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Alarm method of communication intelligent manhole cover based on multiple event fusion

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Abstract

As a comprehensive utilization of pipeline resources, communication intelligent manhole cover (CIMC) can effectively real-time monitor communication manhole cover and protect the safety of communication pipeline. Due to the complex working environment of manhole cover and the random error of sensor, the traditional monitoring method usual leads to frequent false alarm in actual applications. In order to ensure the monitoring service quality and improve the service efficiency, a new alarm method of CIMC with multiple event fusion in this paper via jointing analysis of multi-sensor status signals is proposed based on the equipment status signals generated by the CIMC terminal and 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 of a single sensor, but also reduces the false alarm rate caused by the random error of sensor and CIMC system. It can promote the intelligent monitoring efficiency of the 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

Given the rapid growth of communication manhole covers with the acceleration of urbanization [1, 2], it is more and more difficult to manage the road safety with high automation and intelligence. At present, the main management mode of general communication manhole cover is manual inspection [3]. It results in lots of waste in human resource. 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). It is able to reduce power consumption by means of power saving mode (PSM), discontinuous reception (DRX) and extend discontinuous (EDRX) methods, etc. [4–9]. 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 deployed widely by the ways of in-band, guard band and independent carrier with license frequency [10–12]. It has obvious advantages in the information management of communication intelligent manhole cover (CIMC).

At present, the typical structure of CIMC system usually contains the outer manhole cover, inner manhole cover, lock, manhole cover terminal. To protect communication resources including pipelines, manholes and cables, the CIMC system can conduct real-time monitoring and alarm for abnormal opening of external manhole cover, internal manhole cover and lock [13–16]. However, the application strategies and design methods vary from products to products [17, 18]. According to statistics, there are three design ways of CIMC in the manhole cover monitoring. For example, 1) installing the sensor and Beidou navigation positioning system at the bottom of traditional manhole cover. 2) setting the smart stick and base station beside the manhole cover. 3) combining of material changes, wireless network and cloud platform, etc. [19–25]. 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 issues remained in the daily management of communication manhole cover. For example, (1) the number of communication manhole cover is large and the distribution area is wide, even sharing the same communication pipeline from several kinds of pipelines. (2) When the communication manhole cover damage, loss, blockage and displacement, the management department cannot timely access to specific information and eliminate hidden dangers. (3) The 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. (4) Different communication operators and ownership departments of pipeline often cross lines and place communication facilities discretionary in practice, it is easy to cause disputes and security risks.

As mentioned above, a new alarm method of CIMC based on multiple event fusion is proposed in this paper. The experimental results show that the proposed 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 following are the major contributions of this paper:

1. The alarm event is defined and divided into four categories, and then the corresponding generated signal by multiple sensors is set up.
2. In view of the above different abnormal events, the real-time transmission of alarm information is completed in terms of the NB-IoT.
3. By means of numerical results with analytically and numerically, the alarm method of CIMC based on multiple event fusion is designed and tested in our experiment.

The main idea and structure of this paper is as follows: an overview of related works in CIMC alarm method based on multiple event fusion is first introduced in Sect. 2. In Sect. 3, we present the material and the detailed CIMC alarm methods. The CIMC alarm method is designed and analyzed in Sect. 4. Section 5 contains the experiments and results of CIMC alarm method. We end our study with discussions and conclusions in the Sect. 6.

2 Related works

The IoT usually contains the perception layer, the transmission layer, and the application layer in the system architecture [26–29]. At present, the IoT has been widely used in many fields. For example, remote monitoring of crops with long-range wireless local area network (LoRaWAN) in the agricultural field [30], data collection and platform construction of medical big data in the medical field [31], real-time positioning and route reminding with radio frequency identification (RFID) in the intelligent transportation field [32]. Meanwhile, the IoT has gradually been applied to the precise monitoring and real-time alarm of the communication manhole cover, and the intelligent level of manhole cover management continue to improve [33–35]. The communication manhole cover is an important facility to ensure the integrity and safety of underground equipment and road traffic. And now the protect technology of manhole cover has developed from the initial mechanical theft-against to today's CIMC system with IoT [36, 37]. Although there are many advantages with the usage of mechanical structures and mechanical locks including low cost and easy maintenance, in practice, it cannot prevent violent opening of manhole cover and alarm timely.

