Fluidity Measuring Device for the Concrete using Laser Diode Controller via WSN

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Keywords: Measurement of Concrete Fluidity, Wireless Sensor Network (WSN), Laser Sensors, Driving Mechanism.

Abstract: Presented is a high performance device for the measurement of concrete fluidity using Wireless Sensor Network (WSN). This device is an improvement over the existing method of manual measurement which is subject to significant human-induced error. Using this device we can make measurements automatically and analyze the information simultaneously for the concrete fluidity. In this paper we present a novel device utilizing laser sensors and wireless data acquisition including driving mechanism. The effectiveness of the device is verified through experiment.

1 INTRODUCTION

Fluidity Concrete, a special category of concrete, is becoming increasingly common in the construction of high-rise buildings and bridges (Choi, 2008). Quality control of Fluidity Concrete requires the reliable measurement of the dynamic characteristics of the concrete. Because measurement of concrete fluidity is an important aspect in ensuring concrete quality control, standard measurement techniques have been proposed, such as 2004 KS F 2594 (a slump flow of fresh concrete test method) in South Korea. However, the conventional method of measurement using a slump cone, stopwatch and tape measure is subjective to the experimenter's judgment and may suffer unnecessary variation. Therefore, a more precise and repeatable method of measurement is required. Recent research in the field includes the use of a camera and computer measurement system. This process has proven to be accurate. However it suffers from considerable equipment cost, difficulty in field implementation, and susceptibility to environmental conditions. Furthermore, the testing apparatus must be hard-wired to a computer, limiting the portability of the device. Therefore, to effectively operate in the field, a device must be tolerant to dust, humidity and variable light conditions. Additionally, remote sensing will allow the device to be implemented wherever it is most convenient in the construction site. To surmount these challenges, we have applied a wireless sensor network to gather information from a laser based sensor network. The remote device includes an embedded controller, allowing the collection of data without a PC. Wireless sensor networks are best implemented in environments in which communication infrastructure has not been well-developed and the amount of data to transmit is small. In the field, each node of the network transmits data through the network to a PC where it may be utilized. Therefore, the state of the environment can be measured remotely without established telecommunication infrastructure. Application of wireless sensor networks include global environment monitoring (Mosalam, 2002), habitat monitoring (Mainwa., 2002), traffic planning Shekhar, 2002), medical surveillance (Virone, 2006), intelligent clothing (Lee, 2006), etc.

2 MECHANICAL STRUCTURE

The proposed device is used to measure the concrete flow and thereby calculate the fluidity. It is designed for mobility in the field and repeatability of results. The total structure is divided into two functional blocks; a test plate for containing the actual concrete and the supporting measurement electronics. A diagram of the basic mechanical layout is presented in Fig. 1. The total device has a length and width 130 of cm and a height of 10 cm. The test plate is a 100 cm square plate of acrylic.

Hee Lee B..
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DOI: 10.5220/0003986105700573
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 570-573
ISBN: 978-989-8565-21-1

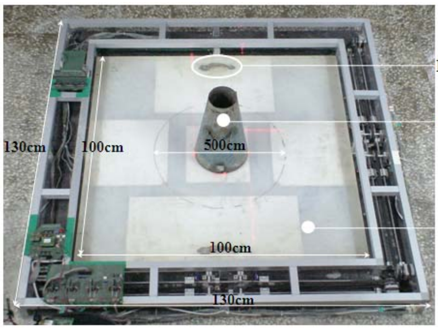

Figure 1: Proposed measurement system.

A slump cone used to deliver the test material is placed in the middle of plate. To spread the concrete evenly in four directions, each side of the device is symmetrical.

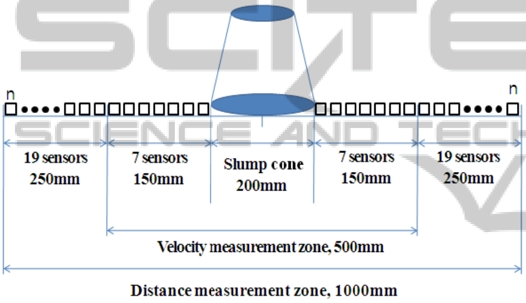

Figure 2: Conceptual figure of measuring.

After the slump cone is filled with a concrete slump, it is lifted off the test plate, allowing the concrete to spread across the plate. Flow of the concrete is measured in four directions (side A, B, C and D) utilizing a total 26 laser sensors and two laser diodes. To remain compliant with the KS F 2594 specification, 7 sensors, each spaced 21 mm apart, measure the time required for the spread to reach 500 mm. An additional 19 sensors, each spaced 13 mm apart, measure the final spread of the slump, up to 1000 mm. From the spread rate and spread diameter, the embedded computer calculates the fluidity of the concrete. Using the laser sensors, the total concrete spread is obtained using equations (1) and (2).

$$A = interval * position + velocity\ zone \quad (1)$$

$$Total = A\ side\ width + B\ side\ width \quad (2)$$

The laser diode module consists of a single movable laser diode used to sweep half the length of the test bed. The laser diode is attached to a servo motor, allowing the pitch of the diode to be adjusted. This ensures the diode remains oriented correctly to the detector on the opposite side of the test bed. The servo motor is then connected to a linear bushing and guide mechanism allowing it to translate half the length of the test bed, as shown in Fig. 3. Therefore, two laser assemblies are used to monitor a single side of the test bed. A stepper motor, controlled by the embedded processor, actuates the movement of the laser diode assembly.

