An Improved Precise Positioning Method for Intelligent Mine Construction

Kang Chen¹,², Zhigang Du¹,², Lin Guo³, Qiqi Kou³*

¹¹stTiandi (Changzhou) Automation Co., Ltd., Changzhou 213015, China
²²CCTEG Changzhou Research Institute, Changzhou 213015, China
³³China University of Mining and Technology, Xuzhou 221116, China

E-mail: rono_back@yeah.net, duzg86@163.com, guolin_1110@163.com, kouqiqi@cumt.edu.cn

Abstract. Precise positioning plays an important role in the construction of intelligent coal mines. However, existing precise positioning methods often have problems with long positioning period, limited positioning capacity and low precision. To overcome these shortcomings, this paper proposes a time-division downlink time-difference-of-arrival (TD-D-TDOA) positioning method. In the proposed method, the base station first implements clock synchronization with the reference clock by direct or relay. Then the base station allocates the time for transmitting two positioning messages according to its serial number. Finally, the label uses these messages to obtain the TDOA and its location information. The proposed precise positioning method has the advantages of millisecond positioning cycle, self-position calculation, unlimited positioning capacity and high positioning accuracy. Moreover, the tag only needs to receive the location information broadcast by the base stations in the positioning process, which reduces the coupling degree between the tag and the location base station, as well as the cost of the tag hardware. Experimental results demonstrate that our method has a positioning accuracy of less than 20cm and a positioning frequency of up to 20 times per second, while also having high positioning stability.

1. Introduction
In the construction process of intelligent coal mines [1], to timely grasp the position and status information of underground personnel and equipment, it is usually necessary to accurately locate these targets. At present, ultra-wideband (UWB) positioning technology [2-4] has been widely used in the fields of personnel positioning, tunnel traffic, power plant inspection, warehousing logistics, etc., and its pulse width is only sub-nanosecond. Therefore, UWB can theoretically achieve centimeter-level positioning accuracy and good resistance to multipath interference.

In the UWB position network, the precise positioning methods can be mainly divided into two types: one is time of flight (TOF) and the other is time difference of arrival(TDOA). In the TOF position system, the positioning base stations and the tags do not need clock synchronization, and the system is easy to deploy, but it requires multiple message interactions, which results in large network...
traffic and low positioning efficiency [5,6]. In the TDOA system [7-9], the clock of the positioning base station is first synchronized by wired or wireless means, so its positioning capacity is greatly improved compared with that of the TOF system. At present, in the large-capacity positioning systems, the most widely used method based on TDOA is uplink time-difference of arrival (U-TDOA). However, since the position coordinates of the tags in U-TDOA are calculated by the position calculation server, the tag cannot directly sense its position. Therefore, the U-TDOA positioning system is not conducive to real-time location-aware services, such as satellite positioning navigation system.

So, to meet the needs of an intelligent coal mine for high-precision and rapid positioning, it is always a research hotspot to study the precise positioning method with high positioning accuracy, large capacity and fast position sensing speed. In this paper, a time-division downlink TDOA (TD-D-TDOA) based on UWB positioning method is proposed which is similar to the theory of satellite positioning and navigation system. The positioning process is as follows: Firstly, a positioning base station is installed at a designated location, and adjacent positioning base stations can communicate with each other. According to the linear model of the clock, the clock drift and clock offset between the positioning base stations are eliminated by wireless message interaction, and the positioning base stations are synchronized by direct or relay mode. Then the location base station broadcasts two location messages at the same time interval according to its sequence number. By using the time interval of the two location messages, the tag calculates the frequency offset between itself and the base station. Furthermore, the tag also calculates the time difference of arrival between itself and the different base stations according to the arrival time of the first location message sent by the base station. Finally, Chan method or Taylor expansion based on iteration method is used to solving the position coordinates of itself according to the time difference of arrival. The proposed TD-D-TDOA not only can effectively shorten the positioning period of the tag, but also has the advantages of quick perception of the position of the label itself and unrestricted positioning capacity.

The remainder of this paper is organized as follows. Section II explains the D-TDOA system model and the detailed design. In Section III, the modified formula is given for practical application cases. In Section IV, the location accuracy performance is analyzed. In Section V, the test result is given and discussed. Finally, Section VI makes some concluding remarks.