The communication and IoT technology is updating rapidly, and the manhole cover theft-against system can make up for the lack of traditional mechanical damage. Once the system detected the alarm signal of manhole cover, it will push the information to the maintenance personnel and remind the maintenance as soon as possible. For example, a monitoring system of road manhole cover based on ZigBee can collect and obtain monitoring data of manhole cover in real-time via combining wireless transmission with sensor and display the accurate position of the manhole cover [38]. A smart manhole cover monitoring system based on NB-IoT can judge the open state of the communication manhole cover by collecting and reporting the parameters of the manhole cover and downhole environment [39]. Although this method can reduce false alarms caused by sensor and communication random errors in terms of the average value after multiple tests, the signal of a single sensor often cannot reflect the true state of the communication manhole cover.

In summary, the related work in CIMC alarm methods are given as follows:

1. Integrating the terminal of the communication manhole cover, web platform, management system, and mobile phone in the CIMC method. 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 [40]. 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. Performing application program (APP) switch lock of mobile phone, handheld device management and status query based on the intelligent monitoring of NB-IoT. It is embedded with a geographic information system (GIS) to realize visual monitoring [41]. 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. Providing a comprehensive solution strategy contains manhole cover terminal, web platform and mobile phone APP, etc. In this method, the 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 Principle of event definition

According to the existing works [42], let us assume the event $T = \{T_1, T_2, \ldots T_n\}(n \geq 1)$, it has m attributes, and the attribute set is A. And then the class event has then the weight of the ith attribute in the kth entity-centered event can be expressed by:

$$w(T_k, A_i) = \frac{\log_2 F(T_k, A_i) \cdot \log_2 \frac{|T|+1}{|N(A_i)+0.5|}}{\sqrt{\sum_{i=1}^{m} \left\{ [\log_2 F(T_k, A_i) + 1] \cdot \log_2 \frac{|T|+1}{|N(A_i)+0.5|} \right\}^2}} \tag{1}$$

where $F(T_k, A_i)$ is the occurrence frequency of event attribute A_i in event T_k; $1 \leq k \leq n, 1 \leq i \leq m$; $|T|$ is the total number of events with the same entity in the event set, $N(A_i)$ is the number of events with attribute T_i.

$$S(T_m, T_n) = \sum_{A \in T_m \cap T_n} w(T_m, A) \cdot w(T_n, A) \tag{2}$$

where $A \in T_m \cap T_n$ is the set with the same attribute between events T_m and T_n.

The calculation of event association strength can be expressed by:

$$R(T_a, T_b) = \frac{\sum_{A_m \in T_a} \sum_{A_n \in T_b} RP(T_a : A_m, T_b : A_n)}{|\vec{T}_a||\vec{T}_b|} \tag{3}$$

where $R(T_a, T_b)$ is the association strength of event T_a and T_b, $RP(T_a : A_m, T_b : A_n)$ is the association strength of event attributes, $|\vec{T}_a|$ and $|\vec{T}_b|$ is the norm of the vector of event T_a and T_b.

Considering factors such as weight, similarity and correlation strength of events, the definition of abnormal alarm event with multi-sensor status signals can be expressed by:

$$M(T_a, T_b) = \begin{cases} S(T_a, T_b) \cdot R(T_a, T_b), & T_a > T_b \\ 0, & T_a < T_b \end{cases} \tag{4}$$

where $T_a > T$ represents the time of the event T_a is earlier than that of the event T_b; otherwise, $T_a < T$ represents the time of the event T_a is later than that of the event T_b.

3.2 Classification and definition of alarm event

In the proposed work, 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 outer manhole cover is closed. 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. And the abnormal opening event of the inner manhole cover can be defined as two following sub-events:

   (1) The violent opening event of the manhole cover is generated as well as the open of the inner manhole cover. It indicates that the inner manhole cover may have been opened violently without authorization. The violent opening can damage the lock bolt and the overall structure of the inner manhole cover.

