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A big data-based workers behavior observation in China metro construction

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Abstract

Metro construction passes beneath through cities and has characteristics of straitness field and complicated surroundings, which lead to frequent accidents, especially because of worker's unsafe behavior. BBS is one of the construction safety management methods, aiming to observe, analyze and modify worker's behavior. In order to reduce the negative impact of limited behavior observation on BBS, this paper proposes the framework of behavior observation in China metro construction based on big data, which includes: (1) establishing behavioral risk knowledge base; (2) collecting image data reflected worker's unsafe behavior through intelligent video surveillance system and mobile app; (3) establishing big data cloud platform for storing data by distributed file manager. We verified its availability from an example that it can analyze semantic information contained in images effectively, extract worker's unsafe behavior knowledge automatically, retrieve the cloud platform quickly as well. Currently, this research has been utilized in partial construction lines in Wuhan metro and we have got massive valuable behavior observation data.

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Keywords: Big data, Behavior observation, Unsafe behavior

1. Introduction

Nowadays, China's metro construction is entering a new period when construction speed and scale are both the first in the world, with 94 lines in operation, 120 lines in construction and over 150 billions gross investment . At the same time ,we cannot ignore the frequent occurrence of accidents which mainly because of worker's behavior. After studying nearly 75000 accidents, Heindrich found that 88% of safety accidents were due to worker's unsafe behavior[1]. Therefore, in order to reduce incidents and improve performance of site safety management, it's necessary to pay highly attention to worker's unsafe behavior[2]. It is also necessary to study behavioral safety because it turns out that unsafe behavior can be controlled by reasonable measures, even by workers themselves[3]. Behavior-Based Safety(BBS), also named Applied Behavior Analysis(ABA) in some other studies[4], is an effective way to conduct and encourage behavior improvement[5, 6] and focuses on what people do, analyzes why they do it,

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and then applies a research-supported intervention technique to improve behavioral processes[7]. BBS was also applied in construction phase in some researches[8, 9], aiming to observe, analyze and modify workers behavior. containing the following steps: (1) listing unsafe behavior list which needed critical focus in construction site; (2) observing worker's unsafe behavior and recording its frequency; (3) giving feedbacks and correcting their unsafe behavior. Among above steps, step 2 is very significant. Past observation relied primarily on people, so there existed three problems: (1) time-consuming and hard-working; (2) need to observe numerous samples; (3) need worker's active cooperation. This paper introduced behavior observation method of metro workers based on big data, aiming to solve these problems by classifying, collecting and storing image data of site workers.

2. Framework of big data-based behavior observation

The framework of observation is shown in Fig. 1, including three parts: (1) data classification; (2) data collection; (3) data storage. Firstly, listing unsafe behavior according to the subway construction safety standards, operating instruction, accident cases and expert experience, then listing construction WBS (Work Breakdown Structure)-classifying worker's unsafe behavior in different construction phase and encoding, by combining with metro classification standard. The second step is collecting data which is derived from photos taken by monitoring videos and site workers(workers or managers), worker's unsafe behaviors are recognized and recorded by rule-based camera behavior analysis technology, and indentifying photo's semantic information and matching it with unsafe acts in our knowledge base by means of JHA (Job Hazard Analysis) and VSM (Vector Space Model). By this step, it realizes the recognition of behavioral risk and the collection of worker's behavior data. Thirdly, storing collected multi-source isomerous data(structured data and unstructured data) by HDFS in big data-based cloud platform. It is possible to realize behavioral risk visualization because recorded images of unsafe behavior are marked by complete semantic information, what's more, it lay the foundation for future correction of worker's behavior.

