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The intelligent crude oil anti-theft system based on IoT under different scenarios

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Abstract

Oil theft always results in huge economic loss, human casualties, and extremely environmental pollution especially when the leaks from crude oil pipeline are not detected and repaired timely. In this paper, we focus on how to detect and monitor abnormal noise and vibration beforehand or in real time by the Internet of Things (IoT). Firstly, the diversities of crude oil theft and the difficulties of oil anti-theft are analyzed in China, and the requirement analysis of the IoT application is stated. Secondly, the intelligent anti-theft system based on the IoT is planned and designed for crude oil transportation by tank trucks and by oil pipelines according to the current situation in China. Thirdly, the problems of anti-theft system implementation are discussed, and the suggestions and advice are put forward to ensure that the system can be implemented successfully. The intelligent anti-theft system application can not only stop oil theft timely, but also prevent oil mice from stealing crude oil beforehand.

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Keywords: crude oil theft, oil pipeline, oil tank truck, anti-theft system, IoT

1. Introduction

Crude oil theft always results in huge economic loss, human casualties, and environment pollution in the world. In China, oil companies lost about more than three billion Yuan every year. Daqing oil field lost one billion Yuan annually just because of crude oil theft, and Royal Dutch Shell lost seven billion dollars only in Nigeria each year. Individuals transfer oil extracted illegally from oil facilities onto barges or containers which then take the oil to tankers (Okon., 2014). With the rapid development of petroleum industry, the length of oil and gas pipelines in China has broken

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through 10 million kilometers. The transportation by oil pipelines that owns many advantages such as safety, stability, lower cost, and higher efficiency. While, the oil pipeline is so long that it is impossible to monitor and supervise the real situation timely although the companies have taken kinds of measures and techniques to detect the illegal taps. Then, the oil thieves named oil mice who know oil companies' operations of detecting technology well began to rob crude oil by pumping from oil tanks or drilling a hole into oil pipeline. The oil mice are becoming the millionaires at one night even relatively small amounts when oil price is very high, and oil companies suffer a huge economic loss at the same time. These oil companies suffer extremely shocking economic loss and negative social influences on society so that most of them are determined to set up perfect intelligent monitoring system. This magnitude system will definitely cost millions of dollars or even more while it is not so big overhead compared with billions of economic loss that the oil theft result in. So how to make use of advanced information technology to improve the current techniques that only detect change of pressure in oil pipelines is the problem to be addressed urgently whether in China or in other countries. The Internet of Things (IoT) with Wireless Sensor Network (WSN) and FRID tags, the next revolutionary technology (Gubbi., 2012), can produce ubiquitous sensing and measure, infer and understand environment indicators which can be used to detect oil pipeline taps.

The objective of this study is to design intelligent anti-theft system based on the IoT and implement it successfully for detecting, monitoring and controlling the illegal taps in real time. The configuration of the network and sizes of oil pipelines are very important for oil companies, and a mixed-integer program model was set up and solved by intelligent algorithms in order to minimize construction cost. (Brimberg et al., 2003). However, the minimal cost is not enough to construct crude oil pipeline, the security and long-term operation should be considered carefully because there are many oil thieves or oil mice who drill holes into pipelines to grab illegal huge profits whether in China or other countries. Oil theft and pipeline vandalization in Nigeria have now become a national shame and embarrassment (Igbinovia., 2014). The main reasons for these problem are poor environmental governance and insufficient investment in infrastructure, and oil leakage from pipelines often occurs as a result of poor management and maintenance in infrastructure (Anifowose et al., 2012). So, it is necessary to improve the construction, management, operation, and maintenance of pipeline. Whereas, the length of pipeline is so long that it is impossible to monitor and control them at any time. Then, investors and policymakers blame for the crude oil pipeline leakage (Yeeles et al., 2016). An effective method to avoid oil theft damage based on low frequency vibration signal is provided to ensure the safety of oil pipeline and send alarm when sensor spacing is 2.4 to 3.0 km (Wang et al.,2004). Oil and gas industry is now positively looking for advanced robotic that can finish inspection, maintenance, and repair of oil plant facilities to increase their productivity and safety with higher frequency and accuracy (Shukla et al.,2015). With the rapid development of information technology, the more advanced monitoring control system is designed to improve the automated range of remote areas based on the IoT for oil production plant. The overall structure of IoT system that is composed of data acquisition, data transmission and management subsystem is built to make better decision and intelligent management for oil and gas production (Li et al., 2013). The improved IoT system was set up to deal with the business problems of oil and gas pipeline companies, and the system is composed of sensor level, transmission level and application level (Cui et al., 2011). In order to monitor pipeline in remoter area, the remote monitoring on oil and gas pipelines with satellite IoT was designed (Xia et al., 2012). All of the documents or papers provide a wonderful basis for this study, and this paper focuses on how to deal with oil theft in crude oil pipelines and oil tank truck by IoT and other advanced information technologies or smart device.