   (2) The violent opening event is not generated and the abnormal lock opening event is established. It indicates that the inner manhole cover lock is opened by some ways, and the vibration is small, which triggers the opening event of inner manhole cover by the abnormal lock opening.

3.3 Signal definition of manhole cover state

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

1. Signal of outer manhole cover

The signal of outer manhole cover is generated by the light sensor (i.e., GL5506) installed in the terminal of the manhole cover. It has two states with closed and opened. Assuming 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

Assuming that the vibration signal is designated as S_v, it includes two states with vibration and non-vibration. The signal S_v is generated by the vibration sensor (i.e., SW-18010P) 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 position sensor (i.e., OKD-GPS01). 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 OKD-GPS01 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 OKD-GPS01 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 OKD-GPS01 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 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 obtained. 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.

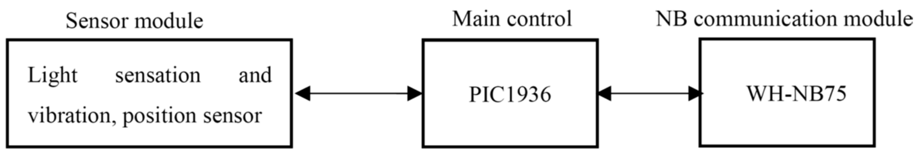

Fig. 1 Overall architecture of manhole cover terminal

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 common communication manhole cover is 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 (i.e., PIC16F1936). NB communication module (i.e., WH-NB75) 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 (i.e., 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.

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

1. The light sensation sensor in our experiment is GL5506 module 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.
2. The vibration sensor in our experiment is SW-18010P module, 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.
3. The position sensor in our experiment is OKD-GPS01 module. GPS-01 sensor is a normally open proximity switch, which has the characteristics of small size, easy

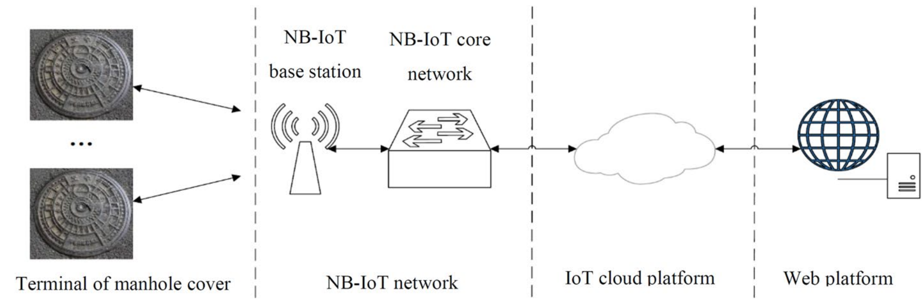

Fig. 2 The overall architecture of the experimental system

Table 1 Comparative analysis of terminal access methods

Web platform	IoT cloud platform
Heartbeat packets every 2 min and waste resources	The terminal does not send the heartbeat packets and only one business interaction within 24 h is required, save the power consumption
The network congestion and packet loss for the massive device access	It can avoid the congestion and improve the reliability of the IoT systems
There is no asynchronous execution between web platform and terminal, increase the overhead and decrease the efficiency	It can cache the commands and wait for the results, issue the commands by the aware of the terminal state and ensure the reliability

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 proposed alarm method 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 collects and reports the state signals of manhole cover and receive and executes 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.

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.

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.

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 $\underline{S}_o = 1$ in the monitoring period is designated as 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.

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 designated as M, and the threshold of the number of vibrations in the same monitoring period is designated as 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.

