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Research Article

# An Intelligent High-formwork Support Monitoring System

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**Abstract:** The high-formwork support is to form and maintain newly poured concrete so that there should be no deformation in the shape. Deflection and shrinkage should be minimum. The intelligent monitoring of high-formwork support based on big data has been dramatically promoted with the advancement of science and technology. The standard of living is constantly improving, and safety is frequently the top priority. The construction industry pays close attention to the safety of high-formwork support during the construction process. Traditional high-formwork support monitoring is based on manual observation and measurement, which is not only time-consuming and labor-intensive but also produces insignificant monitoring data. Because of the strict requirements for pouring quality and construction safety, the traditional high-formwork support has been unable to meet the demand. We must combine information technology to provide the best monitoring means for high-formwork support and effective guarantees for building construction safety. In this paper, we propose an intelligent high-formwork support monitoring system. Every two seconds, the system can obtain equipment monitoring data, which is automatically transmitted. It transmits monitoring data from the collector to the database, thereby avoiding high-formwork support accidents. Decision trees are also used in the analysis of monitoring data. As a result, three decision rules emerge. The main advantages of the intelligent high-formwork support monitoring system are that it is frequently monitored and allows for real-time monitoring. The proposed intelligent high-formwork support monitoring system ensures the safety of the high-formwork support during construction.

***Keywords*:** high-formwork support, formwork, support system, intelligent system, monitoring system

## 1. Introduction

One of the most important steps in construction is formwork support. The main purpose of the formwork support is to form and maintain newly poured concrete so that it reaches a certain strength to withstand the temporary structure [1]. The formwork support has long been used in various models such as wood, metal, etc. Wood formwork is inexpensive, but it takes a lot of time and does not have a long life. High-formwork support is a formwork support at the construction site that construction exceeds 8 meters in height, spans more than 18 meters, or has a maximum bearing weight greater than 15 $N/m^2$, or a concentrated line bearing weight greater than 20 $kN/m^2$ [2-3]. It is primarily used in the construction of large frame structures, such as civil engineering, housing construction, and high-rise buildings. Because of the


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complex operation and construction structure of high-altitude operations, there are occasional safety accidents caused by the instability of the high-formwork support system. Monitoring operational high-formwork support is critical, and the results must be communicated quickly. As a result, the safety of the staff working on the high-formwork support has been improved, as has the quality of the work.

During the monitoring of high-formwork support, the wireless collector perfectly solves the problem of frequency and inefficiency in obtaining data [4]. Various sensors can provide intelligent monitoring of the status of high-formwork support, reducing manpower investment and saving money [5-6]. The primary goal of this paper's research is to create an intelligent high-formwork support monitoring system. It states that the data gathered by the collector installed on the high-formwork support will be received, cleaned up, and stored by the server. The data in the database are refreshed in real time, resulting in a large visual screen of data that can be displayed and updated in real time.

The rest of this paper is organized as follows. Section 2 presents the proposed intelligent high-formwork support monitoring system. Section 3 is the introduction of system design and implementation. Section 4 deals with the intelligent monitoring results. Finally, Section 5 draws conclusions.

## 2. The proposed intelligent high-formwork support monitoring system

This system is based on the monitoring data of the high-formwork support part of three museums and three centers in China. This project includes a library, archive, comprehensive cultural center, women and children's activity center, youth activity center, and staff activity center, with a total construction area of 118,459.64 square meters. The monitoring point is deployed on the basis of the horizontal displacement and angle tilt of the high support mold. The distance between the levels of the monitoring point does not exceed 15 m, and the sinking of the high support mold is carried out. The intelligent high-formwork support monitoring system has 6 measuring points, using three different types of collectors and analyzer.

**Figure 1.** The acquisition instruments used in three museums and three centers

Due to the complexity of the high-formwork composition structure, the height of the building is higher and the weight bearing is larger than traditional building. During construction, the high-formwork support will be loosened due to local deformation or the tilt of the pole shaft, resulting in the collapse of the high-formwork support. The system can timely find the settlement, inclination, and displacement of the high-formwork support in the construction process, monitor the dynamic change data, and timely alarm messages when construction is dangerous. Thus, the risk of collapse of the high-formwork support is greatly avoided. Simultaneously, useful information is extracted from the massive monitoring data, and the data is visualized in the form of charts and visualized. It is convenient for the managers or employees of the enterprise to view the site situation and timely understand the changes to ensure the safety of the construction of the high-formwork support. For an intelligent high-formwork support monitoring system, the acquisition instrument for data includes a loading collector, inclination collector, and displacement collector [7-9]. The acquisition instrument is shown in Figure 1.

