# Drilling Speed Monitoring Based on Integrated GNSS RTK/IMU Technology

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*Abstract*

*In the fields of blasting and geological exploration drilling, understanding the drilling speed at various times and depths is crucial. This speed can reveal valuable insights into the hardness and geomechanical properties of the soil and rock being drilled. The study at hand presents an innovative solution for determining and monitoring drilling speed through the integration of two advanced technologies: the Global Navigation Satellite System (GNSS) and the Inertial Measurement Unit (IMU). The IMU signals play a pivotal role in identifying the precise drilling times, while the GNSS-based elevation data are employed to obtain real-time measurements of drilling speed. By combining these technologies, the study aims to enhance the accuracy and efficiency of drilling operations. The experimental results are promising, indicating that the integrated GNSS RTK/IMU system can automatically monitor real-time drilling speed with remarkable precision, achieving millimeter-per-second accuracy. This approach not only improves the monitoring process but also provides a more detailed understanding of the subsurface conditions. The ability to accurately measure drilling speed in real-time allows for better decision-making and optimization of drilling strategies. Consequently, this integration of GNSS and IMU technologies represents a significant advancement in the field of geological exploration and blasting, offering a reliable and precise method for assessing the geomechanical properties of the soil and rock.*

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**Keywords:** *Drilling speed; GNSS; IMU*

## 1. Introduction

Information during the drilling process is essential for adjusting the technical drilling design [1], [2], [3]. The most common method of obtaining borehole information is determining drilling depth by measuring the length of the drill rod. In this approach, the borehole depth is manually recorded in the field by summing the lengths of the drill rods, which limits the automation of data collection during drilling. In the study by [4], the authors measured drilling speed by analyzing the rotational speed of the drill rod using an air pressure sensor. In the study by [5], the authors integrated multiple sensors, including a length measurement sensor, a rotational speed sensor, and an oil pressure sensor. However, the challenge with these solutions is the complexity of equipment installation, which increases the overall system cost.

The integrated Global Navigation Satellite System (GNSS)/Inertial Measurement Unit (IMU) system has been widely applied in positioning, navigation, surveying, and structural monitoring [6]. A GNSS receiver receives signals from satellites to determine its position. GNSS Real Time Kinematic (RTK) is commonly used to provide real-time positioning information with centimeter-level accuracy. GNSS RTK operates by using a base station occupied at a known point and a rover station. The base station transmits signals to the rover station to calculate the spatial baseline between them. Based on the known coordinates of the base station, the horizontal coordinates X, Y and elevation (H) of the rover station can be determined. When sufficient signals are received and a fixed solution is obtained, the rover station's accuracy can reach the centimeter level.

By setting a GNSS receiver's antenna on the drill rod, changes in borehole depth correspond to changes in the drill rod's elevation. The drilling speed can then be determined based on the variation in the drill rod's elevation over time. However, during the drilling stage, the drill bit does not continuously move downward in a single direction; In contrast, multiple operations might occur, such as rod extraction, rod replacement, and temporary pauses. These activities cause variations in the drill rod's elevation that do not accurately reflect the actual drilling speed.

To address this issue, an IMU is used to detect the precise times when the drill bit penetrates the soil and rock. The IMU typically consists of a gyroscope system and an accelerometer system, capable of measuring angular velocity and acceleration along three axes in an orthogonal coordinate system, with high-frequency data acquisition ranging from tens to hundreds of Hz. The IMU can be used independently or integrated with other positioning and navigation systems, such as GNSS, to guide high-speed

vehicles or mitigate GNSS limitations in environments with signal obstruction and satellite interference [7].

In this study, an integrated GNSS/IMU device is mounted on the drill rod. High-frequency signals from the IMU are used to analyze the vibrations of the drill rod, allowing the detection of the times when the drill is actively penetrating the soil and rock. At those times, elevation data from the GNSS receiver are used to calculate the drilling speed. The drilling speed is displayed on specialized software in the field and simultaneously transmitted to a central computer server, enabling remote access for efficient drilling management and design planning.