In this paper, the overall architecture of IoT application to oil anti-theft system is designed to detect and monitor the real-time situation dynamically. The aim of this paper is to prevent oil mice from robbing crude oil or other leakages from earthquake, debris flow or other uncertain factors. The rest of the paper is organized as follows: In section 1, the background and significance of the study is demonstrated, and the literature and documents are reviewed and analyzed. The crude oil robber behaviors and the complexity of oil anti-theft are analyzed in section 2. In section 3, the necessity of advanced information technology is shown, and the intelligent monitoring system by the IoT is designed according to the different scenarios of stealing crude oil. Then, the possible obstacles and corresponding suggestions are given to ensure the successful implementation of the monitoring system in section 4. Finally, the conclusion and prospection are shown in section 5.

2. Behavior analysis of crude oil thefts and complexity of anti-theft

When oil price is high enough, the stolen crude oil that almost costs nothing can bring huge illegal income for crude oil thieves, and these crude oil robbers think that it is a "good" business that making big profits with a small capital. It is still a tough task for oil companies although advanced information technology or techniques has been applied to detecting the illegal taps.

2.1. Behavior analysis of crude oil theft

Oil exploitation, storage and transportation are main work for the oil production and transportation enterprises. How to store and transport crude oil safely is a tough task for oil companies since oil theft always make them suffer huge economic loss with the high rising of oil price. The quantity of oil theft is believed to exceed 180,000 barrels per day over $7 billion of lost revenue at current oil prices, and the significant impacts of oil theft will bring other loss such as human casualties, insecurity (Wilson., 2014). Stealing crude oil last for a long time in China. There are a number of ways to transport crude oil such as pipelines, tanks, railways, ships. Oil theft maybe happen anywhere and anytime during the transportation. According to investigation of the situ situation, we know that there are two common scenarios depending on the way of crude oil transportation: one is stealing crude oil from oil tank truck, the other is robbing crude oil by drilling a hole into the crude oil pipeline.

For the oil theft from oil tank truck, the oil mice may be oil truck drivers, employees of oil factory, or test technicians of oil unloading department. The crude oil, a naturally occurring form of unprocessed and unrefined petroleum through oil drilling well, is composed of natural gas, oil, a lot of water, and other materials. During the process of oil tank truck transportation, the drivers steal crude oil by pumping devices and pour the same volume of water into the tank in the secret hiding place, and the stealing behavior is hard to be found because the proportion of water and oil from the oil well is not measured accurately. What's more, the drivers and the employees act in collusion with each other sometimes. The employees on duty in oil well site report a fake oil volume or no seals at all in order to make the drivers rob crude oil easily. The worst bad thing is that the drivers and test technicians steal them together, replace most of crude oil with the same volume of water, even more replace all of them for the most daredevils. The test technicians fake data to cover the criminal behavior which causes unbelievable economic loss for oil field.

