

Alarm Method of Communication Intelligent Manhole Cover Based on Multiple Event Fusion

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Title Page

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Abstract

Communication intelligent manhole cover (CIMC) can effectively, accurately and in real time monitor the status change of communication manhole cover and helps protect the safety of communication pipeline and the comprehensive utilization of pipeline resources. The traditional monitoring method often leads to frequent false alarms due to the complex working environment of manhole cover and the random error of sensor. In terms of the equipment status signals generated by the CIMC terminal, a new alarm method of CIMC with multiple event fusion in this paper via jointing analysis of multi-sensor status signals is proposed on the basis of abnormal alarm events definition. The experimental result shows that the proposed CIMC alarm method by means of multiple sensor signals in this paper can not only make up for the defect that it is difficult to fully reflect the real state of manhole cover by a single sensor, but also reduces the false alarm rate caused by the random error of sensor and CIMC system. It has better practicability for the intelligent management of manhole cover and be conducive to the construction of intelligent transportation and smart city.

Keywords

Communication intelligent Manhole cover (CIMC), Multiple event fusion, Abnormal definition, Alarm event, Sensor signal

1. Introduction

With the acceleration of urbanization, urban coverage continues to expand. Given the growing amount of manhole covers [1, 2], the corresponding management difficulty is also increasing. Especially, as an important part of urban manhole cover, the communication manhole cover is closely related to the urban public security. At present, the management mode of general communication manhole cover is mainly manual inspection [3]. Although a lot of manpower, material and financial resources were invested for management and maintenance every year from the different communication operators, the stolen manhole cover, sludge blockage, water immersion, pipeline misconnection, etc. are often appears. It can easily lead to the hidden safety hazards for the communication facilities and personnel life.

As an emerging internet of things (IoT) technology, narrowband-internet of things (NB-IoT) originates from long term evolution (LTE) for narrowband-machine to machine (NB-M2M) and narrowband-orthogonal frequency division multiplexing (NB-OFDM), which the FDMA technology is used in the uplink and the OFDM technology is used in the downlink, respectively. In the NB-IoT, it is usually to reduce power consumption by means of power saving mode (PSM), discontinuous reception (DRX) and extend discontinuous (EDRX) methods, etc. [4-7]. Compared with other low-power wide-area network (LPWAN) methods, the NB-IoT has the advantages of ultra-low cost, low power consumption, ultra-far coverage, stable connection and excellent architecture optimization, and has been widely used in many fields. So far, NB-IoT usual is deployed by the ways of in-band, guard band and independent carrier with license frequency, and coexist with the existing network too [8-10]. With the rapid development of IoT technology, it can realize intelligent monitoring, real-time alarm and remote opening of communication manhole cover, and has obvious advantages in the information management of communication intelligent manhole cover (CIMC).

Under the background of smart city construction, a small number of areas have begun to design and implement CIMC system and form the corresponding CIMC products. At present, the structure of mainstream CIMC products in the market includes the outer manhole cover, inner manhole cover, lock, manhole cover terminal. In order to protect communication resources including pipelines, manholes and cables, the CIMC system can conduct real-time monitoring and alarm for abnormal opening including external manhole cover, internal manhole cover and lock [11-14]. However, the application strategies and design methods of different products are different [15, 16]. Generally speaking, there are three design ways of CIMC in the manhole cover monitoring. For example, 1) realize intelligent monitoring of manhole cover by sensor and Beidou navigation positioning system at the bottom of traditional manhole cover. 2) realize the real-time monitoring of manhole cover by the smart stick and base station beside the manhole cover. 3) realize real-time monitoring by combination of material changes, wireless network and cloud platform, etc. [17-20]. In addition, due to some specified factors including the defect of alarm method, the complex working

environment and the random error of sensor, the real-time monitoring of CIMC often produce false alarm, which not only reduces the availability of the CIMC system, but also increases and wastes the labor and economic costs.

Although NB-IoT technology has become the common solution of intelligent monitoring of communication manhole cover and communication operators, there are many problems remained in the daily management of communication manhole cover. For example, ①the number of communication manhole cover is large and the distribution area is wide, in extreme cases several kinds of pipelines share the same communication pipeline, so it is very difficult to continuously monitor the communication manhole cover. ②when the communication manhole cover damage, loss, blockage and displacement, the management department cannot timely access to specific information, it is difficult to timely deal with the problem and eliminate hidden dangers. ③the traditional manual inspection method expends a large number of maintenance personnel, to some extent, it increases the management cost and the actual inspection effect is not at all agree with the expectation. ④with the rapid development of the network, different communication operators and ownership departments of pipeline often cross lines and place communication facilities discretionary, which is easy to produce disputes and security risks.

As mentioned above, a new alarm method of CIMC based on multiple event fusion is proposed in this paper. That is, the continuously monitoring for communication manhole cover is accomplished by collecting and analyzing various sensor signals. Firstly, the alarm event is defined and can be divided into four categories, such as, abnormal opening event with outer manhole cover, inner manhole cover, lock and violent opening, and then the corresponding generated signal by multiple sensors is set up. Secondly, according to the definition of different sensors and abnormal events, the alarm method is designed to judge the above different abnormal events, and the real-time transmission of alarm information is completed in terms of the NB-IoT. Finally, the proposed alarm method of CIMC based on multiple event fusion is designed and tested in the experiment. The experimental results show that the proposed alarm method can make up for the defect of traditional signal sensor's and reduce effectively false alarm rate. It contributes to improve the management efficiency of CIMC system and reduces maintenance costs. The main idea and structure of this paper is as follows: the first section is the introduction, the second section is the an overview of CIMC alarm method based on multiple event fusion, the third section is the material and the detailed CIMC alarm methods, the fourth section is the design of CIMC alarm methods, the fifth sections is the experiments and results of CIMC alarm method, and we end our study with discussions and conclusions in the last section.

2. Related works

Collecting real-time relevant information of equipment by various sensors, IoT connects between things and things, people and people, and intelligent perception of things and processes based on internet access. The system architecture of IoT mainly includes the perception layer, the transmission layer and the application layer [21, 22]. At present, the IoT has recently attracted scholarly attention and been widely used to many fields. For example, remote monitoring of crops with long-range wireless local area network (LoRaWAN) in the agricultural field [23], data collection and platform construction of medical big data in the medical field [24], real-time positioning and route reminding with the automobile electronic identification and radio frequency identification (RFID) in the field of intelligent transportation[25]. In the field of communication management, the IoT has gradually been applied to the precise monitoring and real-time alarm of the communication manhole cover. Meanwhile, the intelligent level of manhole cover management is also constantly improving [26, 27].

The communication manhole cover is a link that cannot be ignored in the municipal public facilities in the process of urbanization [28]. As an important facility to ensure the integrity and safety of underground equipment and road traffic, the importance of communication manhole cover is self-evident. While the manhole cover manufacturing technology is being updated, the theft-against and damage resistant technology of manhole cover is constantly innovating. And now the protect technology of manhole cover has developed from the initial mechanical theft-against to today's CIMC system with IoT. The shaft pin of theft-against is designed so as to the thief could not pull out the shaft pin and thus could not steal the manhole cover [29]. A self-locking manhole cover is designed so as to prevent the manhole cover from being stolen [30]. All these measures achieve

the purpose of protect communication manhole cover to a certain degree. Although there are many advantages with the usage of mechanical structures and mechanical locks including low cost and easy maintenance, the mechanical theft-against cannot prevent violent opening of manhole cover and alarm timely except preventing the manhole cover being removed away.