## 2. Methods

The calculation of drilling speed based on the integrated GNSS/IMU system consists of two stages: Firstly, the time intervals during which the machine is actively drilling are determined, and secondly, the drilling speed of the machine during these intervals is calculated. Among these two stages, identifying the exact drilling time is the more critical step. If the drilling time is accurately determined, the drilling speed can be easily calculated by:

$$v = \frac{ds}{dt} \tag{1}$$

where $ds = H_t - H_{t-1}$ is the change in elevation of the drilling rod over the time interval dt.

### 2.1. Determination of drilling times based on IMU signals

The data from the IMU sensor (from the gyroscope and accelerometer) provides the angular velocity and acceleration along the pre-defined x,y,z axes. It is necessary to analyze these data. These data over time are presented in Figures 1 and 2.

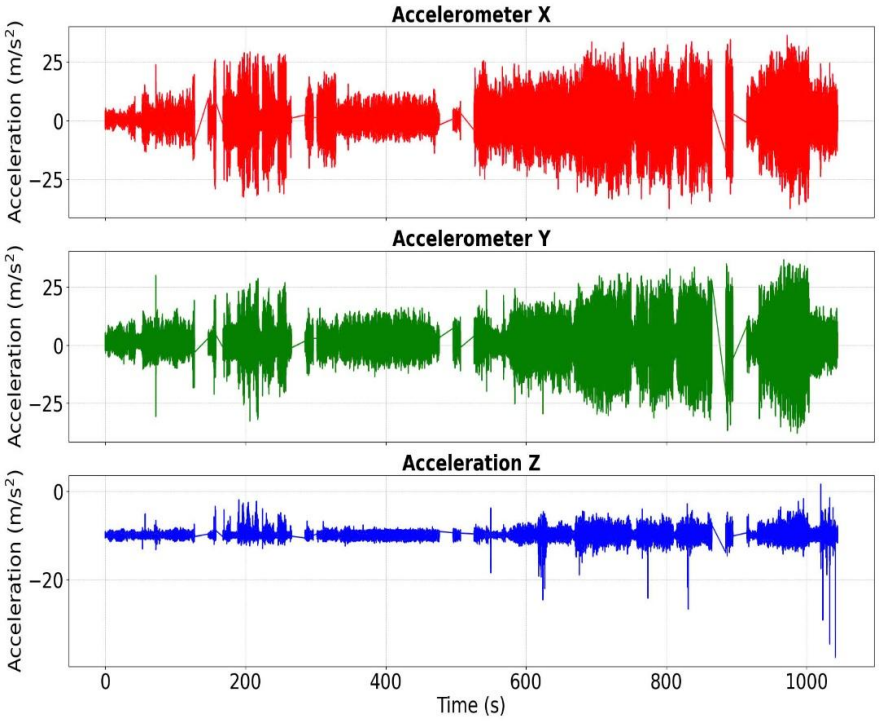


Figure 1. Signal from the accelerometer

Rys 1. Sygnał z akcelerometru

Figures 1 and 2 show that the times during which there was a change in the amplitude of the data along the axes are identical. This suggests the need to study the frequency changes in each segment of the data to accurately identify the drilling times. To obtain a more detailed view of the frequency, a short-time Fourier Transform (STFT) is performed. STFT is a transformation commonly used to analyze the frequency components of time-series signals that are non-stationary by applying Fourier transform to each component of the signal. The general formula for STFT is:

$$\mathrm{STFT}\{x(t)\}(m,\omega) = X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n] \cdot \omega[n - m] \cdot e^{-j\omega n} \tag{2}$$

where $x[n]$ is the data time series, $\omega[n]$ is the window function (filter), which is frequently a smooth continuous function with an expected value of zero, $m$ in the time index indicating the position of the filter, $\omega$ is the angular frequency, $j$ is the imaginary unit, $e$ is the Euler number.

After applying the STFT, we obtain a graph showing the energy levels (amplitude fluctuations) at each time step. The problem now becomes a signal segmentation task. To segment a signal with high accuracy, normalizing the data to a common scale, usually between 0 and 1, is a commonly used approach. Here; since the velocity changes in all directions have an equal impact, the data from different directions can be summed and normalized to the range [0, 1]. The resulting data are presented in Figure 3.