As for the oil theft from crude oil pipeline, the immeasurable loss would happen once it is coming. Sometimes, the economic loss is not a big thing because of the death, severe pollution, or fire and explosion disaster. The thieves drill a hole into pipeline to steal crude oil unscrupulously which cannot be easily found because the following reasons: no real-time nuisance alarms, unable to inform the damage activities in advance, and expensive to maintain and their effectiveness (Wang et al., 2004). When an unsophisticated thief drills a hole into pipeline with very high pressure, the explosion accident will be incurred instantly along with human casualties, incredible economic loss, and severe pollution. The crude oil will flood into fields, fishponds, drinking water, rivers, or oceans. It is not an economic problem anymore but a social and national problem.

2.2. Difficulties and complexities of crude oil anti-theft

Kinds of measures such as acoustic traveling method, pressure point analysis, thermal and electrooptical methods, pipeline leak detecting system based on acoustics (ADS-PLDS), and long distance monitoring system have been taken to prohibit oil theft. These measures actually do reduce the phenomena at that moment, but it is still a tough task to stop these crude oil robbers although oil companies do better at detecting oil leakage than ever because of the difficulties and complexities of monitoring oil leakages from the pipelines.

- Long distance of crude oil pipeline. The total length of oil and gas pipeline in service in China is about 120,000 km until 2015(Gao et al., 2016), and the crude oil pipeline approximates to 20,000 km. Extremely significant damage to environment will be caused in remote land area if the leaks cannot be quickly detected and repaired.
- Crude oil pipeline buried in complicated geographic areas. Many pipelines lie in complicated geographic area where the earthquake, mud-rock flow, or other natural geologic hazards maybe happen to a large extent. If the potential and possible hazards are not well-alarmed and well-prevented, human casualties in large quantities would be caused along with burning oil disasters especially in resident-intensive communities.

- Old pipelines extended service in transmission. China's oil and gas pipelines were mostly constructed in the 1970's. Many crude oil pipelines have been operated and served for more than 30 years. Once the old pipeline was drilled, the catastrophic disaster would be coming along with explosion, fire and poisonous gas diffusion. Otherwise, corrosion, erosion, weld or joint failure, and fatigue can all lead to small hard-to-defect leaks by conventional means. Sinopec has been ready for 12.2 billion Yuan to replace old pipelines that have serviced for 30 years with new ones in three years.

Rear Admiral Suleiman said: "It is very possible to end oil theft if all relevant stakeholders would take responsibility and play their parts very well." Although the companies had taken actively all kinds of advanced technology and techniques to detect and monitor the pipeline, oil theft still occurred now and then. The average rate of crude oil leak accidents is 3 time/1000km·year so much higher than 0.5 time/1000km·year in U.S. and 0.25 time/1000km·year in Europe. More than 40 percent of accidents stem from man-made operation and drilling holes criminally. According to incomplete statistics, the pipelines owed by Sinopec has been drilled to steal oil for 90,000 times by the end of July, 2014. The Lin-Cang crude oil pipeline was drilled more than 860 times over the past twenty years. It is absolutely crucial for oil companies to take a rigorous and perfect method to detect and monitor crude oil pipelines by making use of Internet of Things, Artificial Intelligence, and other advanced information technologies or techniques.

3. Intelligent crude oil anti-theft system planning and design based on the IoT

There are various types of leaks detectors to analyze each type of them (Sandberg et al., 1989), and the application of the IoT is effective and efficient. The IoT is composed of many smart objects sending and receiving data and information (Gubbi et al., 2012). The IoT is of a world in which all physical objects are tagged and uniquely identified to provide real-world intelligence and goal-oriented collaboration of smart objects by RFID, sensors, and objects of global interconnections (Gluhak et al., 2011).

