Visual Monitoring for Pouring Quality Control of Fresh Concrete

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ABSTRACT

The pouring quality control of fresh concrete has been focused on the on-situ construction. By means of the poker vibrator, fresh concrete can be consolidated well via excluding entrapped air. However, construction quality is, in fact, associated with operator’s experience due to lacking effectively monitoring equipment, so improper vibrating actions can easily cause indiscernable and irreparable defects. In this paper, combined with Global Navigation Satellite System (GNSS), sensors, net transmission, 3D visualization and mobile communication technologies, a real-time intelligent monitoring system to supervise the process of vibration and feedback the information of flaws in time is developed, which can solve vibration issues of fresh concrete significantly and compact mixture on the construction site.

INTRODUCTION

During casting concrete on site, Internal vibrator is the most effective way used to compact fresh concrete due to its great excitation force [1, 2]. Nowadays, explicit

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vibration specification has been strengthened in concrete construction codes [3], but the real-time monitoring equipment of the vibration effects is still not well known to instruct employees when and where to insert the poker vibrator into fresh concrete and how long the vibration time is each point.

In order to solve the above problems, an innovative visual system for monitoring vibration effect of fresh concrete is developed, which can record the moving trajectory of poker vibrator by GNSS technology in real time as well as the vibration status referring to whether the poker vibrator inserts in the mixture or not, and then these recorded signals are transmitted to the cloud servers via General Packet Radio Service (GPRS) technology to analyze and display the working information by 3D pictures on the computer. Meanwhile, information of defective areas including degree, location and scope is also able to be sent to the supervisor’s Personal Digital Assistant (PDA) and display them graphically. In all, the new system can show the vibration effects by the way of real-time 3D visualization of the spatial and temporal distribution as well as feedback on flaws in time.

LITERATURE REVIEW

In 2004, Chen developed a monitoring-alarm device mounted on a vibrating machine [4]. The device used ultrasonic sensors to get the distance between the device and the surface of fresh concrete in order to judge whether the poker has been inserted into the mixture or not. Liu [5] applied GPRS technology to wireless data communication between the remote offices including database, server, monitoring PCs and the field watering station when he developed an automatic control and real-time monitoring system for trunk watering on earth-rock dam construction. Burlingame [6] tried to apply infrared thermal imaging technology to determine the extent of vibration, because a working poker vibrator has higher temperature than surrounding concrete.

In 2014, the authors started to develop the monitoring system of vibration quality for fresh concrete based on GPS technology [7]. However, this system had some drawbacks that hadn’t been solved, for example, inconvenient operation, and merely two-dimensional display of vibrating effects and lacking of timely feedback on defective information.
VISUAL MONITORING SYSTEM IN REAL TIME

![Framework of visual monitoring system of vibration quality](image)

Figure 1. Framework of visual monitoring system of vibration quality.

The real-time visual monitoring system integrated satellite positioning, sensors, general packet radio service (GPRS), computer network, and visualization based on primary research of authors. The framework is shown in Fig. 1. Position of poker tip is calculated according to hand-held points which are localized by GNSS technology in real time, and then sends position data to the cloud server and store them. Client computers download positioning data and convert them into a spatial–temporal distribution and analyze the effects of vibration. At last, the effects of vibration are visualized in time on the computer. In addition, the flaws of vibrated concrete are marked so that employees repair them in time. The key components and corresponding functions are explained in detail in the following sections.

Data Acquisition And Transmission

The data including poker orientation, tip position and vibration status need to be obtained. Firstly, the two smaller and lighter antennas (with diameter × height = \( \phi 27.5 \text{ mm} \times 59 \text{ mm} \) and weight about 22 grams) are attached to the operator’s hands in order to receive satellite signal conveniently (see Fig. 2).