With the development of communication technology and the IoT, the manhole cover theft-against system based on the IoT is designed so as to make up for the lack of traditional mechanical damage. The principle is that the manhole cover theft-against system feedback the real-time status information of each manhole cover node to the central system by combining global position system (GPS) positioning and communication technology, then the user can obtain the real-time status information of the manhole cover and control the opening-closing of the manhole cover by the CIMC system. When the system detects the alarm signal of manhole cover, it will push the information to the maintenance personnel and remind the maintenance as soon as possible. A monitoring system of road manhole cover based on ZigBee was proposed by Shi [31]. The system can collect and obtain monitoring data of manhole cover in real-time via combining wireless transmission with sensor, and upload the data to the upper computer (i.e., PC terminal), which displays the accurate position of the manhole cover with the help of map positioning. A smart manhole cover monitoring system based on NB-IoT was proposed by Zhu et al. [32]. The system can judge the open state of the communication manhole cover based on the collection and report the status of the manhole cover and downhole environmental parameters. To some extent, although this method reduces false alarms caused by sensor and communication random errors in terms of the average value after multiple tests, the data of a single sensor often cannot reflect the true state of the communication manhole cover.

At present, the mainstream CIMC alarm methods on the market are given as follows:

(1) The method integrates the terminal of the communication manhole cover, web platform, management system, and terminal of mobile phone. It covers the overall process from front-end products to back-end management. The judgement of alarm signal of communication manhole cover terminal mainly implemented by the inclination sensor. When the manhole cover is illegally opened and an inclination angle of not less than 15° is generated, the sensor will generate the alarm signal and send an alarm [33]. Relevant personnel can obtain all CIMC terminals information only by the mobile phone and monitoring screen. Although this method can well solve the false alarm caused by the slightly vibration (i.e., automobile and car, etc.) of the manhole cover, the system usually generates a false alarm signal due to the single sensor.

(2) Based on the intelligent monitoring of NB-IoT, the method initially realizes application program (APP) switch lock of mobile phone, handheld device management and status query, which is convenient and fast. At the same time, it is embedded with a geographic information system (GIS) to realize visual monitoring [34]. Although this method can perform arithmetic analysis on the signal generated by the manhole cover terminal and reduce the false alarm rate of the system to a certain extent, there is still a lot of room for improvement.

(3) The method provides a comprehensive solution strategy contains manhole cover terminal, web platform and mobile phone APP, etc. and its energy consumption is extremely low via taking advantage of the advanced power management mode. It can display the detailed information contain personnel and communication manhole cover based on GIS map positioning and hierarchical color separation. Meanwhile, the method can support multiple alarm ways, such as voice, speak message service (SMS) and remote-control opening including PC, APP and telephone. However, it has not effectively processed the sensor signal and leads to a certain error in the subsequent alarm judgment.

3. Methods

3.1 Classification and definition of alarm event

According to the physical structure of communication manhole cover and specific usage requirements, in our study, the abnormal alarm of communication manhole cover is divided and defined into the following four types:

(1) Abnormal opening event of outer manhole cover. The normal state of the outer manhole cover is closed state. When the outer manhole cover is opened without authorization, an abnormal opening event of the outer manhole cover is triggered.

(2) Violent opening event of manhole cover. Strong vibration is generated when the outer manhole cover was lifted during the violent opening of manhole cover, and then the violent opening event is

triggered.

(3) Abnormal lock opening event. When the inner manhole cover lock is illegally opened without authorization, the abnormal lock opening event is triggered.

(4) Abnormal opening event of the inner manhole cover. When the inner manhole cover is opened illegally without authorization, the abnormal opening event of the inner manhole cover is triggered. Based on circumstances, the abnormal opening event of the inner manhole cover can be defined as two following sub-events:

①when the violent opening event of the communication manhole cover is generated and the inner manhole cover is opened at the same time, it indicates that the inner manhole cover may have been opened violently by tools, i.e., crowbar, workbench, and hammer. The violent opening can damage the lock bolt and the overall structure of the inner manhole cover.

②when the violent opening event is not generated and the abnormal lock opening event is established, meanwhile, the inner manhole cover is opened, it indicates that the inner manhole cover lock is opened by some ways at this time, and the vibration is small, which triggers the opening event of inner manhole cover by the abnormal lock opening.

3.2 Signal definition of manhole cover state

In the experiment, there are five kind of signals in the CIMC system. For example, signal of outer manhole cover, vibration signal, lock state signal, signal of inner manhole cover, and authorization signal.

(1) Signal of outer manhole cover

There are two state of the outer manhole cover with closed and opened. The signal is generated by the GL5506 light sensor installed in the terminal of the manhole cover. Let us assume that the state signal of the outer manhole cover is designated as S_o , the output voltage threshold and the output voltage value of the light sensor circuit is designated as L_0 and V_o , respectively. The state signal and values are measured in the dark state when the outer manhole cover is opened and closed, respectively. When the output voltage value is less than L_0 , the CIMC judges that the outer manhole cover is opened, and then the manhole cover terminal will transmit the signal with 1 to the IoT cloud platform. In contrast, when the output voltage value is greater than L_0 , the CIMC judges that the outer manhole cover is closed, and the manhole cover terminal transmits the signal with 0 to the IoT cloud platform.

(2) Vibration signal

Let us assume that the vibration signal is designated S_v , it includes two states with vibration and non-vibration. The signal S_v is generated by the SW-18010P vibration sensor installed on the inner manhole cover. When the vibration force generated by the vibration of the manhole cover is greater than the threshold, the vibration switch turns on and generates a vibration signal, at this time the terminal of manhole cover will transmit the signal with 1 to the IoT cloud platform. It transmits the signal with 1 to the IoT cloud platform every time when the manhole cover vibrates. Otherwise, it transmits the signal with 0 to the IoT cloud platform.

(3) Lock state signal

The state of manhole cover lock includes two states with opened and closed. Assuming that the lock state signal is designated as S_l which is generated by the OKD-GPS01 position sensor and is mainly used to measure the relative distance between the lock tongue and the lock hole. The sensor circuit is driven by the change of the relative distance and adjusts the different output voltage. Let us assume that the output voltage threshold value of the position sensor is designated as D_0 , and the output voltage threshold value is finally determined by measuring the output voltage value on condition that multiple opening and closing tests. When the output voltage of the position sensor circuit is less than D_0 , the circuit judges that the lock is closed, and the terminal of the manhole cover transmits the signal with 0 to the IoT cloud platform. In contrast, when the output voltage of the position sensor circuit is greater than D_0 , the circuit judges that the lock is opened, and the terminal of manhole cover transmits the signal with 1 to the IoT cloud platform.

(4) Signal of inner manhole cover

There are two state of the inner manhole cover with closed and opened. The signal is generated by the GL5506 light sensor installed in the terminal of the manhole cover. Assuming that the state signal of the inner manhole cover is designated as S_i , in order to avoid missed detection, the output voltage value of the inner manhole cover in the dark state is measured under the opened and closed conditions, and then the circuit output voltage threshold L_0 is determined. When the output voltage

value is less than L_0 , the CIMC judges that the inner manhole cover is opened, and the terminal of the manhole cover will transmit the signal with 1 to the IoT cloud platform. In contrast, when the output voltage value is greater than L_0 , the CIMC judges that the inner manhole cover is closed, and the terminal of manhole cover transmits the signal with 0 to the IoT cloud platform.

(5) Authorization signal

The authorization signal refers to whether the opening of manhole cover is authorized. The web platform usually issues an order to the manhole cover which allows relevant operations on the manhole cover before opening the manhole cover. Assuming that the authorization signal is designated as S_a , under the circumstance of the received authorization signal S_a remains the state with 1 when the communication between manhole cover terminal and the web platform each time. Conversely, under the circumstance of the no authorization S_a remains the state with 0 when the communication between manhole cover terminal and the web platform each time.

4. Experiment

4.1 Data acquisition

At present, the mainstream communication manhole cover in the market are mainly composed of outer manhole cover, inner manhole cover, lock and terminal of manhole cover. In the terminal of manhole cover, it includes sensor module, main control module and narrowband communication module, etc.