2. System model
In the TD-D-TDOA positioning system, all positioning base stations (i.e., nodes) are synchronized with the reference clock by direct or relay mode [10]. Each positioning base station has a pre-assigned sequence number, and the transmission timestamp of the positioning message is predetermined according to its sequence number. The clock drift of tag is synchronized with the reference clock, then the time difference and its position are calculated.

In our TD-D-TDOA positioning system, assuming that the clock of node A is the reference node, node B and tag M are synchronized with the node A. So, the system model of the TD-D-TDOA is shown in figure 1.
Figure 1. TD-D-TDOA location process

As shown in figure 1, $T_{A_1}$ and $T_{A_2}$ are the transmission timestamps of the node A broadcasting the \( \alpha \) and \( \beta \) messages, respectively. \( (T_{B,A_1}, T_{B,A_2}) \) and \( (T_{M,A_1}, T_{M,A_2}) \) are the timestamps of node B and tag M receiving \( \alpha \) and \( \beta \) messages, respectively. Similarly, \( T_{B_1} \) and \( T_{B_2} \) are the transmission timestamps for broadcasting \( \alpha \) and \( \beta \) messages by node B. Then, the tag M received the two messages, and the two reception timestamps are defined as \( T_{M,B_1} \) and \( T_{M,B_2} \). $T_{ref}^{\alpha}$ is the transmission interval of the adjacent nodes, and $T_{ref}^{\beta} = T_{B_2} - T_{A_1} = T_{B_2} - T_{B_1}$ is the time interval when the \( \alpha \) and \( \beta \) messages are transmitted. In the system model, we define the clock of node A as the reference clock, and the clock of the other nodes and tags are synchronized with node A’s. The detailed positioning process of TD-D-TDOA can be divided into the following two parts.

2.1. Positioning base station (i.e., Node)
The node has two main functions: clock synchronization and broadcasts the messages at the exact timestamp. The node will broadcast two messages \( \alpha \) and \( \beta \) in each positioning loop. The node uses \( \alpha \) to synchronize the clock of the node with the reference clock and the calculation of tag’s TDOA. The TDOA of \( \alpha \) and \( \beta \) is used by tags to calculate the clock drift between its clock and the reference clock.

2.1.1 Clock synchronization:
The clock between the nodes conforms to the linear model in a short time [11], and the clock of node A can be mapped to the clock of node B by the following formula:

$$T_B = \theta_{AB} + \omega_{AB} \cdot T_A$$  \hspace{1cm} (1)

Where $\theta_{AB}$ is the clock offset and $\omega_{AB}$ is the clock drift between the node A and B. $T_A$ and $T_B$ are the clocks for nodes A and B, respectively.
When the node A broadcasts a message at time $T_A^\prime$, the timestamp of the node B receiving the message can be formulated as [12]:

$$T_B^\prime = \theta_{AB} + \omega_{AB} \cdot (T_A^\prime + T_{AB}^{\text{prop}})$$  \hspace{1cm} (2)

Where $T_B^\prime$ denotes the time at which the node B receives the message sent by the node A, and $T_{AB}^{\text{prop}}$ is the TOF between A and B. Since the position of the two nodes is settled, the TOF can be calculated by artificially placed distance or measured by two-way ranging method. According to the formula (2), the clock of node B can be synchronized to the clock of node A after receiving two messages sent by A.

As far as we know, clock synchronization has the characteristics of transitivity. For example, node C cannot communicate directly with node A where the reference clock is located, but the clock of node C can be first synchronized with the clock of node B. So, the clock of the node $T_C$ can be obtained by the following formula:

$$T_C = \theta_{BC} + \omega_{BC} \cdot T_B$$ \hspace{1cm} (3)

According to Equation 1, Equation 3 can be further optimized to:

$$T_C = \theta_{BC} + \omega_{BC} (\theta_{AB} + \omega_{AB} \cdot T_A)$$
$$= \theta_{BC} + \omega_{BC} \theta_{AB} + \omega_{BC} \omega_{AB} \cdot T_A$$ \hspace{1cm} (4)

By Equation 4, we can obtain the clock of the base station C by locating the clock of the base station A. Therefore, when the base station to be located is invisible to the base station where the reference clock is located, the method of relaying the base station can be used to synchronize the relay between the positioning base station and the reference clock.