To verify the accuracy of antenna, the antenna was fixed on the points located in open space and near the obstacle, respectively. The overall deviations were recorded in Table 1 and the error was controlled within 3 cm.

| Condition | Open space | Occlusion |
|-----------|------------|-----------|
| \( \phi \) | \( \phi \) | \( \phi \) |
| X (cm) | X (cm) | X (cm) |
| Y (cm) | Y (cm) | Y (cm) |
| Z (cm) | Z (cm) | Z (cm) |
| Mean error | 0.82 \( \phi \) | 0.46 \( \phi \) | 0.94 \( \phi \) | 1.44 \( \phi \) | 0.68 \( \phi \) | 2.58 \( \phi \) |
| Standard deviation | 1.19 \( \phi \) | 0.54 \( \phi \) | 1.50 \( \phi \) | 1.78 \( \phi \) | 0.82 \( \phi \) | 3.25 \( \phi \) |
Secondly, considering the operator’s working experience and comfortable posture, the hands and vibrator tip are approximately formed a line when the poker is inserted into the fresh mixture. Scheme of two-antennas mounted on hands to calculate the tip position is shown in Fig. 2. In the figure, distance $b$, from the poker tip to hand-held point (Antenna 1) is measured by the inventive depth measuring device.

![Figure 2. Two-antennas positioning setup illustration.](image)

The distance $a$ between the two antennas can be calculated by the following equation after the coordinates of hands-held points are acquired:

$$a = \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2}$$

(1)

According to the similarity of triangles, the following relations between two antennas and the tip in the 3D space are calculated as follow:

$$\frac{x_2-x_1}{x_2-x_1} = \frac{y_2-y_1}{y_2-y_1} = \frac{z_2-z_1}{z_2-z_1} = \frac{b}{a}$$

(2)

$$x_i = x_h - bcos\alpha$$

(3)

$$y_i = y_h - bcos\beta$$

(4)

$$z_i = z_h - bcos\gamma$$

(5)

Where the coordinate of Antenna 1 is $(x_1,y_1,z_1)$, the coordinate of Antenna 2 is $(x_2,y_2,z_2)$ and $(\alpha, \beta, \gamma)$ are angles between the poker vibrator against $x$, $y$ and $z$ directions respectively.

In addition, vibration status, whether the poker is inserted into fresh mixture or not, is judged according to variation of motor current. The distance $b$ is measured by
the inventive device of measuring depth which is based on the principle of Hall Effect. The Hall sensors are sealed and uniformly mounted on the vibrator pipe at the distance of about 7cm. At the end of the pipe, all sensors are connected in series to the depth measuring device whose power is supplied by a lithium battery. (see Fig. 3)

Figure 3. Appearance of devices mounted on vibrator.

**Data Integration and Analysis**

The information is integrated and analyzed such as poker orientation, tip position, vibration status, pre-determined vibration zone and poker IDs. The details of this process are explained as below.

a. The server identifies the collected data of the status value of vibration.

b. Data is automatically matched with corresponding vibration zone according to its ID number. In the same zone, the data from each vibrator is identified by the corresponding ID.

c. 3D CAD drawing of the construction is imported and then the coordinates of reference points in the drawing are transformed into satellite positioning data. The specific process is realized till the transforming error between three non-collinear points in the drawing and corresponding positioning date by satellite at a level of centimeter successfully.

d. The length of poker vibrator in fresh concrete is calculated by the inventive device of measuring depth.

**Visualization of Vibration Effects.**

Information stored in cloud server can be downloaded by developed client software, including 3D CAD drawing converted, real-time insertion length of vibration poker and related angles, and tip positions of poker vibrating in mixture. Then vibration effects are visualized directly.

Moreover, the zone within effective vibration by poker is assumed as a cylinder volume whose center at bottom surface is the tip position of poker. The cylinder is
orientated by the poker directions. Moreover, the radius of action is set according to
the properties of fresh concrete.

In order to calculate cumulative vibration effects exactly, the entire vibrated
zone is discretized and meshed into a grid of cells. Initial value of vibration time in
each cell is set to zero. When the tip position of poker is updated at 1Hz, the value
stored in each cell within the influential zone will increase by one. Each cell will
display different color corresponding to its value.