Figure 1 presents the overall architecture of the terminal of manhole cover. In our experiment, the main control module is the single-chip microcomputer named PIC16F1936. NB communication module is WH-NB75 module, it has two working frequency bands with 850 MHz and 900 MHz, respectively, and the data transmission rate is in the range of 100 bps-100 kbps. Meanwhile, via encapsulating channel user datagram protocol (UDP-2, -7) and constrained application protocol (CoAP), the WH-NB75 module supports the standard command set of 3rd generation partnership project (3GPP) and stably extended instruction set, etc.

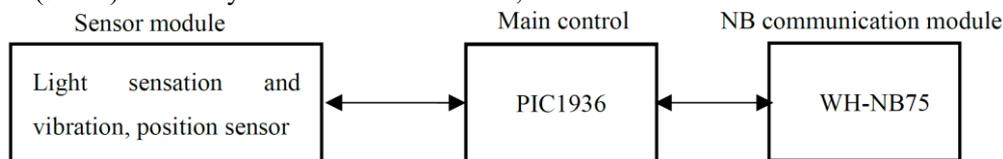


Fig. 1 Overall architecture of manhole cover terminal.

The sensor module mainly includes light sensation sensor, vibration sensor and position sensor, etc.

①the light sensation sensor in our experiment is GL5506 model encapsulated by epoxy resin, which has the characteristics of fast response, small size, high sensitivity and good stability. In the test, two light sensors were used to monitor the outer manhole cover and the inner manhole cover.

②the vibration sensor in our experiment is SW-18010P model, which is a vibration switch, and its sensitivity can be adjusted continuously as needed. one vibration sensor is used in the test to monitor the abnormal vibration of the outer manhole cover and the inner manhole cover.

③the position sensor in our experiment is OKD-GPS01 model. GPS-01 sensor is a normally open proximity switch, which has the characteristics of small size, easy installation, reliable performance, wear resistance and high temperature resistance. The position sensor is usually installed in the lock of the communication manhole cover and mainly responsible for monitoring the relative distance between the lock tongue and the lock hole.

The alarm method proposed in this paper is mainly designed from the aspects of the abnormal opening of outer manhole cover and the inner manhole cover, violent opening of manhole cover, and abnormal lock opening.

4.2 Overall framework

The overall architecture of our experimental system in the paper is shown in Fig. 2. The system mainly includes the terminal of manhole cover, NB-IoT network, IoT cloud platform, and web platform. The terminal of manhole cover is responsible for collecting and reporting the state signals of manhole cover and receiving and executing commands issued by the web platform, respectively. The frequency band of the NB-IoT network is an authorized frequency band with stronger anti-

interference ability. The IoT cloud platform connects the manhole cover terminal with the web platform and provide functions contains connection management, device management, and historical data management of NB-IoT communication. The web platform is the core of the entire system, which implements functions contains data storage, alarm judgment and push, management and maintenance staff information.

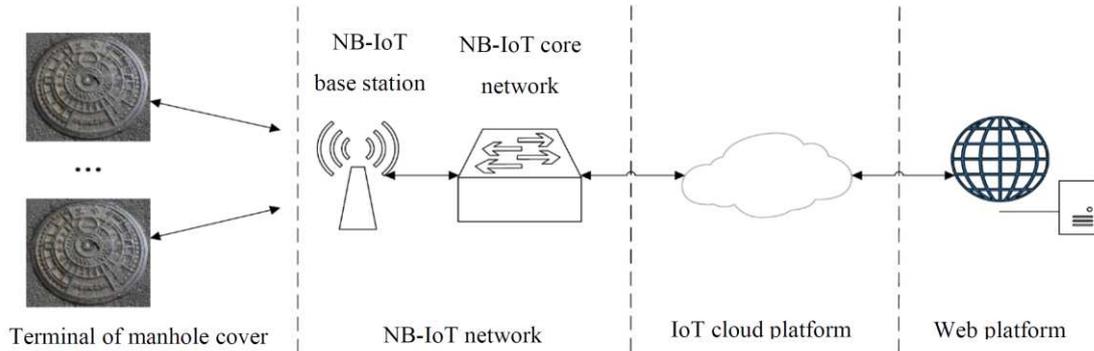


Fig. 2 the overall architecture of the experimental system.

(1) IoT cloud platform

Compared with the traditional direct connection of terminal equipment to the web platform, the IoT cloud platform is developed by defining profiles and codec plugins, which has advantages of congestion control and command-free caching. Table 1 summarizes the detailed comparative analysis of terminal access methods.

Table 1 Comparative analysis of terminal access methods

Web platform connected to the terminal directly	IoT cloud platform
Sends heartbeat packets every 2 minutes and waste resources.	The terminal does not send the heartbeat packets and only one business interaction within 24 hours is required, save the power consumption.
Prone to network congestion and packet loss for the massive device access.	Avoid the congestion and improve the reliability of the IoT systems.
No asynchronous execution between web platform and terminal, increase the overhead and decrease the efficiency.	Cache the commands and have to wait for the results, issue the commands by the aware of the terminal state and ensure the reliability.

In order to ensure the security of data transmission, in the experiment, a two-way communication between the IoT cloud platform and the terminal of the communication manhole cover is established in terms of the CoAP protocol and hypertext transfer protocol secure (HTTPS).

(2) Web platform

In the experiment, the web platform is designed and constructed by the current mainstream browser/server (B/S) architecture. Figure 3 presents the overall architecture of the web platform in the experiment.

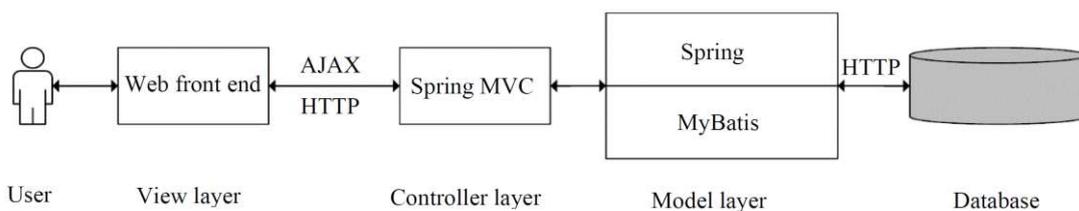


Fig. 3 the overall architecture of the web platform.

The front-end of the web platform system completes functions contains visualization of alarm data, information management of operation and maintenance staff. The back-end completes the analysis, processing, storage, and command issuance of the state signal from manhole cover terminal in the IoT cloud platform.

4.3 Abnormal opening event of outer manhole cover

When the web platform receives the state signal S_o of the outer manhole cover, $S_o=1$, the opening time is the monitoring period with T_1 . Assuming that the duration of the signal $S_o=1$ in the monitoring period is t , and the threshold of the duration of $S_o=1$ is t_1 . When $t > t_1$ and $S_a=0$, the abnormal opening alarm of the outer manhole cover will be triggered. Figure 4 presents the judgment method for abnormal opening of the outer manhole cover.

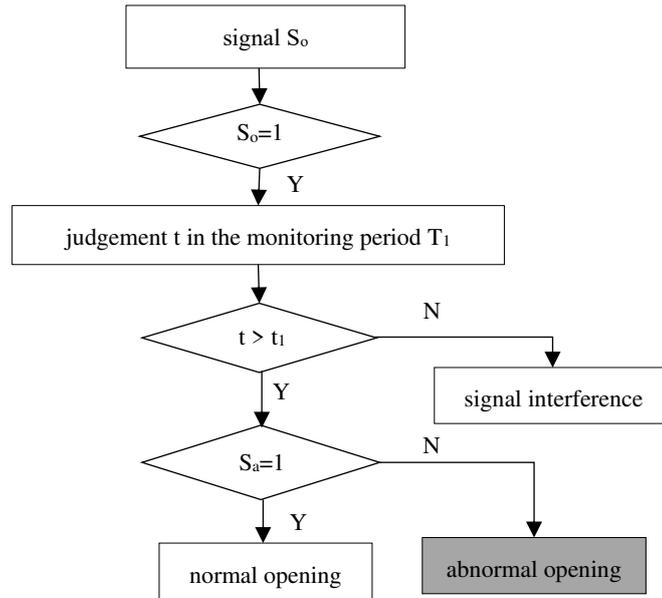


Fig. 4 The judgment method for abnormal opening of the outer manhole cover.

