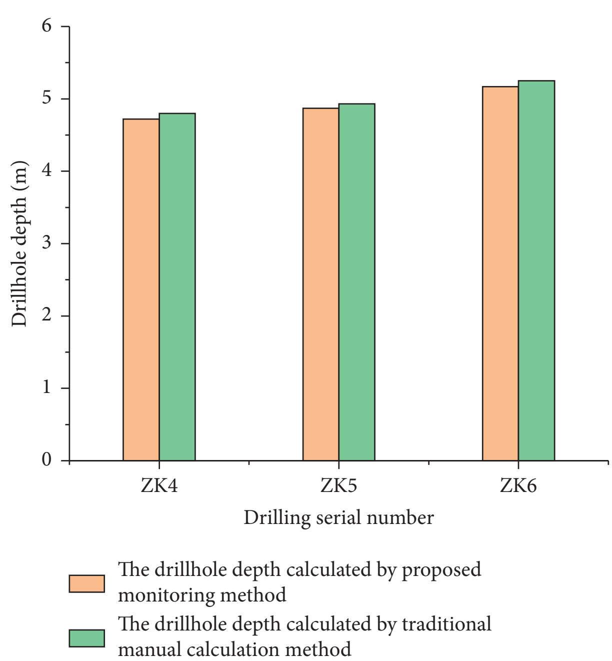

Figure 11: Drillhole depth obtained from the proposed monitoring method and the traditional manual calculation method.

5. Conclusion

A drillhole depth monitoring system while drilling is designed based on summarizing the existing engineering geological exploration drilling technology, and the test results are analyzed. The conclusions are summarized as follows:

(1) Combined with the working characteristics of drilling coring rigs commonly used at this stage, an intelligent drillhole depth monitoring system is built based on the drilling parameter. The system consists of hardware and software, and it could be installed conveniently on-site drilling rigs.

(2) Different working stages of the rig could be matched with the oil pressure and laser displacement data collected by the monitoring system. It is concluded that the effective drillhole depth is reflected by stages a and *b*. Through the data analysis from stage a and *b*, the calculation formula of the drillhole depth suitable for soil layer geology is proposed. Moreover, the calculated drillhole depth is close to the actual situation.

(3) Through the application of monitoring system in the rock layer geology, the effective drillhole depth is mainly concentrated in stage *b*. The results show that the drillhole depth calculated by the proposed formula agrees well with the actual situation, which validates the feasibility of the proposed method and system.

In summary, this paper proposes an intelligent drillhole depth monitoring system for engineering investigation. It is noted that this system is used in common hydraulic core drilling rigs, its applicability to other types of drilling rigs will be further verified. In addition, the proposed system has not been used in the weak intercalated layer, but it would be studied in the future.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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References

[1] C. D. Johnson, "Borehole-Geophysical Investigation of the University of Connecticut Landfill, Storrs, Connecticut," *geological Survey Office of Ground Water Branch of Geophysics*, U.S. Department of the Interior, U.S. Geological Survey, Washington, D. C., U. S. A, 2002.

[2] J. H. Williams, K. Singha, and F. P. Haeni, "Application of Advanced Geophysical Logging Methods in the Characterization of a Fractured-Sedimentary Bedrock Aquifer, Ventura County, California," *Water Resources Investigations Report*, U.S. Department of the Interior, U.S. Geological Survey, Washington, D. C., U. S. A, 2002.

[3] T. Bugge and S. Fanavoll, "The Svalis Dome, Barents Sea - a geological playground for shallow stratigraphic drilling," *First Break*, vol. 13, no. 6, pp. 237–251, 1995.

[4] R. Lindhjem, "Geotechnical investigation by directional core drilling," *Trenchless Technology*, vol. 17, no. 9, pp. 64–67, 2009.

[5] X. F. Gao, "The influence of drilling information on the selection of drilling methods in engineering geological exploration is studied," *World Nonferrous Metals*, vol. 14, pp. 227-228, 2017.

[6] H. Bolt, "Driller's depth quality improvement: way-point methodology," *Petrophysics*, vol. 58, no. 6, pp. 564–575, 2017.

[7] J. Mitchell, *5 Keys for Improving Hole Quality: Hole Depth, Tolerance, and Location Will Determine the Type of Drill Needed*, Canadian Metalworking, Toronto, Canada, 2018.

[8] J. Wang, *Research and Realization on the Method of Counting Drill Pipe' Number Based on Machine Vision*, Xian University of Science and Technology, Xian, China, 2015.

[9] M. Zhou, J. Yuan, Z. Gao, and Z. Huang, "Drill pipe counting method based on local dense optical flow estimation," *Lecture Notes in Computer Science*, vol. 12888, pp. 443–454, 2021.

[10] O. Bello, J. Holzmann, and T. Yaqoob, C. Teodoriu, Application of artificial intelligence methods in drilling system design and operations: a review of the state of the art," *Journal of Artificial Intelligence and Soft Computing Research*, vol. 5, no. 2, pp. 121–139, 2015.