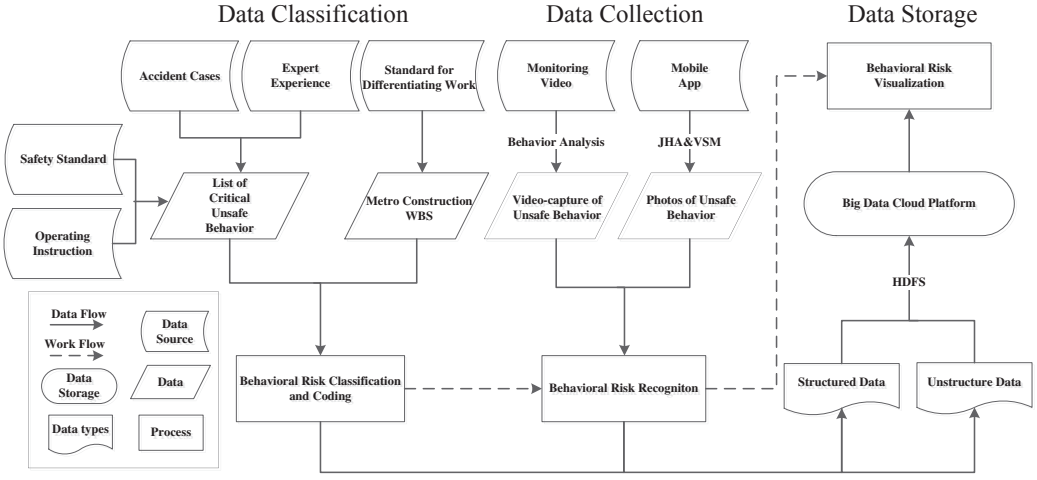

Fig. 1. An overview of data classification, collection and storage in the framework of big data-based behavior observation

2.1. Classification and coding of unsafe behavior data in metro construction

This research classifies unsafe behavior in different types, considering China's actual situation and metro construction's specialty, and encodes them by combing with subway construction work breakdown structure, finally develops the behavioral risk knowledge base of subway construction.

Firstly, organizing unsafe behavior list in four aspects: safety standards, operating instruction, accident cases and expert experience. This paper uses several standards as references to list partial unsafe behavior in metro

construction without clauses and points of objects' unsafe condition, for the reason that domestic metro construction must obey specified laws, regulations, standards and norms. In addition, this research collects 1731 accident cases of domestic subway construction in 2008-2013 to number incidents caused by people and analyze accident mechanism and exact worker's unsafe behavior. Besides, common unsafe behaviors at worksite is summarized to complete unsafe behavior list of metro construction by collecting safety management data of nearly one hundred construction sites in cities of Shenyang, Wuhan, Zhengzhou, Shenzhen and etc.

Finally, 522 unsafe behaviors of seventeen different types are summarized, including civilized construction(01), fire fighting(02), scaffolding(03), pit support engineering(04), formwork engineering(05), the construction of shield-driven tunnel(06), the construction of tunnels by mining method(07), safety protection(08), tower crane(09), gantry crane(10), building material elevator(11), lifting(12), construction equipment(13), tunnel rail line area(14), manual hole digging pile(15), blasting(16), construction electricity(17). The partial unsafe behavior list of the lifting work is shown in the following table 1, including columns-name, code, possible injury.

Table 1. The list of several unsafe behaviors about .lifting

The name of unsafe behavior	Code	Possible injury
Whether the weight of suspended objects exceed machine's rated load is not verified	001	Crane accident
Transporting workers by hanging object	002	High falling
Placing other moving objects on the hanging object	003	Object strikes
Not taking warning during lifting, unwanted workers get into the dangerous areas	004	Object strikes

Besides, classifying metro construction project into five classes-unit project, subunit project, subsection, tender subsection and branch item, according to the standard of urban railway traffic engineering in cities(Beijing, Chongqing, etc). Take one for example, metro station construction contains 6 subunit works, specifically, main structure construction of open-cut metro station includes three division works-foundation enclosure and treatment, waterproof engineering and main structure, foundation enclosure and treatment includes three subdivision works-foundation enclosure, earthwork and foundation treatment, then, earthwork includes four subentry works-precipitation and drainage, earth excavation, support erection and earth backfill. By this way, work tasks of each stage are subdivide into subentry work in metro construction.

Encoding classified unsafe behavior in the following rule, according to list of workers' unsafe behavior and metro construction WBS: *XX-XX-XX-XX-XXX-XX-XXX* (*unit work-subunit work-division work-subdivision work-subentry work-behavior type-unsafe behavior*).