4.4 Violent opening event

When the web platform receives the vibration signal S_v and $S_v=1$, the opening time is the monitoring period T_2 . Assuming that the number of vibrations in the monitoring period is M , and the threshold of the number of vibrations in the same monitoring period is N . If $M > N$, meanwhile, an abnormal opening event of the outer manhole cover has been generated at the same time, and then a violent opening event will be triggered. Figure 5 presents the judgment method of violent opening event of outer manhole cover.

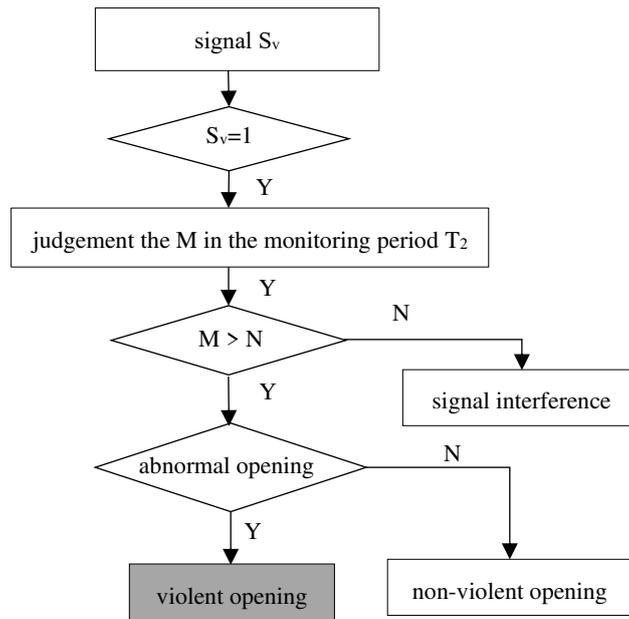


Fig. 5 The judgment method of violent opening event of outer manhole cover.

4.5 Abnormal lock opening event

When the web platform receives the lock state signal S_l and $S_l=1$, the opening time is the monitoring period T_3 . Assuming that the duration of the signal $S_l=1$ in the monitoring period is t , and the threshold of the duration is t_2 . When $t > t_2$ and $S_a=0$, the alarm signal of abnormal lock opening will be triggered. Figure 6 presents the judgment method of the abnormal lock opening event.

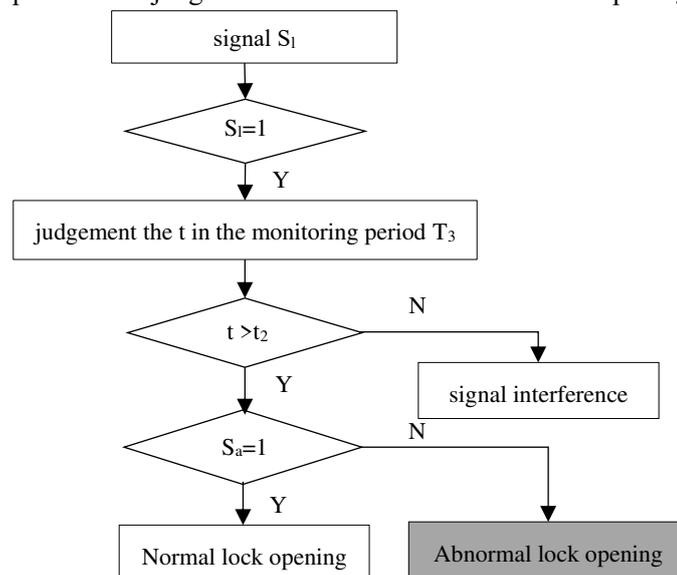


Fig. 6 The judgment method of the lock abnormally opening event.

4.6 Abnormal opening event of inner manhole cover

When the web platform receives the state signal of inner manhole cover S_i and $S_i=1$, the opening time is the monitoring period T_4 . Assuming that the duration of the signal $S_i=1$ in the monitoring period is t , and the threshold of the duration is t_3 . When $t > t_3$, if a violent opening event is currently generated, then a violent opening of the inner manhole cover event will be generated. Even there is currently no violent opening event generated, an abnormal lock opening event of the inner manhole cover will be generated with the condition that an abnormal lock opening alarm signal has been generated. Figure 7 presents the judgment method for abnormal opening event of the inner manhole

cover.

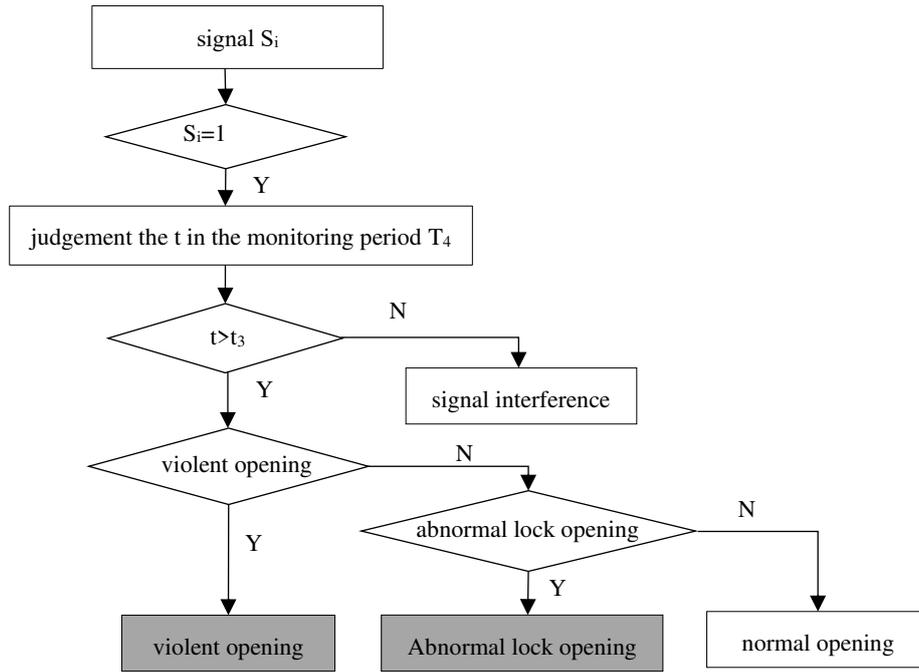


Fig. 7 The judgment method for abnormal opening event of the inner manhole cover.

5. Results and discussion

In the simulation test of alarm method for the communication manhole cover, firstly the simulation transmission of the state signal from the manhole cover terminal is completed by the serial port debugging assistant (SSCOM). Secondly, the IoT cloud platform pushes the received state signal to the web platform for data analysis and processing, and further generates alarm events. Next, record the number of alarms and compare with the number of alarms of the existing methods under the same input signal. Finally, the above comparison results are analyzed and discussed.

5.1 Threshold setting

In the experiment, there are four type of the judgement mechanism in the threshold setting.

①Judgment mechanism for abnormal opening event of outer manhole cover. In the experiment, by introducing the monitoring period T_1 of outer manhole cover and the threshold value t_1 of $S_o=1$ in the monitoring period, then the false alarm caused by the signal mutation is effectively eliminated. Due to the signal mutations in the actual environment are mostly instantaneous signal mutations caused by random errors and some interference, in the experiment the state of the outer manhole cover is finally set to the opening, and the parameter is set at $T_1=10$ s, $t_1=3$ s after many experimental tests.

②Judgment mechanism of violent opening event. By introducing the violent opening monitoring period T_2 and the threshold value N of the number of vibrations in the monitoring period, the false alarm caused by single vibration and non-severe vibration is eliminated. In the experiment, finally the parameter is set at $T_2=60$ s and $N=30$ after many experimental tests.