[11] M. P. Vega, M. Freitas, C. M. Scheid, and A. L. Martins, "Online monitoring and control of an oil well drilling process," *Chemical Engineering Transactions*, vol. 24, pp. 397–402, 2011.

[12] Y. Y. Zha, N. P. Yao, and H. B Dong, "Design of condition monitoring system for coal mine hydraulic drilling rig," *Coal Mine Machinery*, vol. 35, no. 3, pp. 183–186, 2014.

[13] H. Jiang, H. X. Wang, W. J. Lan, and J. Zhang, "Design of a total monitoring system for air drilling process," *Advanced Materials Research*, vol. 705, pp. 400–404, 2013.

[14] Z. Q. Yue, C. Lee, K. Law, L. G. Tham, and J. Sugawara, "Use of HKU drilling process monitor in slope stabilization," *Chinese Journal of Rock Mechanics and Engineering*, vol. 21, no. 11, pp. 1685–1690, 2002.

[15] S. Bratton, "Sonic drilling in support of geotechnical investigation and geo-construction," *Geo-Strata —Geo Institute of ASCE*, vol. 13, no. 2, pp. 24–26, 2012.

[16] H. Li, Y. Meng, G. Li et al., "Propagation of measurement-while-drilling mud pulse during high temperature deep well drilling operations," *Mathematical Problems in Engineering*, vol. 2013, no. 4, pp. 1–12, Article ID 243670, 2013.

[17] P. Cheng, W. Zhang, W. Li, J. He, and Y. Feng, "Vibration behavior during underground drilling based on an innovative measurement method and the application," *Shock and Vibration*, vol. 202110 pages, Article ID 6489298, 2021.

[18] H. Y. Sun, "Technology of magnetic induction transmission of intelligent drill pipe and its channel characteristics," *Journal of China University of Petroleum (Edition of Natural Science)*, vol. 37, no. 6, pp. 127–183, 2013.

[19] S. T. Zhu, F. X. Jiang, X. F. Shi et al., "Energy dissipation index method for determining rockburst prevention drilling parameters," *Rock and Soil Mechanics*, vol. 36, no. 8, pp. 2270–2276, 2015.

[20] O. Kaufmann and T. Martin, "3D geological modelling from boreholes, cross-sections and geological maps, application over former natural gas storages in coal mines," *Computers & Geosciences*, vol. 34, no. 3, pp. 278–290, 2008.

[21] A. G. Li, Z. Q. Yue, and G. H. Tan, "Design and installation of comprehensive instrumentation system for slope in Hong Kong," *Chinese Journal of Rock Mechanics and Engineering*, vol. 22, no. 5, pp. 790–796, 2003.

[22] J. Chen, Z. Q. Yue, and S. J. Liu, "An innovative approach of drilling process monitoring for slope characterization in mountainous regions," *Applied Mechanics and Materials*, vol. 226, pp. 2088–2092, 2012.

[23] Z. Q. Yue, C. F. Lee, K. T. Law, and L. G. Tham, "Automatic monitoring of rotary-percussive drilling for ground characterization-illustrated by a case example in Hong Kong," *International Journal of Rock Mechanics and Mining Sciences*, vol. 41, no. 4, pp. 573–612, 2004.

[24] M. Akula, R. R. Lipman, M. Franaszek, K. S. Saidi, S. C. Geraldine, and R. K. Vineet, "Real-time drill monitoring and control using building information models augmented with 3D imaging data," *Automation in Construction*, vol. 36, pp. 1–15, 2013.

[25] G. Niu, K. Zhang, B. Yu, Y. Chen, Y. Wu, and J. Liu, "Experimental study on comprehensive real-time methods to determine geological condition of rock mass along the boreholes while drilling in underground coal mines," *Shock and Vibration*, vol. 201917 pages, Article ID 1045929, 2019.

[26] R. B. Goobie, E. Tollefsen, S. Noeth et al., "Remote real-time well monitoring and model updating help optimize drilling performance and reduce casing strings," *SPE Drilling and Completion*, vol. 23, no. 03, pp. 242–249, 2008.

[27] Z. Yue, J. Chen, and W. Gao, "Automatic drilling process monitoring (DPM) for in-situ characterization of weak rock mass strength with depth," in *Proceedings of the Paper Presented at the 1st Canada—U.S. Rock Mechanics Symposium Rock Mechanics: Meeting Society's Challenges and Demands*, pp. 199–206, Vancouver, Canada, May 2007.

[28] Z. Q. Yue, Z. F. Fen, and J. T. Luo, "Use of HKU drilling process monitor in slope stabilization," *Chinese Journal of Rock Mechanics and Engineering*, vol. 21, no. 11, pp. 1685–1690, 2002.

[29] Z. Q. Yue, "Automatic drilling process monitoring for soil and rock strengths and their spatial distribution in ground," in *Proceedings of the 2nd World Forum of Chinese Scholars in Geotechnical Engineering*, Nanjing, China, 2005.

[30] Z. Q. Yue, "Drilling process monitoring for refining and upgrading rock mass quality classification methods," *Chinese Journal of Rock Mechanics and Engineering*, vol. 33, no. 10, pp. 1977–1996, 2014.