2.2. Collection of metro construction behavior data

2.2.1. Worker's behavior observation in metro construction by video monitoring

The behavior observation system of metro construction workers in the basis of video surveillance is shown in Fig. 2. Its hardware environment is consisted of Webcam, POE power module and Switch, while its software environment is consisted of camera-based behavior analysis technology. The system indentifies workers' unsafe behavior captured by webcam according to preset rules and then managers can view images stored in big data cloud platform in PC or mobile devices timely.

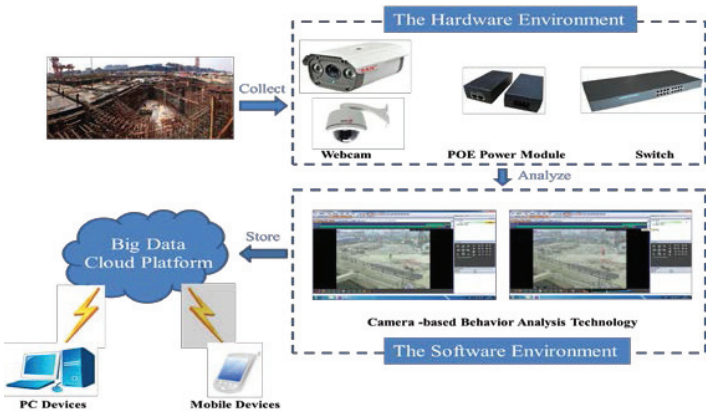

Fig. 2. The behavior observation system of metro construction workers in the basis of video surveillance

Among them, camera behavior analysis technology is the core, The table 2 shows its several possible functions and explanations in all areas, and for these features, it is possible to apply this method to observe worker's specific unsafe behavior by combining with actual worksite situation. The third column therein lists partial recognized unsafe behavior of workers.

Table 2. Camera function and its application in construction

Function	Functional explanation	Application in construction
Intrusion detection	Analyzing, positioning and tracking objects entering into prohibited area	Workers enter into lifting dangerous area
Stay identification	Tracking over-stayed objects in protected area	Workers stay too long at the edge of the foundation pit
Reverse detection	Monitoring objects moving against the rules	Crane-driving and excavator-driving violators

2.2.2. 2.2.2. Worker's behavior observation in metro construction based on the site photos

This paper discusses the observation data collecting system based on the site photos, explains the affecting factors of worker's unsafe behavior by means of JHA, finally matches unsafe behavior items described by observers in specified rules via VSM method.

JHA is an analysis method of eliminating and controlling dangers by ensuring potential dangers in every stage and then putting forward safety management regulations. JHA's precise describing words can also be used in describing unsafe behaviors in metro construction because construction behavior risk also exist in an given activity of a given stage. Therefore, we stipulate observers describe worker's unsafe behavior in the following structure: **Action(s)** executed on **object(s)-worked-on** using **resource(s)** at **location(s)** with **nearby object(s)** and **nearby action(s)**.

As shown in Fig. 3, reflecting the unsafe behavior of " There is a worker doing the welding work around the excavator during the excavation of foundation pit". Its semantic structure is "Digging(**action**) soil(**object-worked-on**), in the foundation pit(**location**) using excavator(**resource**), there is a worker in the dangerous area(**nearby object**) doing the welding work(**nearby action**)", so we can see its potential risk brought by this behavior clearly.

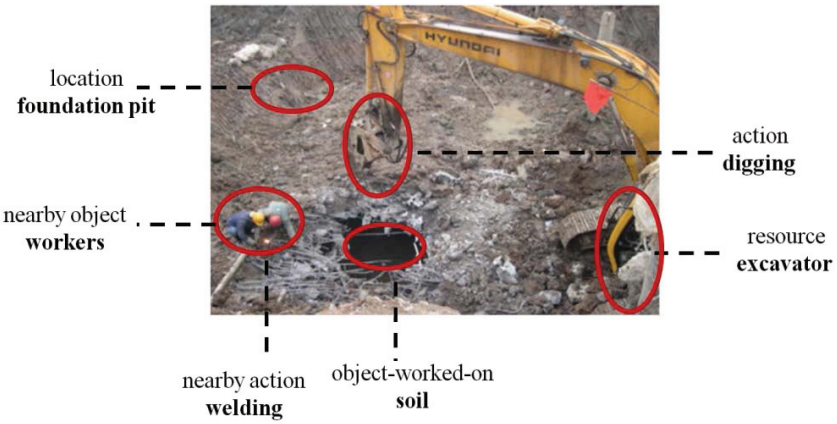

Fig. 3. An example of the photo analysis

On the one hand, we ask for the training observers(site managers or workers) to describe collected photos in the structure above, then exacting six affecting factors keywords from the text to stick semantic labels on each picture; On the other hand, we define all of the 522 unsafe behaviors with these six keywords. So, we transfer the analysis of which unsafe behavior is in accordance with observer's describe into the analysis of the similarity of its six keywords.