③Judgment mechanism of abnormal lock opening event. Similar to the sudden change of the state signal of the outer manhole cover, the false alarm caused by the sudden change of the signal is eliminated by introducing the outer manhole cover state monitoring period T_1 and the threshold t_1 for the $S_o=1$ in the monitoring period. In the experiment, finally the parameter is set at $T_3=10$ s, $t_1=3$ s after many experimental tests.

④Judgment mechanism for abnormal opening event of inner manhole cover. Similarly, by introducing the monitoring period T_4 of the inner manhole cover and the threshold t_3 of the $S_i=1$ in the monitoring period, the false alarm caused by the signal mutation is eliminated. In the experiment, finally the parameter is set at $T_4=10$ s, $t_3=3$ s after many experimental tests.

5.2 Abnormal opening test of outer manhole cover

In order to test the alarm method of the outer manhole cover proposed in this paper and its performance, a variety of outer manhole cover state signals and authorized signals is introduced and used as the input signals, then record the number of alarms of the proposed method in this paper and the existing method, and finally analyze and discuss the results. In the test, the presetting input signals with the duration of 10 s as shown in Table 2. Table 2 summarizes the comparison of alarm method with the five types of presetting signals.

Table 2 Comparison of alarm method with the five types of presetting signals

Input signal	Number of Alarm	
	The existing method	The proposed method
Signal 1, $S_a=0$, $S_o=0$	0	0
Signal 2, $S_a=0$, the duration lasts 1 s with $S_o=1$	1	0
Signal 3, $S_a=0$, the duration lasts 2 s with $S_o=1$	1	0
Signal 4, $S_a=0$, the duration lasts 3 s with $S_o=1$	1	1
Signal 5, $S_a=0$, $S_o=1$	1	1

As can be seen from Table 2, the number of alarms for the existing method and the proposed method in this paper under the same input signal conditions. The test results show that the proposed method in this paper can eliminate the false alarm caused by the duration $t \leq 2$ s when the state signal $S_o=1$. Corresponding, both the proposed method in this paper and the existing methods can achieve accurate alarm when the signal $S_o=1$ and the duration $t \geq 3$ s.

5.3 Violent opening test

In order to test the alarm method of violent opening proposed in this paper and its performance, a variety of vibration signals is introduced and used as the input signals, then record the number of alarms of the proposed method in this paper and the existing methods, and finally analyze and discuss the results.

In order to simulate possible vibration sources in the real environment, the duration of the vibration signal is set to 60 s in the experiment. There are two types of vibration signals in the test including single vibration and gap vibration. In the type of single vibration, the vibration gap is set from 1 s to 30 s within the 60 s duration, so there are total 30 kinds of vibration signals. In the type is the gap vibration, three vibrations with a vibration gap of 1 s are used as a vibration unit in the 60 s duration, and the gaps of the vibration units are set from 1 s to 30 s, respectively, so there are total 30 kinds of vibration signals. When the vibration signal is input each time, the outer manhole cover is divided into the two following states, for example, alarm and no alarm event of abnormal opening has been generated for outer manhole cover. Table 3 summarizes the detailed comparison of the number of alarms for the violent opening.

Table 3 Comparison of number of the alarms for the violent opening

Input signal		Number of Alarm	
		The existing method	The proposed method
No generated alarm event of abnormal opening, $S_a=0$	single vibration	250	0
	gap vibration	438	0
Alarm event has been generated of abnormal opening, $S_a=0$	single vibration	250	31
	gap vibration	438	23

As can be seen from Table 3, the number of alarms of the existing method and the proposed method in this paper under the same input signal conditions. The test results show that when the outer manhole cover is not opened, that is, there is no abnormal opening event of the outer manhole cover, the proposed method in this paper infers that the abnormal opening of the outer manhole cover may be caused by the car and does not further alarm in the unauthorized state. Therefore, the proposed method in this paper can effectively eliminate the mild vibration and false alarms generated in the unauthorized state. In contrast, when the outer manhole cover is opened, that is, when an alarm event of abnormal opening of the outer manhole cover is generated, for the severe vibration in an unauthorized state, the proposed method in this paper infers that the abnormal opening of the outer manhole cover may be caused by violent opening, and an alarm event of violent opening is generated at this time.

5.4 Abnormal lock opening test

In order to test the alarm method of abnormal lock opening event proposed in this paper and its performance, the state signal of lock and authorization signal are used as the input signal, and then the number of the alarm between the proposed method and the existing methods are recorded, and finally the results are analyzed and discussed.

In the test, the presetting input signals with the duration of 10 s as shown in Table 4. Table 4 summarizes the detailed comparison of the number of alarms for the abnormal lock opening.

Table 4 Comparison of the number of alarms for the abnormal lock opening

Input signal	Number of Alarm	
	The existing method	The proposed method
Signal 1, $S_a=0$, $S_l=0$	0	0
Signal 2, $S_a=0$, the duration lasts 1 s with $S_l=1$	1	0
Signal 3, $S_a=0$, the duration lasts 2 s with $S_l=1$	1	0
Signal 4, $S_a=0$, the duration lasts 3 s with $S_l=1$	1	1
Signal 5, $S_a=0$, $S_l=1$	1	1

The test results show that when the duration $t \leq 2$ s with the lock state signal $S_l=1$, the proposed method in this paper infers that it is a false alarm caused by a sudden change in the signal, and the abnormal lock opening event can be ignored. Correspondingly, when the lock state signal $S_l=1$ and the duration $t \geq 3$ s, the proposed method in this paper infers that the real lock state at this time is the opening, and then generates an alarm event of abnormal lock opening.

5.5 Abnormal opening test of inner manhole cover

In order to test the abnormal opening method proposed in this paper of the inner manhole cover, a variety of state signals from inner manhole cover is input, and record the number of alarms of the proposed method in this paper and the existing method, and then analyze and discuss the results.

In the experiment, the duration of the input state signal S_i of inner manhole cover is set to 10 s, and the input signal of the inner manhole cover includes the following five categories:

Signal 1: the state signal S_i of the inner manhole cover is always 0.

Signal 2: the duration is 1s when the inner manhole cover status signal $S_i=1$.

Signal 3: the duration is 2 s when the inner manhole cover status signal $S_i=1$.

Signal 4: the duration is 3 s when the inner manhole cover status signal $S_i=1$.

Signal 5: the state signal S_i of the inner manhole cover is always 1.

Due to the violent opening event and the abnormal lock opening event have both states with generated and ungenerated, respectively, therefore, there are a total of 20 input signals before each input of the state signal of the inner manhole cover in the experiment.

Table 5 summarizes the detailed test results of violent opening event, whereinto, T represents that an alarm is generated, and F represents that no alarm is generated.

Table 5 Test results of violent opening event

Input signal	Alarm event of violent opening generated		No alarm event of violent opening generated		
	Lock abnormal opening event generated	No lock abnormal opening event generated	Lock abnormal opening event generated	No lock abnormal opening event generated	
Signal 1	F	F	F	F	
Signal 2	F	F	F	F	The
Signal 3	F	F	F	F	proposed
Signal 4	T	T	T	F	method
Signal 5	T	T	T	F	
Signal 1	T	T	T	T	
Signal 2	T	T	T	T	The
Signal 3	T	T	T	T	existing
Signal 4	T	T	T	T	method
Signal 5	T	T	T	T	

The experimental results show that, on the one hand, the alarm method proposed in this paper can effectively eliminate the caused false alarm when the duration is less than 2 s with the state signal of the inner manhole cover $S_i=1$. On the other hand, in the generation of non-violent opening events and abnormal lock opening events, when the duration larger than 3 s with the state signal S_i of inner manhole cover, the alarm method proposed in this paper infers that only the outer manhole cover is abnormal opening at this time, and the inner manhole cover is not generated alarm event. It eliminates effectively false alarms of abnormal opening of the inner manhole cover caused by strong light refraction when the outer manhole cover is opened. In addition, when the duration is larger than 3s with state signal of inputted inner manhole cover, for the violent opening event and the abnormal lock opening event that has been generated, both the proposed method in this paper and the existing method can both realize the abnormal alarm.