## 2.1 *Loading collector*

The acquisition instrument used in this system is the YL-FLC (W) wireless loading collector, which monitors the sinking of the high-formwork support and can monitor the size of the shaft force of the high-formwork support. It can also monitor the settlement value of high-formwork support such as bridge piers, bridges, and urban buildings. It has a small structure, takes up almost no space when installed on high-formwork support, has no effect on the construction, is precise, does not require external cables, and is relatively easy to install.

When there is a sinking change on the high-formwork support pole, the sensor plate inside the loading collector can detect the sinking change. After that, the sensor plate will produce a change and pass the change to the vibrating string then becoming the stress of the vibrating string to change its oscillation frequency. The electromagnetic coil calculates the frequency of the vibration through the vibration of the vibrating string and transmits the frequency information through the cable to the reading device so that the settlement value of the high template being monitored can be measured.

## 2.2 *Inclination collector*

The acquisition instrument used in this system is the YL-IMG (W) wireless inclination collector, which is mostly used in the measurement of inclination and equivalent horizontal displacement measurement of bridges, buildings, foundation pits, slopes, and other projects. It has ultra-low power consumption, fast response, and excellent temperature stability. It can maintain the accuracy of measurements in various environments and is suitable for long-term outdoor monitoring. In the internal differential converter, it can also simultaneously use a fifth-order filtering algorithm to calculate changes in the acquirer, and the output is monitored for high-bid-mode generation Oblique angle.

The wireless inclination collector adopts the principle of a capacitive micro-pendulum. Using the principle of gravity generated by the Earth, the high-formwork support being monitored with changes in tilt and gravity will produce a corresponding force on the pendulum, so the capacitance will change accordingly. By amplifying, filtering, and converting the capacitance, the X, Y, and Z-axis values of the measured height mask can be obtained.

## 2.3 *Displacement collector*

The YL-RDS(W) wireless displacement collector is mostly used for bridges, slopes, foundation pits, buildings, tunnels, high support mold, and other displacement measurements, which can be automatically monitored for a long time. It is small in size, small in space to install, high in precision, and hard to rust in quality. It has anti-corrosion technology treatment on the wire wheels and tow ropes, allowing it to work well in outdoor environments.

The YL-RDS(W) wireless displacement collector converts the distance of the monitor into an electrical signal. When the altimeter is deflected, it will pull the wire rope connected to the pole. Then, the wire rope will drive the transmission device of the collector to drive the sensing element to rotate. When the wire is moved in reverse, the internal swing retracts the wire rope, and the tension of the wire rope remains constant during the process of extension and retraction. It allows the electrical signal generated by the wire rope to be calculated and the horizontal displacement distance of the high-formwork support to be calculated.

## 3. The system design and implementation

The used software includes ECharts, Bootstrap, ThinkPHP, MySQL, and MongoDB. These technologies are briefly described as follows. ECharts is a free data visualization chart developed by Baidu, which can be developed according to different needs. ECharts have the characteristics of wide compatibility, low difficulty, and simple development with various charts [10-11]. ECharts can also be compatible with most of the current browsers and devices. Bootstrap is a responsive front-end framework that allows web pages to adapt to various screen sizes in most cases, achieving the effect of adapting to multiple screens [12]. It is a CSS and HTML framework that is simple and flexible, making front-end development easier. ThinkPHP is a light PHP framework based on MVC, which supports several databases with strong compatibility [13]. ThinkPHP implements the most recent architectural ideas, adds more configurations, performs numerous optimizations, and is a subversive and refactored version. MySQL is a relational database system that is widely used in web applications. It is conducive to optimizing the running speed of the system [14]. MySQL stores data in each table, rather than putting all the data in a separate repository. As a result, data is read and stored more quickly. Most enterprise websites or systems are usually developed with MySQL databases because of their small size, fast operation, and relatively inexpensive cost. MongoDB mainly stores distributed files, and it is a non-relational database. The structure of the data has no paradigm requirements, often used to save non-standard unpurged raw data. Mongo DB's collection storage is its biggest advantage. There is no relational restriction to storing raw data and it is convenient for big data. Its syntax is similar to an object-oriented retrieval language and it is dynamically retrievable and fully indexed by basically implementing most of the functionality in relational database forms retrieval. Moreover, it has an efficient way of storing data and has the rich features of a non-relational database [15]. The intelligent high-formula support monitoring system first stores the received data in MongoDB, then processes it with a Python script and dumps it in MySQL. It transmits data via the ThinkPHP API interface, processes it, and then analyzes it. The system mainly implements the front-end basis framework through HTML, CSS, and JavaScript. It also uses Ajax technology to transfer parameters and automatically refreshes the data received in the MySQL database. ECharts technology is used to render data and visualizes it in the form of charts. Figure 2 is an architecture diagram of the system. Figure 2 includes four modules, i.e., project monitoring, site management, alarm management, and equipment information.