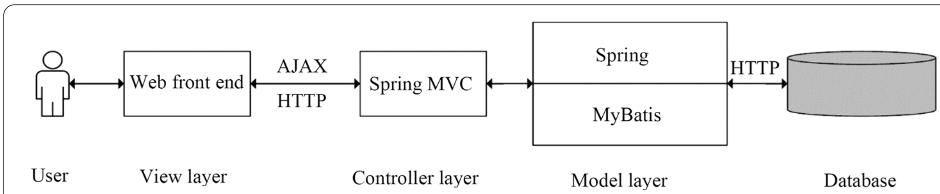

Fig. 3 The overall architecture of the web platform

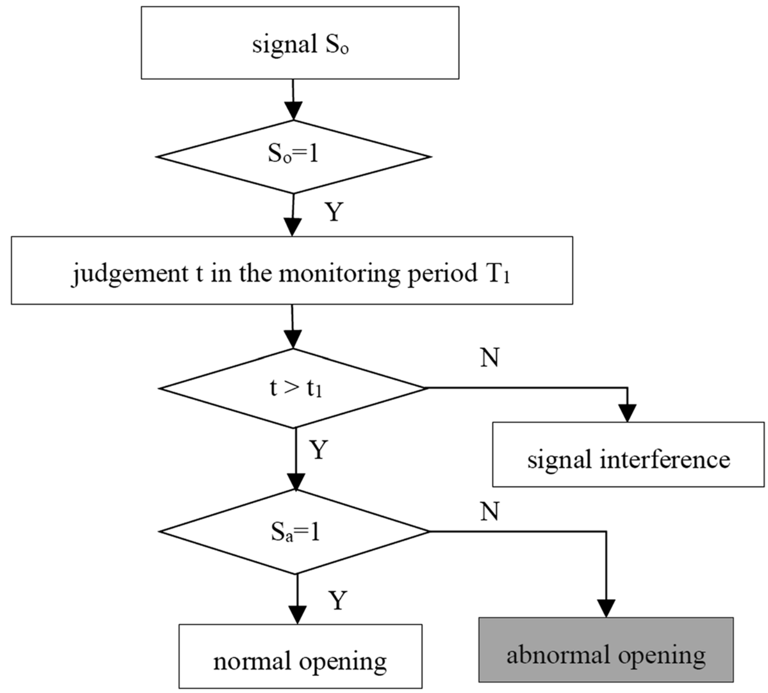

Fig. 4 The judgment method for abnormal opening of the outer manhole cover

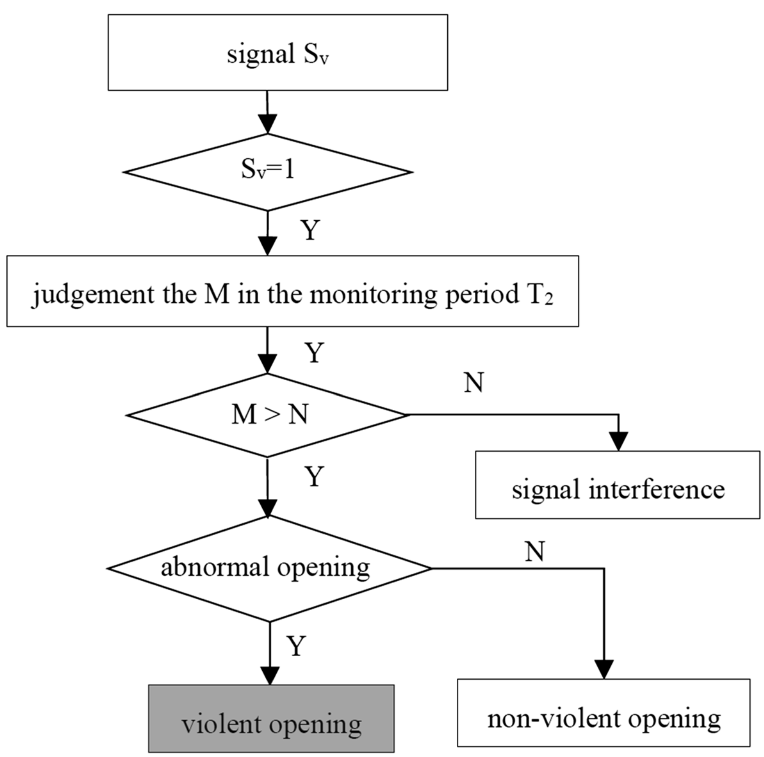

Fig. 5 The judgment method of violent opening event of outer manhole cover

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 designated as t, and the threshold of the duration is designated as 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.