6. Conclusions

Based on the IoT and the current CIMC system, this paper proposes a new alarm method with multiple event fusion. The experimental results show that the proposed method in this paper can perform the transmission of state signal and generate and push the alarm events. Compared with the existing alarm method, the proposed method in this paper can significantly reduce the abnormal false alarm rate of the CIMC and improve the usability and practicability of the CIMC system. The detailed research work of this paper mainly as follow:

(1) Aiming at the actual application of the current CIMC, in this paper a new alarm method on the basis of multiple event fusion in terms of different components of the CIMC terminal.

(2) System performance test and simulation test of the proposed alarm method of CIMC in this paper is performed from by the outer manhole cover, violent opening manhole cover, lock abnormal opening and inner manhole cover, respectively.

The alarm method proposed in this paper can make up for the defect that a single sensor cannot fully reflect the true state of the communication manhole cover, and reduce the false alarm caused by the random error both sensor and communication, it has good practicability. However, there are some shortcomings of proposed method in this paper. For example, (1) at present, the abnormal alarm of the CIMC is rely on the static analysis of the manhole cover terminal signal, and the work about the dynamic interactive alarm that is more closely real-time monitoring is rarely involved. (2) the factors affecting the alarm method of CIMC mainly include the complexity of environment around, random errors of sensors, etc. So, the specific method and deployment systems need to be explored and designed according to the actual situations. (3) the alarm threshold of the proposed method in this paper is mainly derived from the simulation scenarios. In the specific applications,

due to the differences in network signals, regions and product parameters of equipment manufacturers, etc., whether the same alarm method of CIMC is applicable or not is still to be explored. In summary, these are the important directions for our future work.

Abbreviations

CIMC: Communication intelligent manhole cover; IoT: Internet of things; NB-IoT: Narrowband-internet of things; LTE: Long term evolution; NB-M2M: Narrowband-machine to machine; NB-OFDM: Narrowband-orthogonal frequency division multiplexing; PSM: Power saving mode; DRX: Discontinuous reception; EDRX: Extend discontinuous; LPWAN: Low-power wide-area network; LoRaWAN: Long-range wireless local area network; RFID: Radio frequency identification; GPS: Global position system; APP: Application program; GIS: Geographic information system; SMS: Speak message service; UDP: User datagram protocol; CoAP: Constrained application protocol; 3GPP: 3rd generation partnership project; HTTPS: Hypertext transfer protocol secure; B/S: Browser/server; SSCOM: Serial port debugging assistant.

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Author's contributions

X. Liu and C. Li conceived of the designed the study. X. Liu, G. Guo and S. Gu developed the simulations and performed the computation. L. Liu and J. Zhao wrote the paper. X. Liu and C. Li reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Competing interest

The authors declare that they have no competing interests.

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Figures

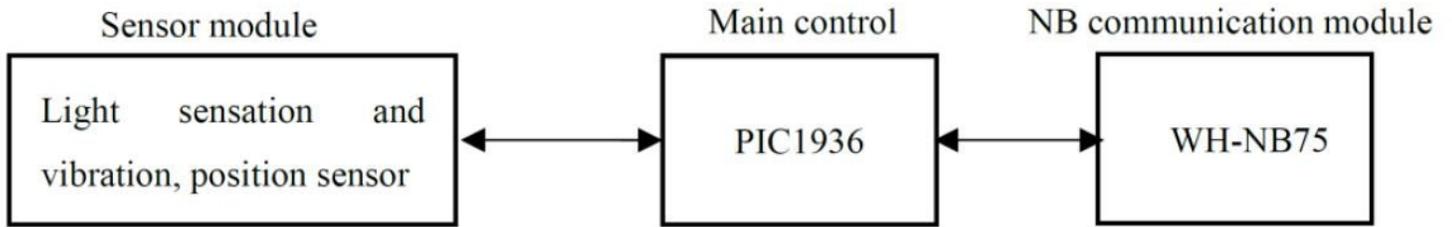


Figure 1

Overall architecture of manhole cover terminal.

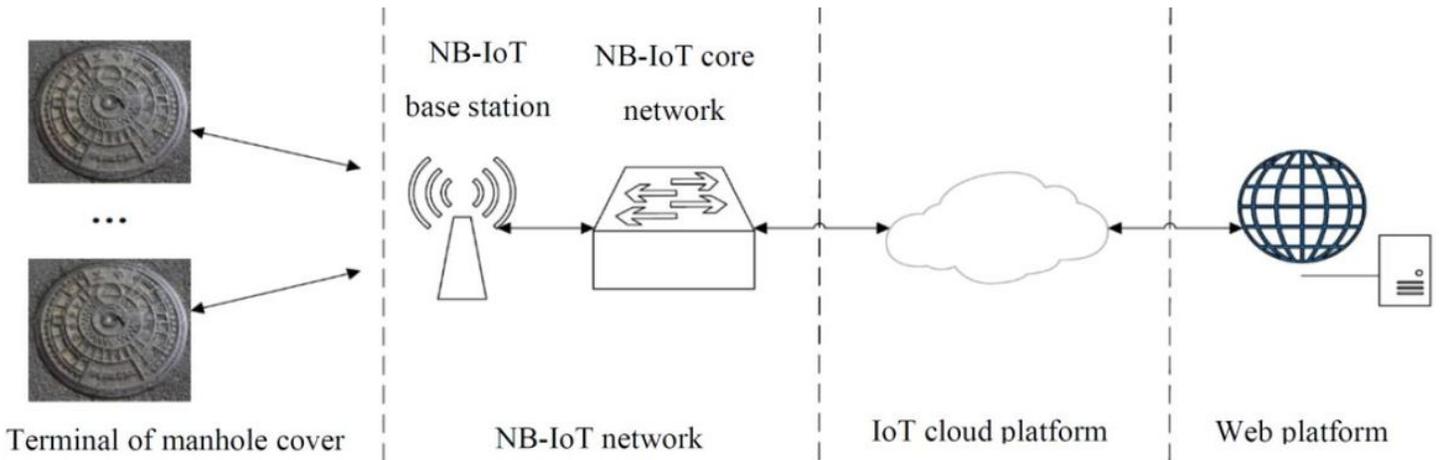


Figure 2

The overall architecture of the experimental system.

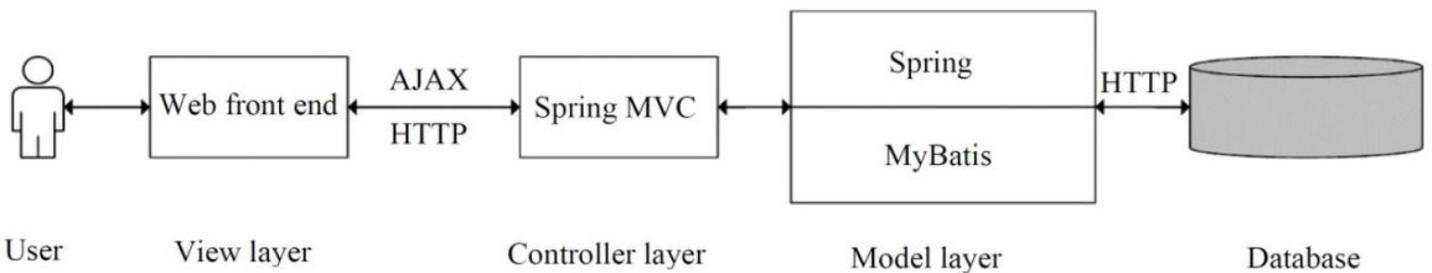


Figure 3

The overall architecture of the web platform.