![Figure 4. Casting site appearance.](image1)

![Figure 5. The visualization of defective areas.](image2)

## Experiment and Application

Real-time visual monitoring system was applied on site casting of one plinth
with distributed steel bar. Plinth dimensions are 4.4m × 3.4m × 0.5m (see Fig. 4) and
boundary lines are marked in red. Data updating rate was set to 1.0 Hz.

The overall tracking accuracy of poker tip on site was also tested on fixed points
at first and results are shown in Table 2. The accuracy of tip position decreased
slightly because of occlusion caused by dense steel. The final effect of vibration is
showed as follows (see Fig. 5). Operators can move the poker vibrator to defective
zones according to visualization and re-vibrate concrete there until no flaw appears.

| Two hands | One hand |
|-----------|----------|
| X (cm)    | Y (cm)   | Z (cm) |
| Mean error| 17.5     | 18.4   | 7.1    |
| Standard deviation | 1.8 | 4.4    | 2.2 |

![Table II. Overall poker tip tracking deviation on site.](image3)

We can get vibration effects at different depth are displayed directly on the
computer during the course of vibration and see Fig. 6. (The blue area represents
that fresh concrete is compacted very well by poker vibrator).
In the Fig. 6, the system shows vibration effects at different depth accurately. In the area within the depth layer of 30cm from ground, the part region between vibrated areas and the formwork are not vibrated enough. The results match the designed plan very well and show that this system also can be applied on vertical structures which have a large volume such as columns and slabs.

Discussion And Future Research Needs

This study presents a new visual monitoring system of fresh concrete during casting process. The advantages of this system include convenient operation, 3D visualization of vibration effects and real-time graphical in-situ quality feedback. Moreover, each device at moving station is minimized such as satellite receiver and wireless radio station, which can be easily carried by operator. However, there are still some limitations in the system. For example, the effective range of vibration is simply without considering attenuation effect when vibration energy is propagating. Moreover, the positioning accuracy of the vibrator tip still needs to be improved.

CONCLUSIONS

In this research, a real-time intelligent system for monitoring concrete vibration effect is developed, and the functions of this system are validated by on-site tests. The following conclusions as follows:

(1)Vibrator tip position is real-time calculated based on the assumption that the tip and operator’s hands are collinear. Test results indicate that the locating accuracy of poker tip is controlled within 20cm, satisfying operating requirements.

(2) More intuitive 3D vibration effects are visualized. Additionally, CAD diagram of construction plan can be imported into the visualization program, which greatly saves modeling time.

(3) Field test showed that the system is stable and reliable. Spatial trajectory and vibration time of each motion can be visualized. Graphical flaw information can be
timely transmitted to operator. To sum up, the new system will significantly improve consolidation quality of fresh concrete.

REFERENCES

1. State-of-the-art report on behavior of fresh concrete during vibration, “American Concrete Institute ”, 309.1R-08, 2008.
2. G.H. Tattersall, P.F.G. Banfill, 1983, “The rheology of fresh concrete”, Pitman Advanced Pub. Program, Boston.
3. J. Kolek, 1963, “Research on the vibration of fresh concrete”, Conference on Vibrations-Compaction Techniques, Budapest, Hungary.
4. R. Navon, Y. Shpatnitsky, 2005, “A model for automated monitoring of road construction”, Construction Management and Economics23 (9)941–951.
5. K.W. Chau, M. Anson, J.P. Zhang, 2004, “Four-dimensional visualization of construction scheduling and site utilization”, Journal of Construction Engineering and Management 130 (4) 598-606.
6. A.A. Oloufa, W.-S. Do, H.R. Thomas, 1999, “An automated system for quality control of consolidation operations: receiver tests and algorithms”, Proceedings of 16th International Symposium on Robotics and Automation in Construction, Gaithersburg, Maryland, USA.
7. Z.H. Tian, CeBian, 2014, “Visual monitoring method on fresh concrete vibration”, KSCE J. Civ. Eng, 18 (2), 398-408.