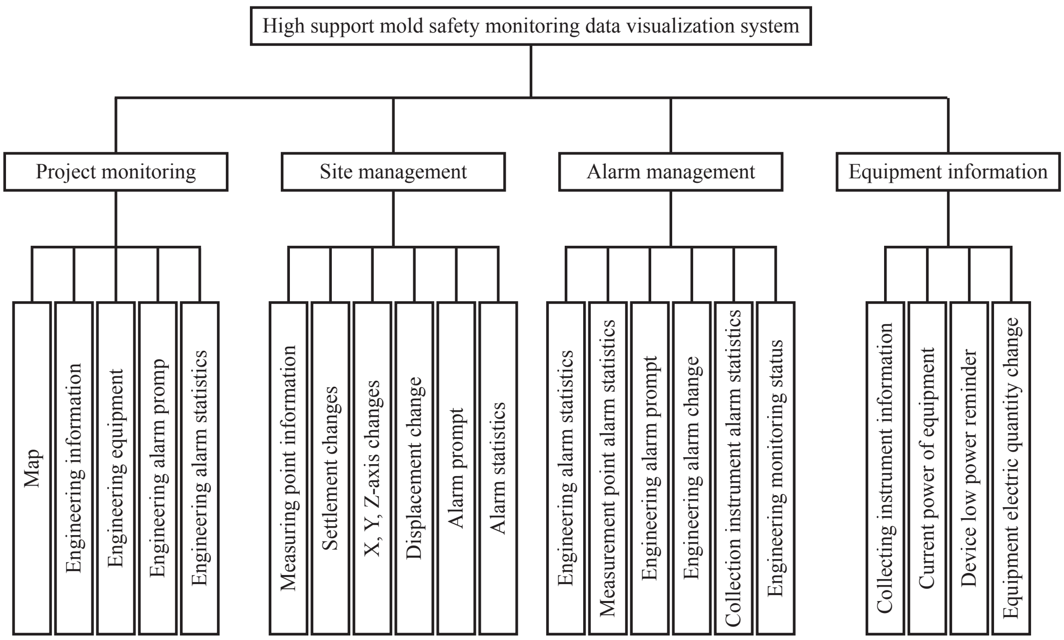


**Figure 2.** The architecture diagram

The project monitoring module displays the basic information of the system with six measurement points. The equipment used in the system includes 6 loading collectors, 6 inclination collectors, 6 displacement collectors, and 1 analyzer. The engineering alarm message is in the form of a rolling broadcast, and the alarm reminder is carried out as soon as there is an alarm situation. Engineering alarm statistics are divided into 3 categories, namely early warning, alarm, and control, the system will conduct real-time statistics on the three types of situations, once the situation changes, real-time cumulative update, and real-time display of dynamic changes in an alarm situation.

The site management module shows the measurement point information. The horizontal coordinate uniformly adopts the time axis in seconds intervals, and the vertical coordinate can automatically adjust the measurement interval according to the size of the displayed value. Settlement and displacement changes are displayed in the form of histograms, while X, Y, and Z-axis (inclination) changes are displayed in multi-line charts. Each chart has a message box and it will appear when mousing over the chart while displaying the X-axis record values and the Y-axis record values.