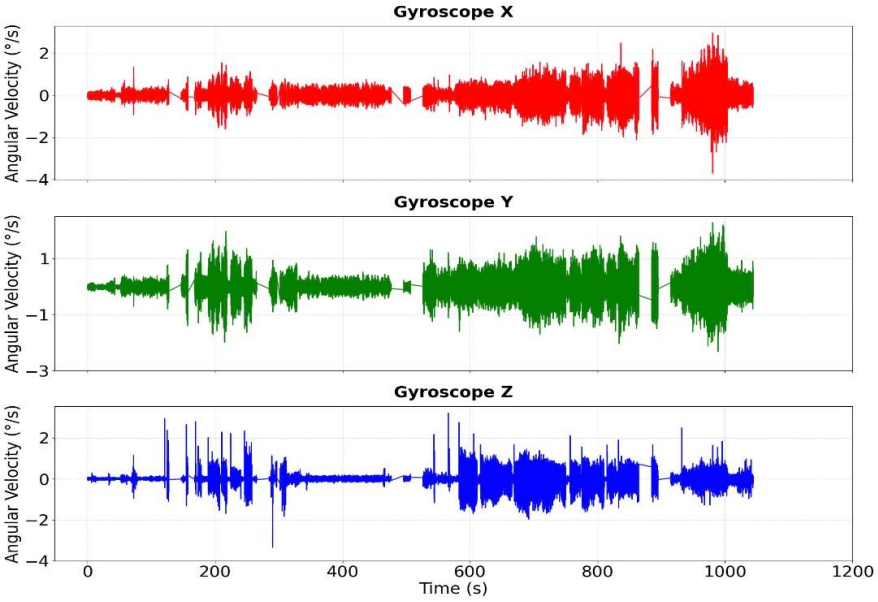


Figure 2. Signal from the Gyroscope Sensor

Rys 2. Sygnał z czujnika żyroskopu

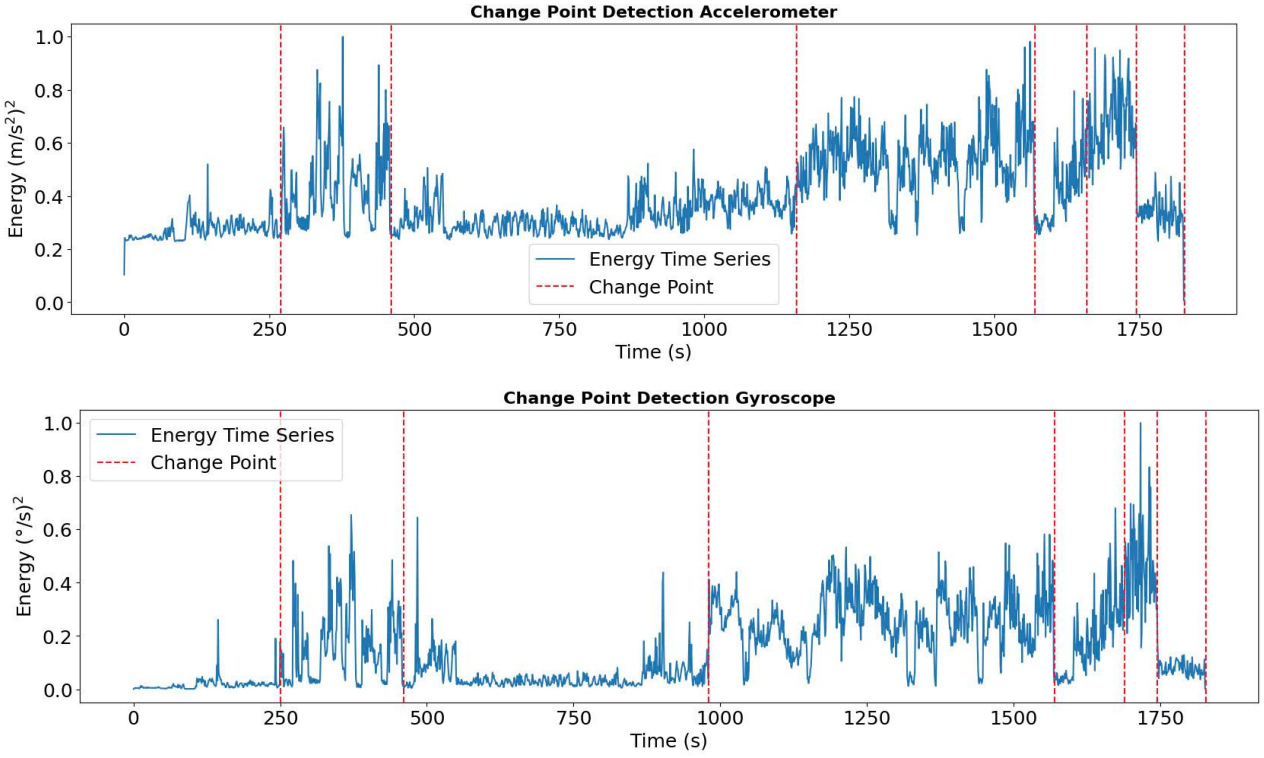


Figure 3. Results of signal segmentation according to drilling state

Rys 3. Wyniki segmentacji sygnału według stanu wiercenia

### 2.2. Calculating drilling speed based on GNSS data

While the IMU component provides information on acceleration and rotational movement, which helps identify specific drilling times, the GNSS component provides accurate position data. By combining these two data sources, we can reliably calculate the drilling speed. However, an issue in this step is the synchronization of the IMU and GNSS time using a common time source, typically GNSS time. Once the time is synchronized, the drilling distance can be calculated based on the distance between the starting and ending positions along the z-axis or other appropriate methods. To calculate drilling speed, it is important to consider two types of drilling speeds: instantaneous drilling speed and average drilling speed. To calculate the instantaneous drilling speed, we divide the drilling distance by the drilling time. To calculate the average drilling speed over a longer period, e.g., hours or

days, we take the average of instantaneous drilling speeds. The principal diagram for determining drilling speed based on the GNSS/IMU system is shown in Figure 4.