This research uses VSM(Vector Space Mode) to analyze the similarity of keywords. Specific analysis steps are as follows: (1) calculate the weights of the key words by TF-IDF method; (2)determine document vectors of listed unsafe behaviors; (3)determine the query vector of keywords exacted from photo's description; (4) match photo with unsafe behavior via querying the angles between the query vector and different document vectors by means of Cosine Law. The document vector of unsafe behavior entry k in the vector space and the query vector of photo's description l are shown as:

$$\vec{V}(d_k) = \{W_1, W_2, ..., W_N\} \tag{1}$$

$$\overrightarrow{queryVector_l} = \{W_1, W_2, ..., W_N\} \tag{2}$$

Including: $\vec{V}(d_k)$ means the corresponding vector of unsafe behavior entry k, $\overrightarrow{queryVector_l}$ means the corresponding query vector of photo's description, N means the Nth keyword of vector space.

Calculating the angle between the query vector and document vector via the Cosine Law, then, matching the photo with the listed unsafe behavior entry according to the similarity of the document.The following Fig. 4 shows the document vector $\vec{V}(d_k)$ and query vector $\overrightarrow{queryVector_l}$ visually. By calculating, the larger the cosine, the smaller the angle and the higher the similarity.

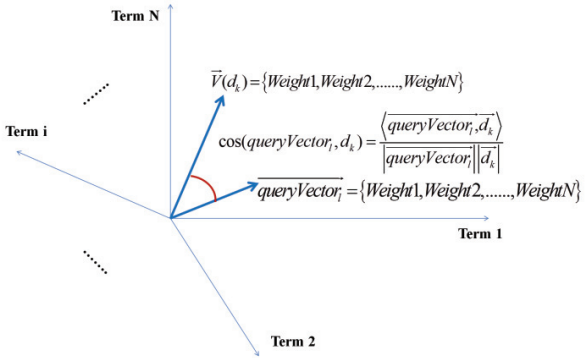

Fig. 4. The expression of cosine angle between the query vector and document vector in VSM

We develop a mobile APP for collecting site photos. By this app, managers or workers take photos reflected unsafe behaviors in daily work and then describe the photos in pre-set semantic rules.

2.3. The cloud platform based on the large data

The image data of unsafe behavior collected from the monitoring video and the site photos will be stored in the big data cloud platform. In order to meet the demand of storage of large amounts of behavior data, this research adopts the Apache Hadoop to realize the platform. The design idea of the Hadoop is originally from the GFS and MapReduce of Google. Users can store and apply the distributed mass data without understanding the detailed situation of the distributed system in the basis of the infrastructure established by the Hadoop. Data analysis service provided by the platform aims at correcting worker's unsafe behavior later, therefore will not be discussed here in detail.

In this research, the big data cloud platform collects data from the surveillance video and the phone app, behavioral risk knowledge base, schedule management information and the identified image's semantic information.

The data in the big data cloud platform is stored at the HDFS, which is short of the Hadoop Distributed File System. The HDFS, based on the Java version of the Google GFS, provides a distributed file system satisfying the demand of Huge amounts of data calculation and Scalable extension.

The image data exacted from various resources in the platform can support the records' scientific effectively, while the Fast reading and writing data services provided by HDFS guarantee storage and retrieval of data, realize the visualization of the behavior risk as well.

3. Case study

The unsafe behavior of lifting “Not taking warning during lifting, unwanted workers get into the dangerous areas” (No.004 in Table 1) is selected to observe by methods above and introduce how to realize the collection and storage of the behavior data.