The alarm management module displays the engineering alarm statistics, measurement point alarm statistics, collection instrument alarm statistics, engineering alarm messages, engineering alarm changes, and engineering monitoring. Engineering alarm statistics and collection instrument alarm statistics are displayed using a column chart, while the measurement point alarm statistics are displayed by a horizontal bar chart. Also, engineering alarm changes use line charts to display three kinds of police situations in different time periods; The engineering monitoring situation is displayed using a pie chart, showing the overall number of monitoring times of the project, and the alarming probability can be seen above the mouse hover.

The equipment's information module shows the collector information monitored by the current power of the equipment, the device low power reminder, and the device power change. The equipment information is presented to show the basic information of the equipment used at each measurement point. The equipment's low power reminder is reminded in the form of a rolling broadcast, and the current power of the equipment is displayed with a diversified column chart. The device power change is displayed by a line chart, and a drop-down box button can be made to view the device power change at different measurement points.

### 3.1 *The use case diagram*

The use case diagram is shown in Figure 3. It can monitor the high-formwork support data on the system [16]. The system has a certain interactive function, according to the need to view the monitoring of the corresponding measurement points. As can be seen from Figure 3, the system has functional modules such as project monitoring, site management, alarm management, and equipment information. It represents the basic information of the monitoring equipment used and the power change of the equipment, the real-time data of each measurement point, and the various alarm situations.

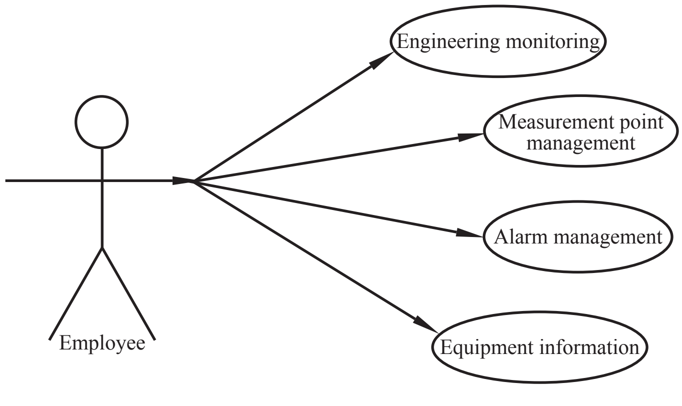


**Figure 3.** The use case diagram

## 3.2 *The timing diagram*

The timing diagram is shown in Figure 4. Enterprises can use the browser to enter the address of the intelligent high-formwork support monitoring system [17]. The system requests data from the background API interface once every 2 seconds, queries the corresponding data from the database, and returns them to the system for rendering. Enterprises can view the real-time changes of engineering and measurement points on the system, the changes in the template and pillars of the high-formwork support in the pouring process, and the automatic alarm messages of the change arc exceeding the limit. The system can also monitor the changes in the settlement, inclination angle, and displacement of each measurement point, and the power changes of the monitoring equipment.