2.1.2 Message transmission:
The timestamp at which the node transmits the message is predetermined by the reference clock and the node’s sequence number. In this paper, a node sends the message at the clock $nT_{\text{ref}}^\alpha$, where $n$ is the sequence number of the node. Before transmitting the message, each node needs to convert $nT_{\text{ref}}^\alpha$ to its clock, so does the $\beta$ message. Generally, the interval between $\alpha$ and $\beta$ is set to a constant value for calculation.

2.1.3 Synchronization deviation analysis:
The deviation of the node for synchronization clock is mainly introduced by the TOF between the two nodes [12]. Suppose that the TOF deviation between the two nodes obeys normal distribution $N(0, \sigma_d^2)$, then the synchronization deviation between the two nodes also obeys normal distribution $N(0, \sigma_d^2)$.

In the case of relay synchronization, the synchronization deviation of the two nodes is cumulative. When there are $k$ relay synchronizations, the deviation between the node and the reference clock obeys the normal distribution $N(0, k\sigma_d^2)$. In other words, the more the relay synchronization times, the worse the synchronization accuracy.

2.2 Tag part
In a precisely positioned system, the tag has two main functions: clock drift synchronization and TDOA calculation.

2.2.1 Clock drift synchronization:
Similar to positioning a node, the relationship between the tag and the reference clock can be expressed as:
Where $T_M$ is the tag clock, $\omega_{ref,M}$ is the clock drift between the tag and the reference node. Meanwhile, $T_{ref}$ is the time of the reference clock, and $\theta_{ref,M}$ is the clock offset between the tag clock and the reference clock.

By using the time difference of arrival of the $\alpha$ and $\beta$ message, the tag can calculate the drift of the local clock and the reference clock.

$$\omega_{ref,M} = \frac{T_{M,\alpha} - T_{M,\beta}}{T_{ref}} \omega_{ref,x}$$  \hspace{1cm} (6)

Where $T_{M,\alpha}$ and $T_{M,\beta}$ are the received timestamps of the message $\alpha$ and $\beta$ from node $x$, $\omega_{ref,x}$ is the frequency offset between node $x$ and the reference clock.

Since TOF of the tag and each node is unknown, $\theta_{ref,M}$ which relates to the message sending time of the node can’t be obtained. However, it can be eliminated by subtraction using TDOA method.

### 2.2.2 Message broadcast:

Taking node A and node B in figure 1 as an example, the timestamp of the tag which receives $\alpha$ message from node A can be obtained by:

$$T_{M,A,\alpha} = \theta_{ref,M} + \omega_{ref,M} \left( T_{ref,A,\alpha} + T_{prop,M,A} \right)$$  \hspace{1cm} (7)

Where $T_{ref,A,\alpha}$ denotes the sending timestamp of node A which broadcasts $\alpha$ message and that is already known. $T_{prop,M,A}$ is the flight time between the tag and the positioning node A which is an unknown quantity.

In regard to the time of arrival of $\alpha$ message from positioning node B, it can be expanded to

$$T_{M,B,\alpha} = \theta_{ref,M} + \omega_{ref,M} \cdot T_{ref,B,\alpha}$$

$$= \theta_{ref,M} + \omega_{ref,M} \left( T_{ref,A,\alpha} + nT_{ref} + T_{prop,M,B} \right)$$  \hspace{1cm} (8)

Where $T_{ref,A,\alpha}$ and $T_{ref,B,\alpha}$ are timestamps that the $\alpha$ messages of node A and node B transmit, which are known value and can be embedded in broadcast message. $n$ is the sequence number interval of the node A and B, and $T_{ref}$ is the time interval for the sequenced neighboring base station to transmit $\alpha$. $T_{prop,M,B}$ is the flight time between the tag and the positioning base station B, which is an unknown quantity.

Let the time difference of the $\alpha$ message of the nodes A and B be $\Delta T_{M,AB,\alpha} = T_{M,B,\alpha} - T_{M,A,\alpha}$, then the formula can be obtained after shifting the item.

$$\omega_{ref,M} \left( T_{prop,M,B} - T_{prop,M,A} \right) = \Delta T_{M,AB,\alpha} - n\omega_{ref,M} T^\alpha_{ref}$$  \hspace{1cm} (9)

As far as we know, $T_{prop,M,A}$ and $T_{prop,M,B}$ are usually small, the influence of frequency offset $\omega_{ref,M}$ can be ignored. Therefore, it also can be expressed as:

$$T_{TDOA,AB} = T_{prop,M,B} - T_{prop,M,A}$$

$$= \Delta T_{M,AB,\alpha} - n\omega_{ref,M} T^\alpha_{ref}$$  \hspace{1cm} (10)