Firstly, introducing the process of collecting behavior data via the intelligent video monitoring system. The following Fig. 5 showed its application in one station of Wuhan metro, China. After finishing equipment establishment and directing camera at the lifting area, the system backstage was set as *a* showed. In detail, adjusting the behavior analysis engine of camera to intrusion detection function, defining ruled case as unsafe behavior above and pre-defined dangerous areas (the red circle position) within the scope of monitor. *b* showed the process

thereafter that the system recognized workers' entry into dangerous areas automatically and exacted multi-photos by observing workers' motion.

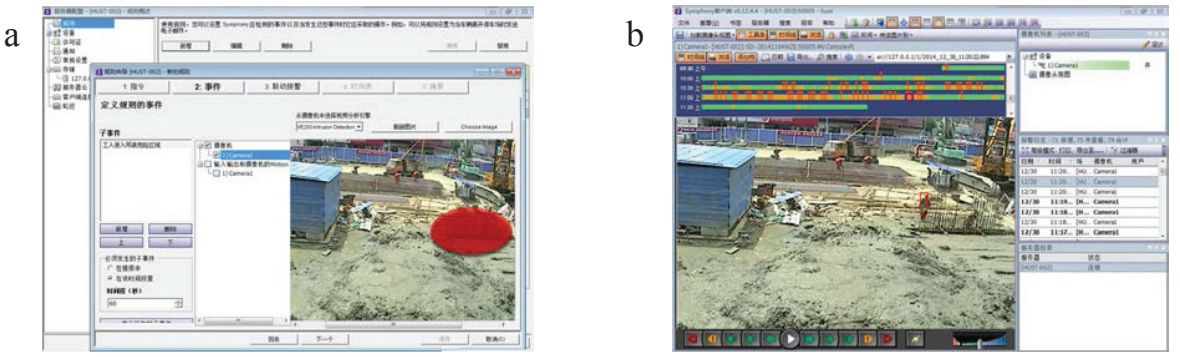

Fig .5. The application of intelligent video monitoring system

Secondly, The following Fig.6 showed the collection process of a photo reflecting this unsafe behavior in another station of Wuhan metro via the mobile APP, *a* showed that a observer took the photo reflecting this unsafe behavior; *b* showed the description process by inputting voice or characters. As example required, keywords about six affecting factors must be contained in description sentence.

Fig .6. The interface design of the mobile APP for collecting site photos with unsafe behavior

The core of data collection process by this mobile APP is matching the observer description with unsafe behavior in the list. The six affecting factors exacted from were lifting, object, the sides of the foundation, crane and worker, without nearby action. Then, defining the query vector of this description by calculating the corresponding weights of each keyword by means of TF-IDF. Then calculating its components in six dimensions. What's more, judging the similarity of documents by their cosine value. The computed result showed in that $\cos(queryVector, d_4) = 0.8751$ was the maximum, therefore, the best matching was $\overrightarrow{d_4}$ named "Not taking warning during lifting, unwanted workers get into the dangerous areas".

Finally, storing these behavior data with complete semantic information into big data cloud platform.

4. Conclusion

This study introduced big data-based behavior observation to exact site workers' unsafe behavior data. Firstly, exacting and purifying vital unsafe behaviors of multiple dimensions in metro construction and then forming the behavioral risk knowledge base combining with metro construction's WBS. Secondly, getting observation data from surveillance video and site photos. Recognizing site workers' unsafe behavior via camera behavior analysis technology, and analyzing the factors affecting workers' unsafe behavior by JHA and matching them with pre-defined unsafe behavior by VSM, therein, the mobile APP was a shooting aid equipment. Finally, uploading these image data with complete semantic information to the cloud platform based on big data and storing them by HDFS distributed document manager.

The achievement has been applied in the construction phase of Wuhan metro line 3 and line 6, containing 15 stations and 8 running tunnels. The data collected by the surveillance video or the mobile APP in daily observation is more than 300GB, containing over 150 thousands of image data reflected worker's unsafe behavior with complete semantic information. Therein, the number of images exacted from the monitoring video is bigger than from the site photos, while the kind of reflected unsafe behaviors is smaller, but with the accumulation of the data, it can guarantee the complete collection of worker's unsafe behavior to some degree. In addition, the application of HDFS distributed document manager with characters of high reliability, high performance and easy extensibility can provide effective storage and quick retrieval for the behavior large data.

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