3.1. Anti-theft alarm system for oil tank trucks

If crude oil is transported by oil tank truck in oil factories, the common business process from oil loading to oil unloading is demonstrated as follows:

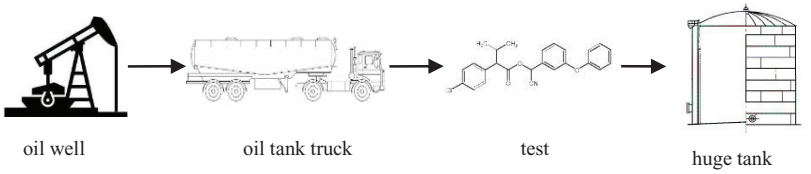

Fig. 1. The business process from loading to unloading

Oil theft often occurs in the process of crude oil transportation by tank trucks (Guo et al., 2013). The oil tank truck driver and disgruntled employees may or may not work in collusion to steal crude oil. The anti-theft alarm system can send a real-time alarm to intelligent terminals once the volume of crude oil changes abnormally or the lid of oil tank is operated unauthorized opening, then the position of targeted truck can be located, locked, and tracked. The whole transportation process will be recorded to improve operation business, standardize monitoring process of supervision departments, and provide real-time data to make better decisions. The functional modules of anti-theft alarm system are shown in Fig.2.

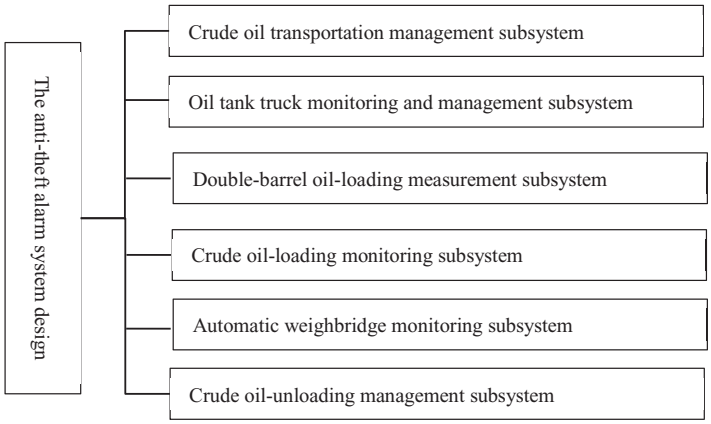

Fig. 2. The subsystems of anti-theft alarm system

The operation process of anti-theft system is as follows: The volume and ingredients of crude oil loading for one oil tank truck are produced automatically by double-barrel measurement subsystem and transmitted simultaneously to crude oil transportation management system which makes vehicle scheduling, process data recording, compliance checking and testing, and warning management, etc. The license numbers of trucks, the faces and fingerprints of truckers, and the whole process of oil loading will be identified and controlled by crude oil-loading monitoring system. At the same time, the oil tank trucks have been installed Beidou satellite positioning and navigation system (Beidou) and Global Position System (GPS), video monitoring system, and crude oil-unloading management system. When the oil tank truck arrives the designated destination, the automatic weighbridge system starts to weigh a loaded truck and an unloaded one and monitoring the license number and the face of driver again. Then, the volume and ingredients of crude oil will be measured by crude oil-unloading management system. Once any abnormal changes happened in the process of transportation, whether oil tank trucks' location, volumes, ingredients, or unauthorized lid opening, the warning signals will be presented in remote computer terminals online for relative departments or personnel. Then, the Android APP can be developed to monitor the real time situation anytime, anywhere (Karande et al., 2016).

3.2. Intelligent anti-theft IoT system for crude oil pipelines

The current anti-theft monitoring system of crude oil pipelines in Chinese oil and petrochemical enterprises is mainly detecting pressure changes by installing pressure sensors at the entrance and exit of the pipelines. If oil theft happened, the pressure at the exit of pipeline would be less, and the monitoring system will present the changes. The oil mice always run away from the criminal scene and rob the quantity of crude oil what they wanted because it took a long time to identify the fact and specific location of oil theft by employees on duty. The traditional monitoring system cannot tell them the destructive position accurately. If the hole on pipeline is very tiny and the speed of oil spilling is very slow, it is very difficult to detect the oil theft timely by the traditional methods and system (Jia et al., 2011). It is necessary to develop an intelligent monitoring system based on the IoT so that the oil theft can be prevented in advance when oil mice are digging the ground, drilling a hole, and other illegal constructions. The architecture of intelligent anti-theft system based on IoT is planned and designed in Fig.3.