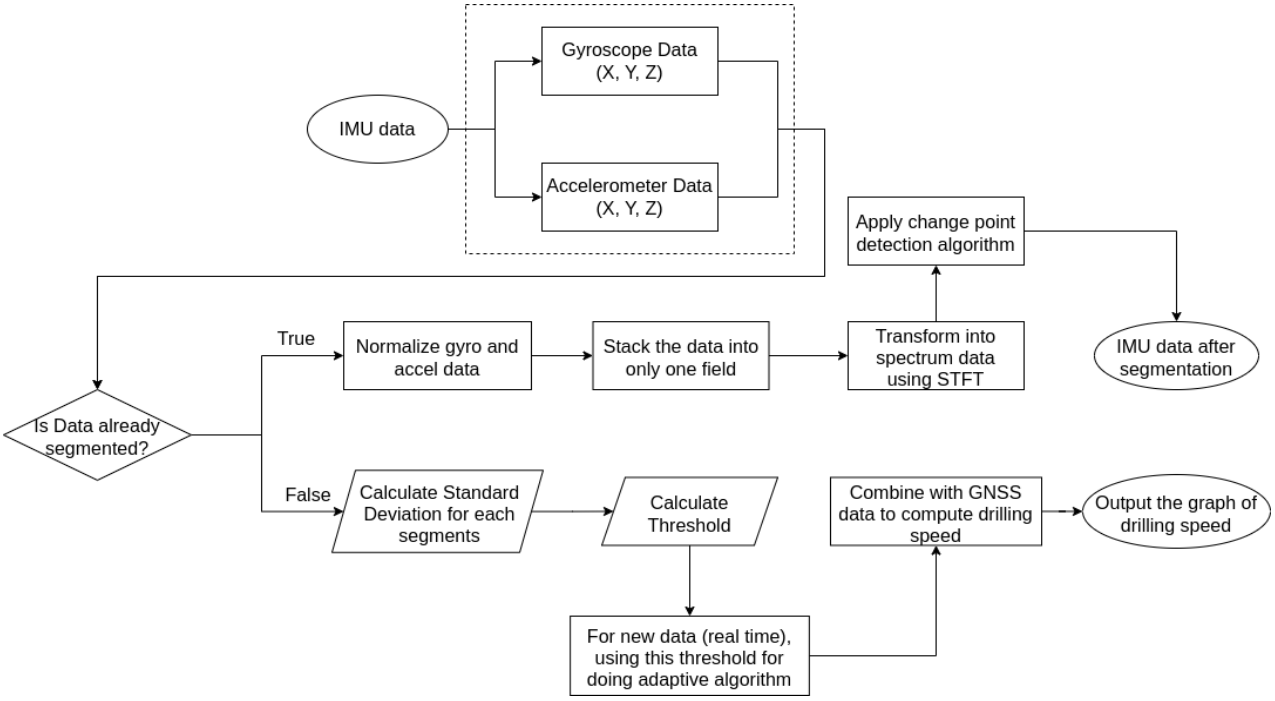


Figure 4. Workflow of computing drilling speed

Rys 4. Przebieg pracy przy obliczaniu prędkości wiercenia

### 3. 3. Results and discussions

Experimental data were collected in the field at Lam Hong commune, Me Linh district, Hanoi city, using the XY-1 geological drill. An integrated GNSS/IMU device was mounted on the drill rod to determine the drilling speed, as shown in Figure 5a. The GNSS/IMU device is connected to a mobile smart device via Bluetooth connection for data collection, analysis, and display, as shown in Figure 5b. A software module was developed to collect data and automatically calculate the drilling speed (see Figure 6), with the main functions including connecting and configuring the GNSS/IMU device, connecting to the base station for