Based on the value of TDOA, the tag can calculate its position.
2.2.3 Deviation analysis
According to Equation 8, n and $T^{\alpha}_{ref}$ are fixed values. What’s more, the deviation between timestamp $T_{M,B,\alpha}^\alpha$ and $T_{M,A,\alpha}^\beta$ obeys the normal distribution $N(0,\sigma_M^\alpha)$. $\omega_{ref,M}$ is expanded by the formula, and $T^{\beta}_{ref}$ is a fixed value. The deviation of the receiving timestamp $T_{M,x,\beta}$ and $T_{M,x,\alpha}$ also obeys the normal distribution $N(0,\sigma_M^\beta)$. Besides, the deviation of $\omega_{ref,x}$ is the synchronization deviation of the node which relates to the TOF deviation. It can be obtained that the deviation of $\omega_{ref,M}$ obeys the normal distribution $N(0,\frac{2\sigma_M^2}{T^{\beta}_{ref}}\omega_{ref,x})$, thus the TDOA deviation of the tag also obeys the normal distribution, which is $N(0,2\sigma_M^2(1+n\frac{T^{\alpha}_{ref}}{T^{\beta}_{ref}}\omega_{ref,x}))$. In a word, the larger the interval between the nodes is, the greater the TDOA deviation is. Meanwhile, the greater the synchronization deviation of the node $x$, the larger the TDOA deviation.

3. Synchronization optimization in application
In view of some UWB positioning chips, the transmission time should start at an integral point (like DW1000, the transmission timestamp’s last 9 bits must be zero). So, we need to add $\delta$ to $T^{\alpha}_{ref}$ and $T^{\beta}_{ref}$ most time. Considering that $\delta$ is usually smaller than 10 ns, and the clock drift is less than 50 ppm, the clock drift caused by $\delta$ can be ignored.

In other words, what we need to do is subtract it from the receive timestamp. Taking node A and B in figure 1 as an example and according to equation 4, $\omega_{ref,M}$ can be modified as

$$\omega_{ref,M}^{\text{modified}} = \left( T_{M,x,\beta} - \delta_{M,x,\beta} \right) - \left( T_{M,x,\alpha} - \delta_{M,x,\alpha} \right) \omega_{ref,x}$$

(11)

$\delta_{M,x,\alpha}$ and $\delta_{M,x,\beta}$ are the deviations between the message $\alpha$ and $\beta$ sent by the node $x$ as well as the reference clock, respectively.

Then, the $\Delta T_{M,AB,\alpha}$ can be modified as follows:

$$\Delta T_{M,AB,\alpha}^{\text{modified}} = \left( T_{M,B,\alpha} - \delta_B \right) - \left( T_{M,A,\alpha} - \delta_A \right)$$

(12)

Where $\delta_A$ and $\delta_B$ are the deviations between the message sent by node A and B, respectively. Moreover, the modified TDOA equation can be given by

$$T^{\text{modified}}_{\text{TDOA},A,B} = \Delta T^{\text{modified}}_{M,AB,\alpha} + n\omega_{ref,M}^{\text{modified}} - T^{\alpha}_{ref}$$

(13)

4. The shortest positioning period
In the above positioning system, the shortest positioning period is related to the following two: the tag reception time $T_{\text{recv}}$ and the positioning solution time $T_{\text{calc}}$. The shortest positioning period can be defined as $T_{\text{period}} = T_{\text{recv}} + T_{\text{calc}}$.

4.1 The tag reception time
The shortest reception time of the tag is $T_{\text{recv}} = nT^{\alpha}_{ref}$. The shortest reception time is proportional to the number of nodes around the tag and the transmission time interval of the nodes, which are adjacent to each other. Generally, the number $n$ of nodes around the tag is determined. Therefore,
\[ T_{ref}^\alpha \propto \left( L_{msg} + T_{proc} \right) \]

where \( L_{msg} \) is the length of the positioning message, \( T_{proc} \) is the message processing time of the embedded processor. It can be inferred that \( T_{ref}^\alpha \) is proportional to the sum of the message transmission time and the processing time.