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 designated as 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.

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

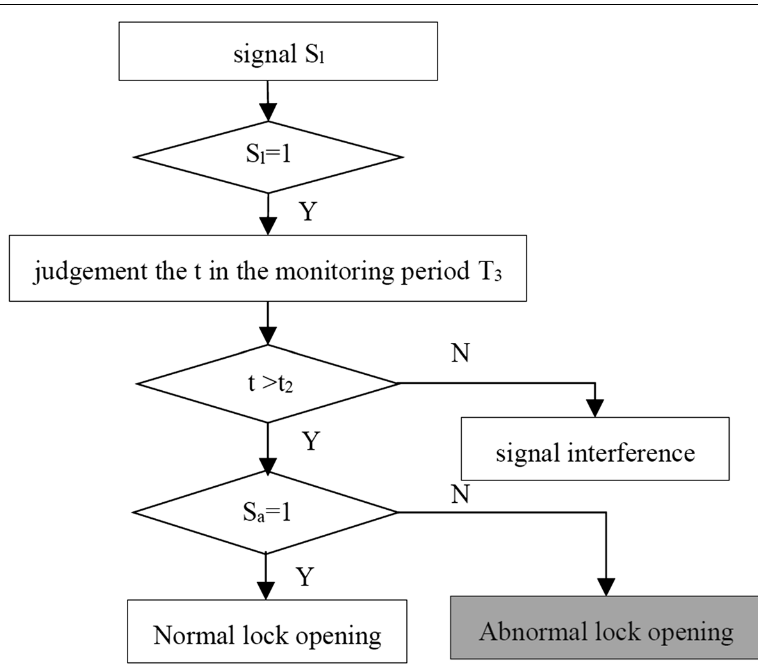

Fig. 6 The judgment method of the lock abnormally opening event

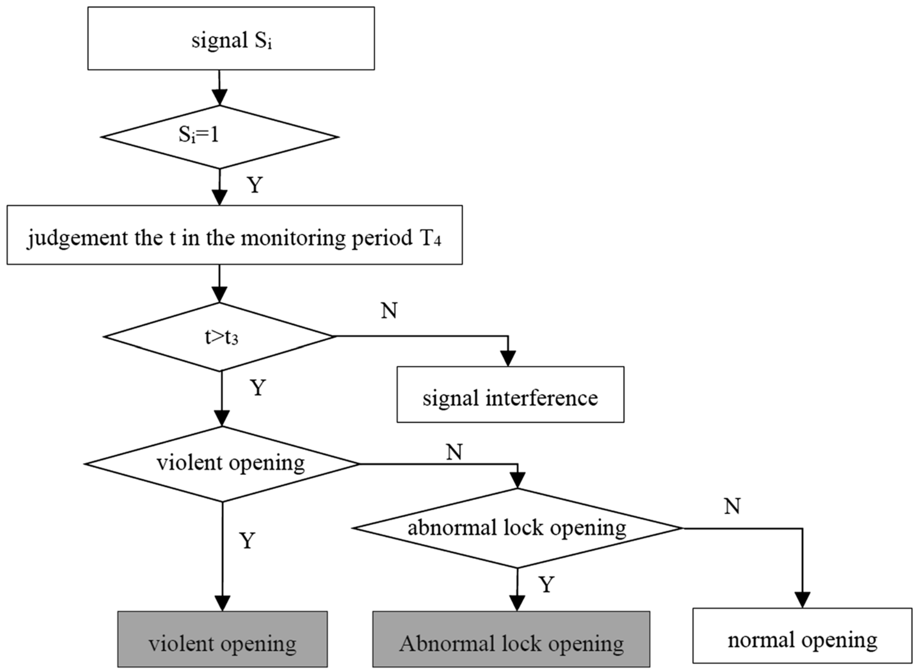

Fig. 7 The judgment method for abnormal opening event of the inner manhole cover

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.