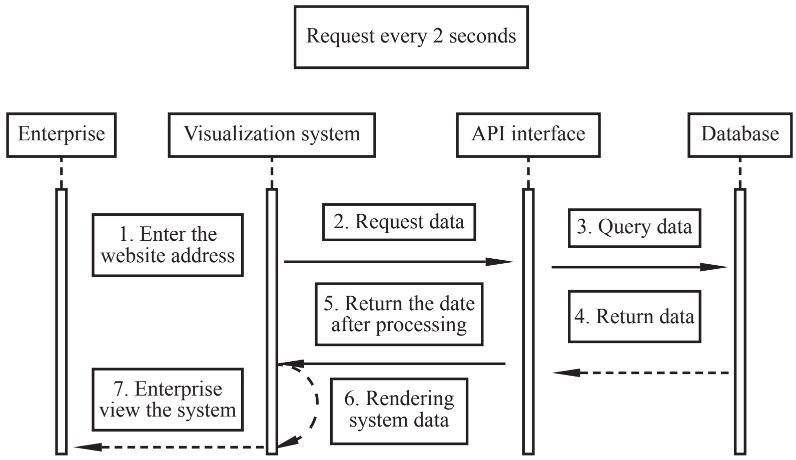


**Figure 4.** The timing diagram

## 3.3 *The ER diagram*

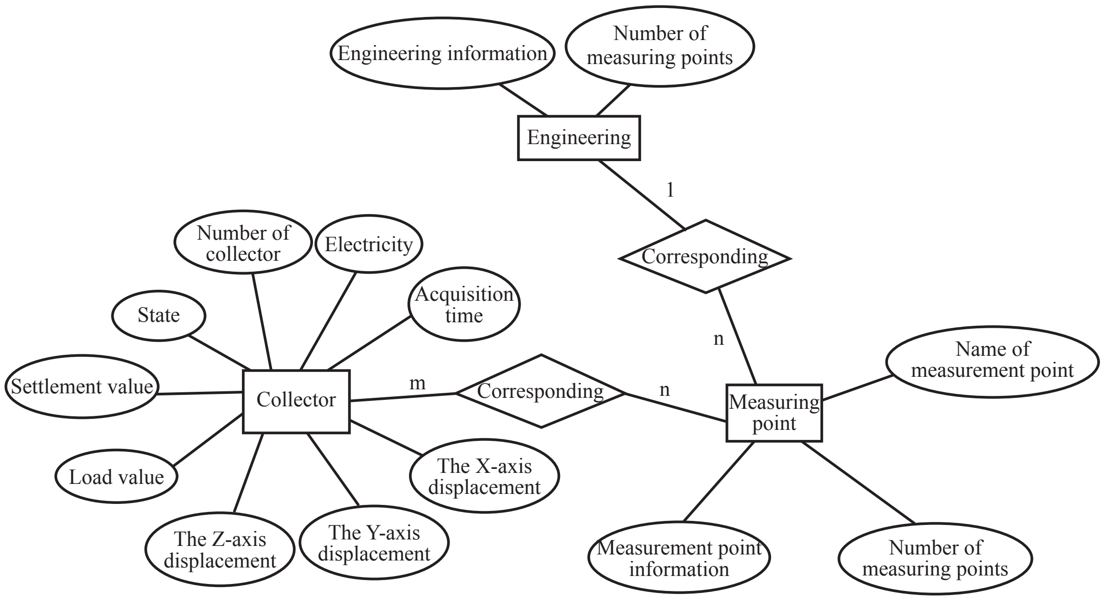


**Figure 5.** The ER diagram

Considering the convenience of storage and invocation, two databases are used, namely MongoDB and MySQL. MongoDB has a decentralized data structure that is often used to store relatively cumbersome data types, and it is suitable for storing the received collector raw data. The processed data are then dumped in MySQL. The MySQL database has the relationship between tables and tables, which has the advantages of fast reading speed and high storage efficiency. The data are stored in a table, which optimizes the requested speed and improves the efficiency of system operation [18-19]. The ER diagram is shown in Figure 5. According to the ER diagram, the used tables are listed from Table 1 to Table 3.

**Table 1.** The used table of collector

| Column name | Type | Null is allowed | Primary key | Memo |
|---|---|---|---|---|
| id | int(11) | no | yes | |
| Number of collectors | int(11) | yes | no | Collector number |
| State | enum (‘0’, ‘1’, ‘2’, ‘3’) | no | no | Status 0 = OK, 1 = Early Warning, 2 = Alarm, 3 = Control |
| Settlement value | float | yes | no | |
| Load value | float | yes | no | |
| X-axis displacement | float | yes | no | X-axis value |
| Y-axis displacement | float | yes | no | Y-axis value |
| Z-axis displacement | float | yes | no | Z-axis value |
| Acquisition time | int (11) | yes | no | Timestamp |
| Electricity | float | no | no | |

**Table 2.** The used table of engineering

| Column name | Type | Null is allowed | Primary key | Memo |
|---|---|---|---|---|
| id | int (11) | no | yes | |
| Number of measuring points | int (11) | yes | no | Measure points |
| Engineering information | varchar (255) | yes | no | |

**Table 3.** The used table of measuring points

| Column name | Type | Null is allowed | Primary key | Memo |
|---|---|---|---|---|
| id | int (11) | no | yes | |
| Number of measuring points | int (11) | yes | no | Measure points |
| Name of measuring points | varchar (255) | yes | no | |
| Measuring point information | varchar (255) | yes | no | |