4.2 Positioning solution time

The most common method for solving TDOA equations is the Chan method [13] or the iterative method based on Taylor expansion [14]. The calculation of Chan method is very fast, but the precise of the position coordinates obtained is low. The Taylor expansion is usually combined with the Levenberg-Marquardt method (LM) to improve the speed and stability of iterative convergence [15]. In this paper, the Chan method is used to calculate the initial value, and the LM iteration is used to solve the position coordinates. Thus, \( T_{calc} = T_{Chan} + mT_{iter} \), where \( T_{Chan} \) is the calculation time of the Chan method, \( m \) is the number of iterations and \( T_{iter} \) is the time of the iteration.

5. Experiment result

In this section, we conduct a test to verify the performance of the proposed TD-D-TDOA. Especially, DW1000 which produced by Decawave is used as UWB location IC in the experiment. Moreover, both nodes and tags are using TCXOs with a tolerance of 1 ppm as a clock source. Besides, the TDOA equation obtains the initial value by Chan method, and further solved through the LM iterative method based on Taylor expansion.

The 2D positioning experiment deployment is shown in Figure 2. In the test experiment, 4 nodes are placed at (0,0), (0,6), (6,6) and (6,0), respectively, while tags are placed at (2,2),(4,2), (4,4) and (2,4), and the unit of coordinates is meters.

![Figure 2. The location of base station and the tag](image)

As shown in figure 2, node 0 is the reference node, node 1 and 2 are synchronized with node 0 directly. Since the signal between node 3 and node 0 has non-line-of-propagation, therefore, node 3 synchronizes with reference node through node 2 by relay. In this paper,

\[ T_{ref}^\alpha = 0.10000000 \text{ (tick) } \approx 4.2 \text{ms} \]  \hspace{1cm} (14)

\[ T_{ref}^\beta = 0.80000000 \text{ (tick) } \approx 2.1 \text{ms} \]  \hspace{1cm} (15)

Where tick is the clock cycle of DW1000, and the reception time is:

\[ T_{recv} = 4 \times 4.2 \text{ (ms) } \approx 17 \text{ (ms) } \]  \hspace{1cm} (16)
Through multiple tests, we can get that: \( T_{\text{chan}} \approx 8\text{ms} \), \( T_{\text{iter}} \approx 2\text{ms} \), \( m = 5 \), \( T_{\text{calc}} \approx 20\text{ms} \). Consequently, the shortest period \( T_{\text{period}} \approx 37\text{ms} \). After an appropriate amount of protection time added based on \( T_{\text{period}} \), the positioning period selected for this experiment is 50\text{ms}, which means the positioning frequency is 20 Hz.

The tag is positioned 250 times at each test location and the test results are presented in figure 3.

![Test results](image)

(a) Test result at (2, 2)  (b) Test result at (2, 4)
(c) Test result at (4, 2)  (d) Test result at (4, 4)

Figure 3. Tag’s location results in a different position

Counting and analyzing the information of the above test results, the average position measured at each coordinate point, the root mean squared error (RMSE), and the R95 [16] (Centered on the real position, containing a radius of 95% of the positioning results) can be listed as follows:

| Test coordinates(cm) | Average(cm)   | RMSE(cm) | R95(cm) |
|----------------------|---------------|----------|---------|
| (2,2)                | (1.91,1.96)   | 5.0      | 13.3    |
| (2,2)                | (1.99,3.91)   | 4.8      | 18.7    |
| (4,2)                | (3.94,1.95)   | 4.7      | 12.0    |
| (4,4)                | (3.92,3.98)   | 4.7      | 17.8    |

As can be seen from Table 1, the calculated deviation between the average positions coordinates of the base station and the coordinates of the standard position is less than 10 cm, and the R95 is less than 20 cm, which means that the positioning accuracy is better than 20 cm.

At the same time, the RMSE of the four position coordinates information and the standard position coordinate information is less than 10cm, which proves that the proposed TD-D-TDOA positioning method has reliable stability. Finally, we can conclude that the success rate of label positioning in the experiment is 100%.

It can be seen from Table 1 that the average value of the measured position differs from the standard position distance by less than 10 cm. Meanwhile, R95 is less than 20 cm, which means the positioning accuracy is better than 20 cm. At the same time, the RMSE of the distance between the four positions and the standard position is less than 10cm, thus the positioning stability is better. Besides, the success rate of tag positioning in the experiment was 100%.
6. Conclusion
In this paper, a new and effective precise positioning method TD-D-TDOA is proposed. In our method, the base station to be located first synchronizes with the clock of the reference clock by direct or relay. Then, the base station determines the time for sending two positioning messages of α and β according to its sequence number. Subsequently, the tag uses these messages to get the TDOA and its location information. Finally, we analyze the synchronization error of the locating base station in the TD-D-TDOA method and the error when the tag calculates the TDOA, and verify the positioning accuracy and positioning stability of TD-D-TDOA through testing. Experimental results demonstrate that our method has the advantages of millisecond positioning cycle, self-position calculation, unlimited positioning capacity and high positioning accuracy.