GNSS RTK measurements, analyzing IMU data to determine drilling moments, calculating drilling speed, displaying drilling speed, and sending drilling speed information to the server.

Figure 5. Field experiment setup (a) and device connection (b)

Rys 5. Konfiguracja eksperymentu terenowego (a) i podłączenie urządzenia (b)

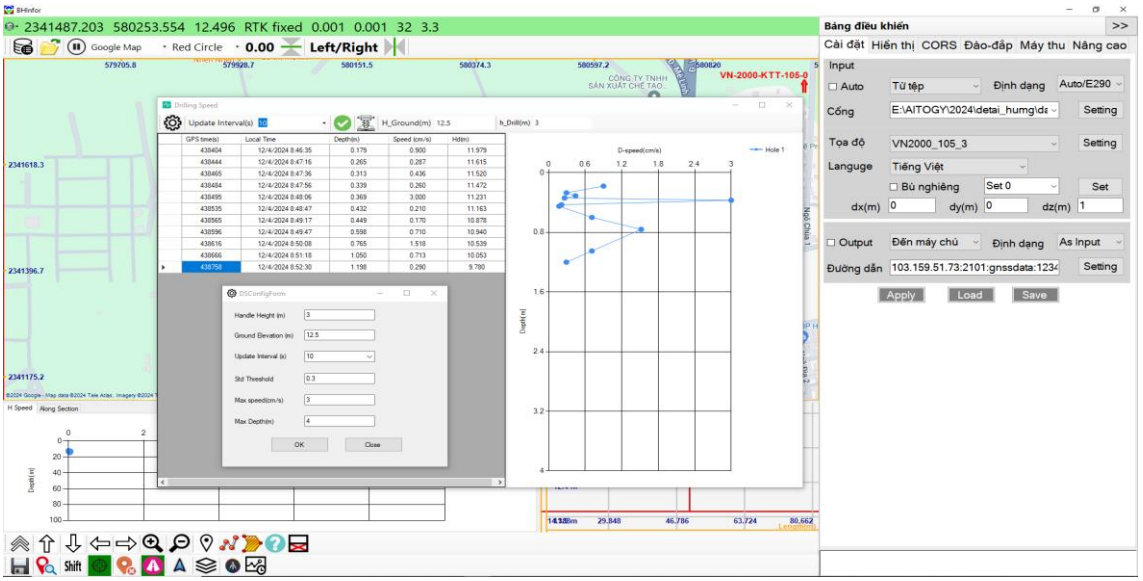


Figure 6. Software module interface

Rys 6. Interfejs modułu oprogramowania

The results show that the drilling speed determined based on the integrated GNSS/IMU technology aligns well with the results calculated from the drilling logbook, with the largest discrepancy being around 1.2 mm/s. This discrepancy is mainly due to two factors that are the identification of drilling times and the elevation error of the drill rod using GNSS.