## 4. The intelligent monitoring results

In the intelligent high-formwork support monitoring system, a decision tree is used to analyze the alarm data. The decision tree is a predictive model that graphically presents each outcome by dividing samples into branches based on various attributes [20]. In the internal nodes of the decision tree, it needs to be judged once according to the attributes of the results divided into different branches. Through continuous judgment and division, it finally obtains each leaf node, thus obtaining the classification results. The steps of the decision tree are described as follows [21-22]:

*Step 1*: Calculate $Info(P)$ and $Info_Y(P)$ to identify the class in the set $P$.

$$Info(P) = -\sum_{i=1}^{k}\left\{\left[freq(C_i, P)/|P|\right]\log_2\left[freq(C_i, P)/|P|\right]\right\} \tag{1}$$

where $|P|$ is the number of samples in the training set. $C_i$ is a class, $i = 1, 2, ..., k$. $k$ is the number of classes and $freq(C_i, P)$ is the number of samples included in $C_i$. Then, the information value $Info_Y(P)$ for attribute $Y$.

$$Info_X(P) = -\sum_{i=1}^{L}\left[(|P_i|/|P|)Info(P_i)\right] \tag{2}$$

where $L$ is the number of outputs for attribute $Y$, $P_i$ is a subset of $P$ corresponding to the $i^{th}$ output and $|P_i|$ is the number of samples of the subset $P_i$.

*Step 2*: Calculate the gain according to $Y$.

$$Gain(Y) = Info(P) - Info_Y(P) \tag{3}$$

*Step 3*: Calculate the partition value $Split\_Info(X)$ acquired for $P$ partitioned into $L$ subsets.

$$Split\_Info(Y) = -\sum_{i=1}^{L}\left[\frac{|P_i|}{|P|}\log_2\frac{|P_i|}{|P|}\right] \tag{4}$$

*Step 4*: Calculate the gain ratio of $Gain(Y)$ over $Split\_Info(Y)$.

$$Gain\_Ratio(Y) = Gain(Y)/Split\_Info(Y) \tag{5}$$

After that, the attribute with the highest $Gain\_Ratio(Y)$ is taken as the root of the decision tree.

The number of collected alarm data is 13,403 from 07/08/2021 to 11/15/2022. The obtained three rules from the decision tree are as follows.

Rule #1: If the Z-axis value of the inclination collector is less than or equal to -0.79 cm, then the collector is in an early warning state.

Rule #2: If the Z-axis value of the inclination collector is greater than -0.79 cm and less than or equal to 0.775 cm, then the collector is in a normal state.

Rule #3: If the Z-axis value of the inclination collector is greater than 0.775 cm, then the collector is in an early warning state.

## 5. Conclusions

The intelligent high-formwork support monitoring system can pre-process and analyze the received data. Then, it stores data in the database and renders data to the system. In this paper, we use a decision tree to analyze the alarm data. From the results, three decision rules are obtained. These rules, based on the inclination collector's Z-axis value, could be used to distinguish between a normal and an early warning state. These obtained rules from the decision tree could be used for decision-making.

The proposed system has the advantages of strong automation, real-time feedback on monitoring results, and a reduction in costs. The relevant personnel of the management grasps the situation of the high-formwork support in time to achieve safe construction. For future work, researchers could collect more construction data to ensure the safety of the high-formwork support construction site and prevent collapse accidents.

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## Conflict of interest

The authors declare no competing financial interest.

## References

[1] Liu L, Wang JC, Wang B, Liu YN. Research on influence of concrete pouring sequence on stability of high-formwork support system. *Applied Mechanics and Materials*. 2014; 580-583: 2235-2238. Available from: https://doi.org/10.4028/www.scientific.net/amm.580-583.2235.

[2] Romanovskyi R, Mejia LS, Azar ER. BIM-based decision support system for concrete formwork design. *Proceedings of the 36th International Symposium on Automation and Robotics in Construction*. Banff Alberta, Canada: IAARC Publications; 2019. p. 1129-1135. Available from: https://doi.org/10.22260/ISARC2019/0150.

[3] Dong JF, Liu HQ, Zhao ZW. Buckling behavior of a wheel coupler high-formwork support system based on semi-rigid connection joints. *Advanced Steel Construction*. 2022; 18(1): 425-435. Available from: https://doi.org/10.18057/IJASC.2022.18.1.1.