1. Judgment 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 in the monitoring period $S_o=1$, 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.
2. Judgment mechanism of violent opening event. By means of 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.
3. Judgment 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

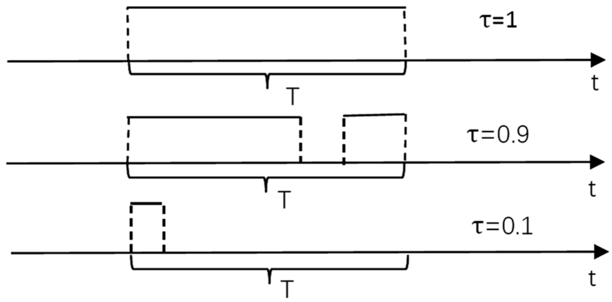

Fig. 8 The test signal of abnormal opening of outer manhole cover

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

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.

4. Judgment 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

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. The Fig. 8 shows the detailed test signal of abnormal opening of outer manhole cover. Thereinto, $t = 10$ s, $\tau_0 = 0.8$, $S_a = 0$.

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.

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

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.

To simulate the 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 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 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.

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.

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

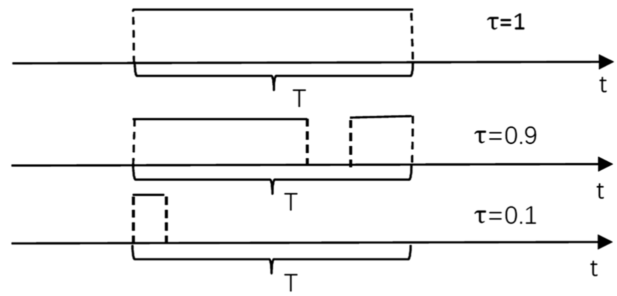

Fig. 9 The test signal of abnormal lock openings

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

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.

The Fig. 9 shows the detailed test signal of abnormal lock opening. Thereinto, $t = 10$ s, $\tau_0 = 0.8$, $S_a = 0$, $t_1 = 600$ s.

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.

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, $\tau_0=0.8$, $S_a=0$, $t_1=600$ 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.

As shown in Table 5, on the one hand, the proposed method in this paper can effectively eliminate the 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, the proposed method in this paper can eliminate the false alarm when the duration is larger than 3 s with the state signal S_i of inner manhole cover. Meanwhile, the inner manhole cover is not able to 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 3 s 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.

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
The proposed method				
Signal 1	F	F	F	F
Signal 2	F	F	F	F
Signal 3	F	F	F	F
Signal 4	T	T	T	F
Signal 5	T	T	T	F
The existing method				
Signal 1	T	T	T	T
Signal 2	T	T	T	T
Signal 3	T	T	T	T
Signal 4	T	T	T	T
Signal 5	T	T	T	T

6 Conclusions

Based on the IoT and the current CIMC system, in this paper, a new alarm method with multiple event fusion was investigated. Compared with the existing alarm method, the proposed CIMC alarm method can both perform the transmission of state signal, generate, and push the alarm events. It can effectively reduce the abnormal false alarm rate of the CIMC and improve the practicability and service efficiency 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 based on multiple event fusion of the CIMC terminal is tested, and then the result is evaluated by analytically and numerically.
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 proposed CIMC alarm method 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 can effectively guarantee the quality of CIMC system. However, there are some shortcomings of proposed CIMC method in this paper. For example, (1) at present, the abnormal alarm of the CIMC mainly rely on the static analysis of the manhole cover terminal signal, and the work about the dynamic interactive alarm with real-time monitoring is rarely involved. (2) the factors affecting the CIMC alarm method mainly include the complexity of environment around, random errors of sensors, etc. Therefore, the specific method and deployment systems need to be further discussed and designed in terms of the actual situations. (3) the alarm threshold of the CIMC method is 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. Our future concerns will be the joint dynamic interactive alarm with real-time monitoring, robustness, and university in practice.

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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Authors' 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 interests
The authors declare that they have no competing interests.

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