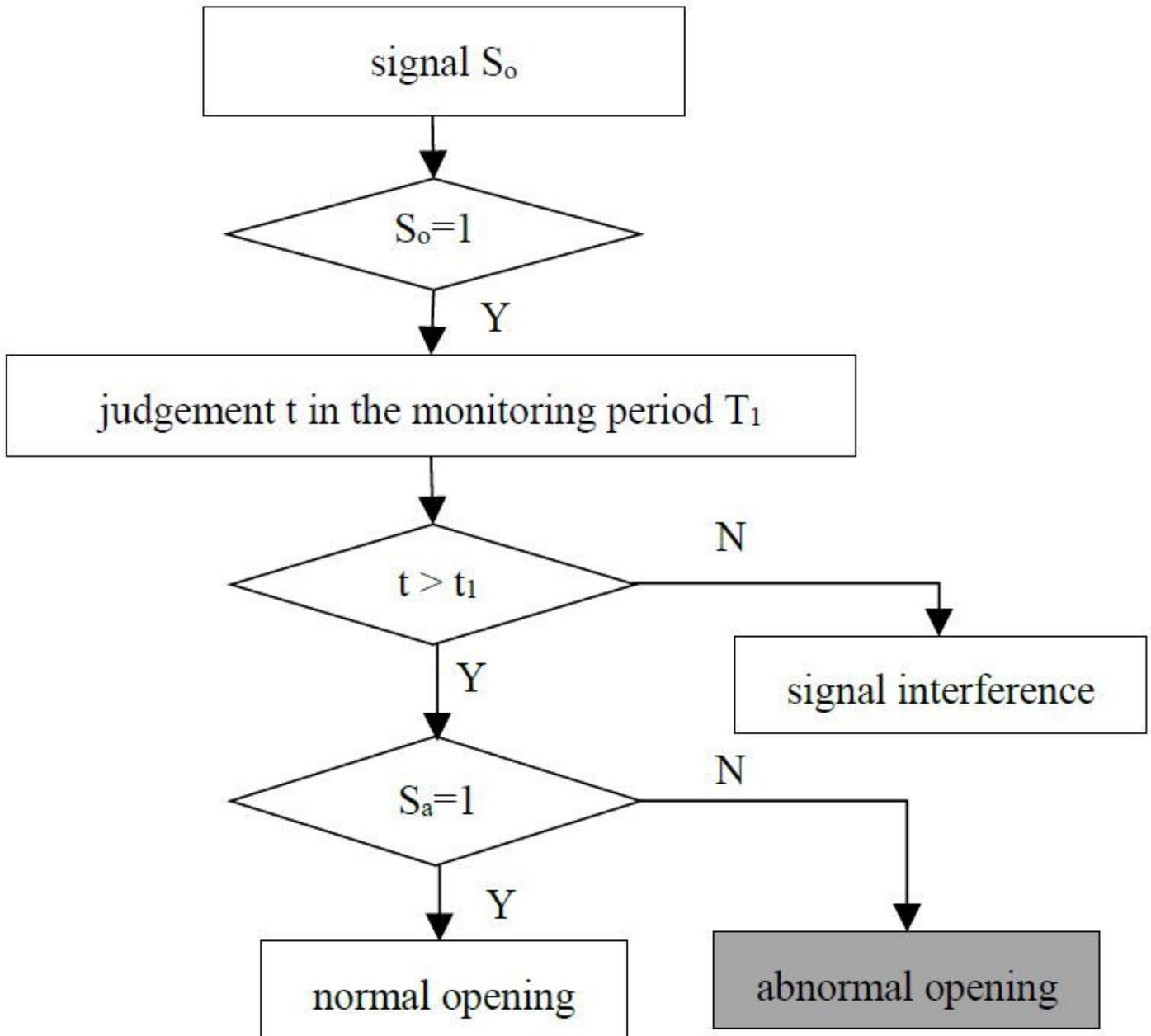


Figure 4

The judgment method for abnormal opening of the outer manhole cover.

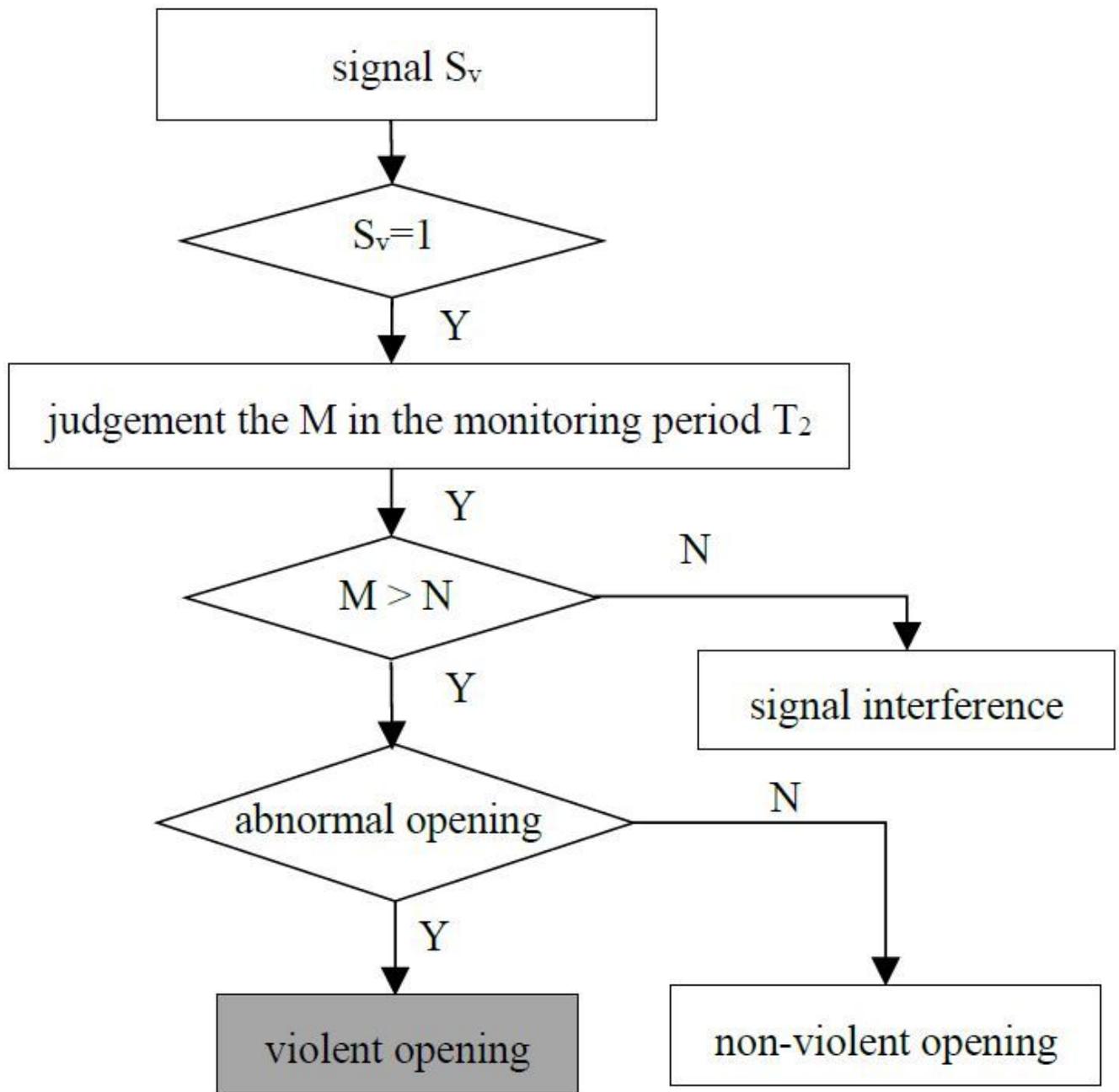


Figure 5

The judgment method of violent opening event of outer manhole cover.