In the future work, we are going to integrate the TD-D-TDOA positioning method with other positioning methods such as inertial navigation, which will lay the foundation for building intelligent applications such as precise positioning in intelligent coal mines.

7. References
[1] Ghasemi E, Ataei M, Shahriar K. An intelligent approach to predict pillar sizing in designing room and pillar coal mines[J]. International Journal of Rock Mechanics & Mining Sciences, 2014, 65(75 ( Pt 2)):86-95.
[2] Fontana R J. Recent system applications of short-pulse ultra-wideband (UWB) technology[J]. IEEE Transactions on Microwave Theory & Techniques, 2004, 52(9):2087-2104.
[3] Shi G, Ying M. Survey of Indoor Positioning Systems Based on Ultra-wideband (UWB) Technology[M]. Wireless Communications, Networking and Applications. 2016.
[4] Zhou Q, Chong S, Chen X, et al. UWB wireless positioning technology in the application[C]. Wireless Sensors. 2017.
[5] Chen Y, Yan L I, EFENDIEV, et al. Time-of-flight (TOF)-based two-phase upscaling for subsurface flow and transport[J]. Advances in Water Resources, 2013, 54(Complete):119-132.
[6] Yan J, Sun S S, Cheng L I, et al. BESIII barrel time-of-flight (TOF) calibration using cosmic ray data[J]. Chinese Physics C, 2010, 34(3):368-373.
[7] Jin B, Xu X, Zhang T. Robust Time-Difference-of-Arrival (TDOA) Localization Using Weighted Least Squares with Cone Tangent Plane Constraint.[J]. Sensors, 2018, 18(3):778-.
[8] Lui K W K, So H C. A study of two-dimensional sensor placement using time-difference-of-arrival measurements[J]. Digital Signal Processing, 2009, 19(4):650-659.
[9] Nawaz H, Bozkurt A, Tekin I. A novel power efficient asynchronous time difference of arrival indoor localization system using CC1101 radio transceivers[J]. Microwave & Optical Technology Letters, 2017, 59(3):550-555.
[10] Bo Z, Liu Y, Tao M. Adaptive scheduling for OFDM bidirectional transmission with a buffered relay[C]. Wireless Communications & Networking Conference. 2013..
[11] Wu Y, Chaudhari Q, Serpedin E. Clock synchronization of wireless sensor networks[J]. IEEE Signal Processing Magazine, 2011, 28(1):124-138.
[12] Gholami M R, Gezici S, Strom E G. TDOA Based Positioning in the Presence of Unknown Clock Skew[J]. IEEE Transactions on Communications, 2013, 61(6):2522-2534.
[13] Chan Y T, Member S, IEEE, et al. A Simple and Efficient Estimator for Hyperbolic Location[J]. IEEE Transactions on Signal Processing, 2002, 42(8):1905-1915.
[14] Foy W H. Position-Location Solutions by Taylor-Series Estimation[J]. IEEE Transactions on Aerospace and Electronic Systems, 1976, AES-12(2):187-194.
[15] Kang C, Jianjun B, Wei W. Research on a robust positioning algorithm for mine proximity detection[J]. Industry and Mine Automation, 2018, 44(06):11-15.
[16] C. McElroy, D. Neirynck, M. McLaughlin, Comparison of Wireless Clock Synchronization Algorithms for Indoor Location Systems[C]. Communications Workshops (ICC) 2014 IEEE International Conference on, pp. 157-162, Jun 2014.
Acknowledgments
This work was supported in part by the Science and Technology Innovation and Entrepreneurship Special Fund General Project of China Coal Technology and Engineering Group under Grant No. 2018-TD-MS016, in part by the Science and Technology Innovation and Entrepreneurship Special Fund Youth Project of China Coal Technology and Engineering Group under Grant No. 2018-TD-QN013 and in part by the Science and Technology Innovation Special Fund Key Project of China Coal Technology and Engineering Group under Grant No. 2018-TD-ZD005.