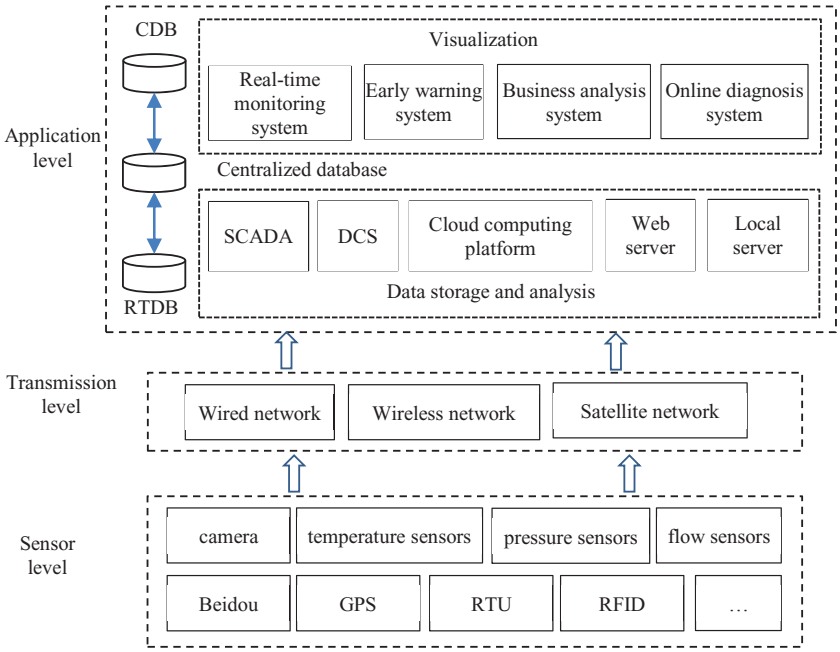

Fig. 3. Three-tier architecture of intelligent anti-theft system based on IoT

The involved technologies of anti-theft system mainly include wired network, wireless network, sensor technology, database, and smart terminals. The integration of these technologies is to collect, process, analyze, and transmit data and information in real time for monitoring crude oil pipeline dynamically and timely.

In sensor level, kinds of sensors, pan-tilt and fixed camera, and remote terminal unit (RTU) are installed to capture situ signals, image and videos. Radio Frequency identification (RFID) tags are used to identify automatically anything attached to acting as an electronic barcode (Ghosh et al., 2008; Sang et al., 2006; Gubbi et al., 2013), and the FRID system composed of readers can help to monitor these objects in real time. Once oil mice dig the ground near crude oil pipeline, drill a hole into pipeline, and other abnormal motion and noise, the warning messages will be send to the monitor center immediately. Then, Beidou/GPS can help workers on duty to find the static or dynamic precise oil-theft positioning timely. These smart devices can interact with each other through unique addressing scheme.

In transmission level, sensor data such as signals, texts, images, and videos will be transmitted to the server and application system via wired network, wireless network, or satellite communication networks. Wireless and wired network play the same important role and supplement each other in transmission. The wire communication technology includes medium and long distance Wide Area Network (WAN) and short distance Field Bus. The wireless communication technology consists of long-distance wireless WAN, medium and short distance wireless local area network, and ultra-short distance wireless personal area network.

In application level, the main work is composed of two parts: one is data storage and analysis, the other is system application. The supervisory control and data acquisition (SCADA) is a great system for remote monitoring and control that operates coded signals by integration of computer technology, cybernation technology, communication channels. The data center should be built and artificial intelligence algorithms are designed for making better monitoring and decision. Data warehouse, data mining, and business intelligence will be used in the process of data analysis and management. Then, the knowledge obtained must be presented visually once the data has been processed thoroughly and intelligently. The IoT application make the users interact with the environment, and the efficiency will be better if smart mobile terminals have been connected with the anti-theft system.