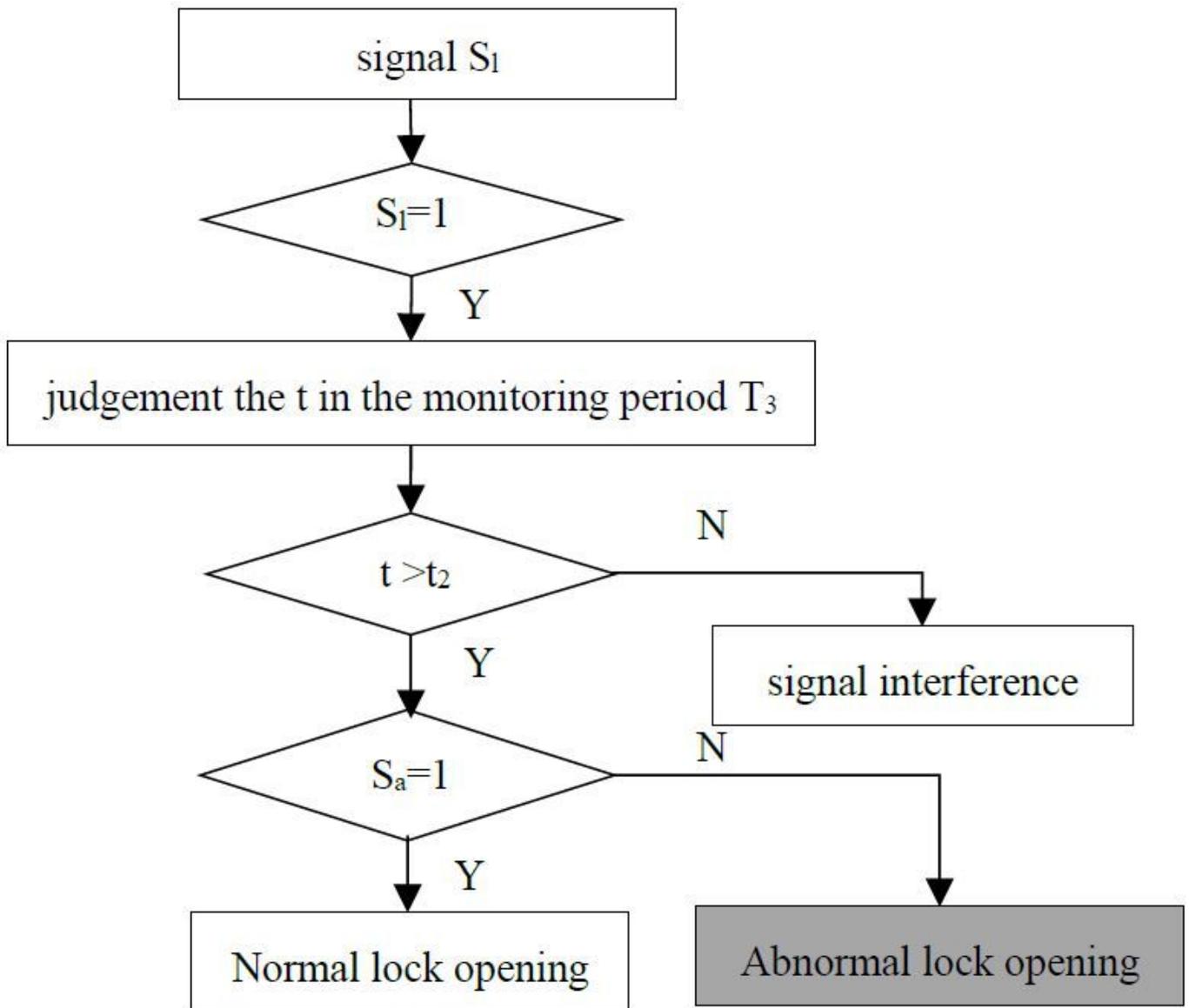


Figure 6

The judgment method of the lock abnormally opening event.

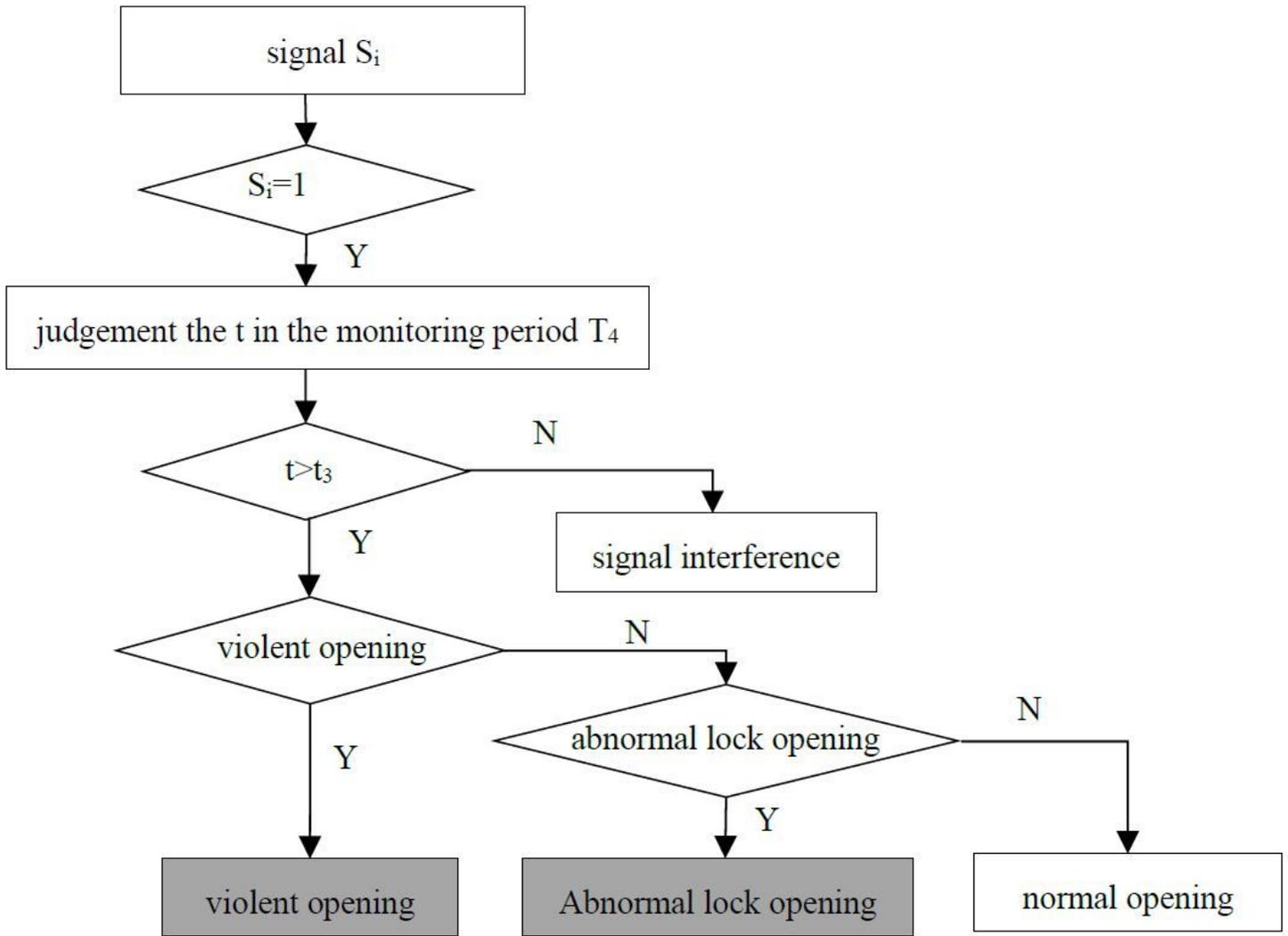


Figure 7

The judgment method for abnormal opening event of the inner manhole cover.