Table 1. Comparison between monitoring and logbook results

Tabela 1. Porównanie wyników monitoringu i dziennika pokładowego

| Session | Local time | | GPS time (s) | | Depth (m) | Logbook drilling speed (mm/s) | Monitoring drilling speed (mm/s) |
|---|---|---|---|---|---|---|---|
| 1 | 8:38 | 8:40 | 437898 | 438018 | 2.03 | 2.2 | 2.1 |
| 2 | 8:45 | 8:52 | 438318 | 438738 | 5.21 | 6.5 | 7.7 |
| 3 | 8:55 | 8:58 | 438918 | 439098 | 6.95 | 4.7 | 4.5 |

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## 4. Conclusion

This study has proposed a solution for measuring borehole drilling speed based on the integrated GNSS and IMU technology. In this solution, signals from the IMU were used to determine drilling times, and data from the GNSS receiver were used to determine the elevation of the borehole at the drilling times. Methods of signal analysis for the IMU have been proposed to automatically identify drilling times during a range of tasks in the drilling process. The GNSS RTK solution was applied to determine the borehole depths in real-time with centimeter-level accuracy.

Experimental data were conducted in the field, and a software module was developed to calculate the drilling speed based on the methods proposed in the study. The experimental results showed that the proposed method can be used to determine drilling speed in real-time. To evaluate the accuracy of the proposed method, further field experiments and reference measurement systems are needed for comparison.

## Acknowledgements

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## Conflicts of Interest

The authors declare no conflict of interest.

**References - Literatura**

1. Tang, Z., (1989). The related program of drilling geology. Geol. Explor. 11, 60–62.
2. Veeger, A.; Murray, D.; Hermes, O.; Boothroyd, J.; Hamidzada, N., (2003). Geographic information system-based digital catalog for managing subsurface geotechnical and geologic data. Transp. Res. Record, 1821, 90–96.
3. Zhao, W., (2006). The three projects of geomechanics, deep geology, and scientific drilling opened a new chapter in the history of Chinese geosciences-celebrating the 50th anniversary of the founding of the Chinese Academy of Geological Sciences. Acta Geosci. Sin. 27, 385–392.
4. Sliwa, T.; Jarosz, K.; Rosen, M.A.; Sojczyńska, A.; Sapińska-Śliwa, A.; Gonet, A.; Fąfera, K.; Kowalski, T.; Ciepielowska, M., (2020). Influence of Rotation Speed and Air Pressure on the Down the Hole Drilling Velocity for Borehole Heat Exchanger Installation. Energies. 13, 2716. https://doi.org/10.3390/en13112716.
5. Guo, P.; Zhang, Z.; Wang, X.; Yue, Z.; Zhang, M., (2022). A Novel Borehole Cataloguing Method Based on a Drilling Process Monitoring (DPM) System. Energies. 15, 5832. https://doi.org/10.3390/en15165832.
6. Gebre-Egziabher D., Gleason S, (2009). GNSS Applications and Methods, Artech.
7. Trung, D.T., (2024). The integration of GNSS RTK and IMU with extended particle filter. J. Hydro-Meteorol. 20, 66-74.

***TYTUŁ: Monitorowanie prędkości wiercenia w oparciu o zintegrowaną technologię GNSS RTK/IMU***

*W przypadku wierceń strzałowych lub geologicznych, prędkość wiercenia w różnych momentach i na różnych głębokościach może dostarczyć informacji o twardości i właściwościach geomechanicznych gleby i skały. W niniejszym badaniu przedstawiono rozwiązanie do określania i monitorowania prędkości wiercenia w oparciu o integrację Global Navigation Satellite System (GNSS) i Inertial Measurement Unit (IMU). Podczas gdy sygnały IMU są wykorzystywane do identyfikacji czasu wiercenia, dane wysokościowe oparte na GNSS są wykorzystywane do uzyskiwania prędkości wiercenia w czasie rzeczywistym. Wyniki eksperymentów wskazują, że zintegrowany system GNSS RTK/IMU umożliwia automatyczne monitorowanie prędkości wiercenia w czasie rzeczywistym z dokładnością do milimetra na sekundę.*

**Słowa kluczowe**: *Prędkość wiercenia; GNSS; IMU*