Fig.4. The schematic diagram of anti-theft system effectiveness

The schematic diagram of crude oil anti-theft system is presented in Fig.4. Data and information such as abnormal noise, vibration, pressure changes, and flow changes etc. detected by kinds of sensors, cameras, and RFID will be transmitted to cloud storage center by communication network. The monitoring center is mainly responsible managing, storing, analyzing, and sending all of control command orders or warning messages, and the supervision department or personnel who has been authorized can log in computer terminals or other smart mobile devices to check the real-time operation of crude oil pipelines at anytime and anywhere.

4. Suggestions and advice

The suggestions and advice are provided for successful implementation of crude oil anti-theft system based on IoT.

- Improve the lifetime and cost of sensors. Wireless sensors operations by embedded batteries are mostly used in detecting the situation of crude oil pipelines. So it is a key technology problem to be addressed by engineers to prolong a favorable lifetime of sensors. However, many sensors are commonly customized and the cost is relatively high so that they cannot be used in oil fields in large scale. How to reduce the cost of wireless sensors and prolong their durable life must be paid attention before implementing the anti-theft monitoring system.
- Install UPS for the anti-theft monitoring system. Uninterrupted power supply (UPS) are required to ensure that the intelligent anti-theft system is operating without a break because you cannot know when oil theft will happen. The sensors and other devices for data acquisition and collection cannot work constantly depending on the batteries. The solar panel and wind turbine generator system should be utilized alternately to charge up the batteries.
- Set up voice-alarm system at the fore-end terminals. When the anti-theft system sends the abnormal warning signals, the workers on duty can locate the position immediately by using on-site monitoring system platform. Then, they can shout loudly and make big motions by remote microphones to frighten oil mice, and the voice-alarm system should be installed especially for remote crude oil pipelines.
- Ensure the security of anti-theft system. The length of crude oil pipeline mainly lasts very long more than 1800 km, like the western oil pipeline from Urumchi to Lanzhou, the longest one in China. Partial sections of pipelines lie in remote area so that it is impossible to transmit data, images, and videos by wired network because of the high complexities, big difficulties, long implementation, and huge investment. Then, wireless network is used to transmit the data and information. The potential threats exist in the process of anti-theft system operation because the information channels are open during transmitting via wireless network. The information security, key encryption techniques, and contingency measures should be used and made in planning and designing the anti-theft system.
- Solve the difficulty of IoT devices interconnection. The things or objects in real world are interacted and cooperated with each other by using RFID tags, sensors, smart terminals, etc. The development and implementation of the anti-theft IoT system involve application of multidisciplinary knowledge. Whereas, there is no unified national or professional standards of these devices from different suppliers in China, and it is difficult and expensive to make these devices interconnection now. The unified standard should be set indispensably to allow the connection and coordination easily and economically.

5. Conclusions

The oil thefts often happened by pumping from oil tanks during transportation or drilling a hole into crude oil pipelines. The huge economic loss, human casualties, and environmental pollution were incurred once the oil theft cannot be found and stopped timely. An intelligent anti-theft system based on the IoT was designed in this paper to detect and monitor the criminal behaviors in real time under different scenarios. The novel anti-theft system cannot only locate and lock the theft position precisely by using Beidou or GPS, but also prevent oil mouse from stealing crude oil from pipeline in advance by detecting abnormal dynamic changes in situ. The smart terminals, especially mobile ones, should be used widely to receive, identify, and deal with warning messages online whether oil theft in oil tank truck or in remote long-distance crude oil pipeline. Whereas, the implementation of intelligent anti-theft system is facing numerous difficulties amid security and privacy, non-unified professional standards, and wireless sensors used in large scale. The integration of management methods and advanced information technology is preferred to intelligent anti-theft IoT system for oil and gas industry over the coming decades.

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