[4] Yang Y. Research on automatic safety monitoring system of high support mold. *Guangdong Civil Engineering and Construction*. 2020; 27(2): 66-69. Available from: https://doi.org/10.19731/j. gdtmyjz.2020.02.015.

[5] Tang S, Shelden DR, Eastman CM, Pishdad-Bozorgi P, Gao XH. A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. *Automation in Construction*. 2019; 101: 127-139.

[6] Lokshina IV, Greguš M, Thomas WL. Application of integrated building information modeling, IoT and blockchain technologies in system design of a smart building. *Procedia Computer Science*. 2019; 160: 497-502.

[7] Jisha K, Pradeepa K. Lifetime enhancement of wireless sensor using multiple mobile data collectors and optimised trajectory. *International Journal of Mobile Network Design and Innovation*. 2021; 10(2): 104-112.

[8] Chen LQ, Tang JR, Lu XT. Safety management in substation project construction based on advanced internet of things and smart sensors technologies. *2022 IEEE 5th International Electrical and Energy Conference (CIEEC)*. IEEE; 2022. Available from: https://doi.org/10.1109/CIEEC54735.2022.9846498.

[9] Li SX, Wang H, Xu T, Zhou GP. Application study on internet of things in environment protection field. *Informatics in Control, Automation and Robotics*. Springer, Berlin, Heidelberg; 2011. p. 99-106.

[10] Li DQ, Mei HH, Shen Y, Su S, Zhang WL, Wang JT, et al. ECharts: A declarative framework for rapid construction of web-based visualization. *Visual Informatics*. 2018; 2(2): 136-146.

[11] Wu Q, Chen XL, Yu HY, Liu Q, Yang YH. Real-time data visualization method for oil pipeline monitoring based on Internet of Things. *IOP Conference Series: Materials Science and Engineering*. 2020; 768: 052124. Available from: https://doi.org/10.1088/1757-899X/768/5/052124.

[12] Wehrens R, Putter H, Buydens LMC. The bootstrap: A tutorial. *Chemometrics and Intelligent Laboratory Systems*. 2000; 54(1): 35-52.

[13] Li JY. Construction of training platform for teachers professional ability of normal students based on ThinkPHP. *Frontiers in Educational Research*. 2021; 4(15): 99-104.

[14] Rawat B, Purnama S, Mulyati. MySQL database management system (DBMS) on FTP site LAPAN bandung.

*International Journal of Cyber and IT Service Management*. 2021; 1(2): 173-179.

[15] Matallah H, Belalem G, Bouamrane K. Comparative study between the MySQL relational database and the MongoDB NoSQL database. *International Journal of Software Science and Computational Intelligence (IJSSCI)*. 2021; 13(3): 38-63.

[16] Ab Rahman S, Binti HW, Yusof A. Designing a use case diagram for developing an electricity consumption (EC) system. *2021 International Conference on Computer & Information Sciences (ICCOINS)*. IEEE; 2021. p. 282-285.

[17] Appiah F. *A logic circuit simulation on marriage problem predicate with timing diagrams*. Easy Chair Preprint; 2021. p. 5317.

[18] Liu YF, Zeng XQ, Zhang K, Zou Y. Transforming entity-relationship diagrams to relational schemas using a graph grammar formalism. *2018 IEEE International Conference on Progress in Informatics and Computing (PIC)*. IEEE; 2018. p. 327-331.

[19] Lee ZJ, Zu ZY, Cheng X, Chen ZZ, Lian ZX, Wu JY, et al. Design an online shopping store based on opencart. *Artificial Intelligence Evolution*. 2020; 1(1): 1-7.

[20] Christa S, Suma V, Mohan U. Regression and decision tree approaches in predicting the effort in resolving incidents. *International Journal of Business Information Systems*. 2022; 39(3): 379-399.

[21] Lee ZJ, Lee CY, Yao J. A distributed simulated annealing based decision tree (DSABDT) for cancer classification. *2021 IEEE 4th International Conference on Knowledge Innovation and Invention (ICKII)*. IEEE; 2021. p. 1-4.

[22] Lee ZJ, Chen Y, Lee CY. An intelligent approach for learning satisfaction. *2021 IEEE International Conference on Computer Science, Electronic Information Engineering and Intelligent Control Technology (CEI)*. IEEE; 2021. p. 264-267.