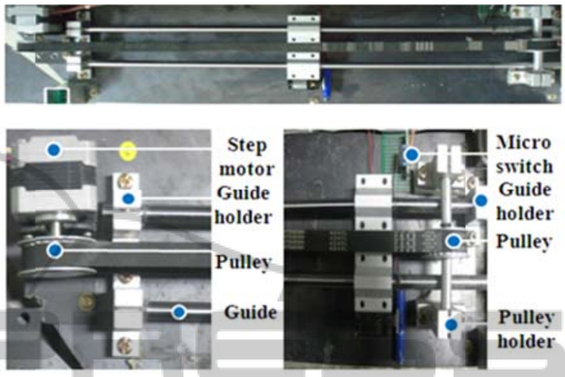

Figure 3: Laser pointer driver.

At both sides of the translation mechanism is a micro-switch used for realignment of the system. The switch also serves as an inhibitor to prevent the laser diode from exceeding maximum translation limits. Feedback from the diode is used to control the positioning of the laser.

3 CONTROLLER DESIGN

An electrical controller was designed for use with the laser measurement system. The controller is divided into three function modules; the central processing unit (CPU), sensor interface unit and motor drive unit. The central processing unit has a 32-bit Jennic JN5139 microprocessor. This processor is loaded with the Zigbee stack, and includes four 12-Bit analog to digital converters (ADCs), 21 general purpose I/O ports, timers, comparators and additional embedded circuitry. All of control software is integrated on CPU with stack, so there is no need to install another interface for user program. In order to measure the velocity of spread, we break the control unit into four parts, which are installed with a laser diode and stepping motor respectively. The CPU aggregates the sensor data, calculates the velocity of the concrete from the spread extent and transmits the data through the remote coordinator to the host computer without wire. It means this method is very effective when we need to measure something at messy environment like construction field because of using wireless communication. The laser detector arrays are connected to a single decoder (HEF4514) for velocity measurement and two decoders for distance measurement. The output of the decoder is then connected to the CPU where it is aggregated using the internal ADC. Each of the four stepper motors is independently controlled, thereby allowing independent measurement of the four sides of the slump spread. The wireless network responsible for connecting the client PC to the testing device is implemented using the ZigBee protocol that is embedded on the Jennic JN5139 processor. If distances between the testing device and host become too great to directly communicated, a router may be used to extend the range. The client software is responsible for providing a user interface. Software on the test device is responsible for network construction, command execution and control of the measurement process.

The test device software first initializes the ZigBee network. It then waits for a command from the client PC. Once received, the software will move the laser diodes to the starting point and begin checking for concrete. If concrete is detected (i.e., the laser beam is broken), a timer is started and the laser diode assembly is moved to the next sensing location. Once the flow reaches 500 mm, the timer is recorded. Measurement of the flow continues until the flow has stopped, at which point the total spread distance is measured. This process is implemented in parallel for all four laser diode assemblies. From the velocity and distance measurements, the fluidity of the concrete is calculated and transmitted to the client PC.

4 RESULT

An experiment was performed to determine the fluidity of concrete using the new method, as depicted in Fig. 4.

As Fig. 4 illustrates, the lasers are able to measure the movement of the slump in four directions. Once the flow has stopped, which means viscosity of concrete is lost, the user can command all data to be transferred to the client PC to examine the characteristic of concrete. In the Fig. 5 shows the 500mm spreading times for concrete with respect to 4 directions. Seen on the graph, the spread of 4 directions are not completely radial because of difference of uniformity for a concrete. We have also designed graphic user interface to show the measured data using Labview 8.6 in Fig. 6. All of measured data is displayed on user console to check the properties like transit time, velocity, and distance.

From the sample data, the spread distance for each side can be calculated using equation (1) to 330,306,306 and 322mm.

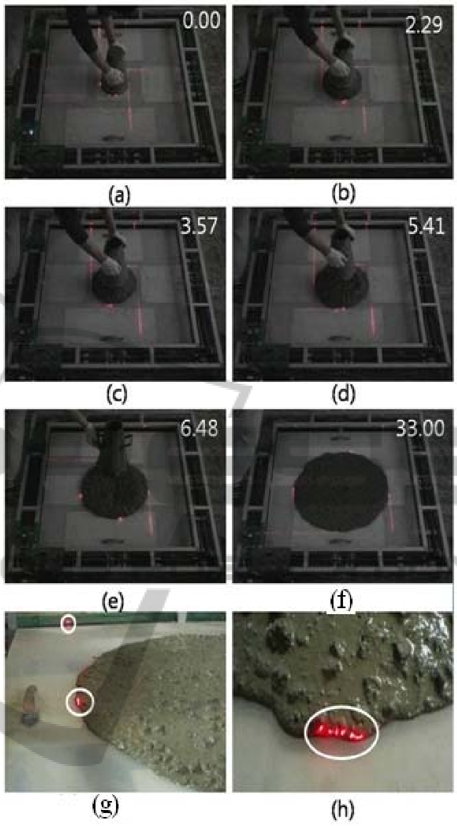

Figure 4: (a) shows the initial placement of the slump cone. (b)-(d) shows the spread of the concrete with detection occurring on four sides. (e)-(h) demonstrates the lasers ability to track the edge of the concrete spread.

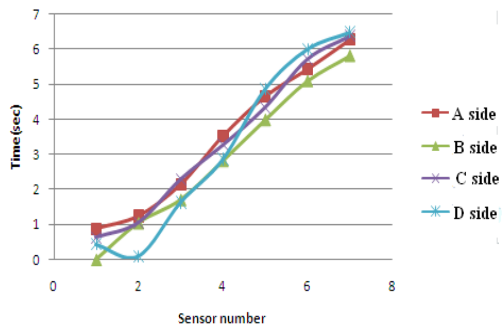

Figure 5: 500mm spreading times for concrete.

The equations assume a spread of at least 500 mm, and utilize the spacing in between the 19 distance sensors. Experimental results indicate the spread is asymmetric each of the four directions and the spread length and width can be calculated using equations (3-4), respectively.

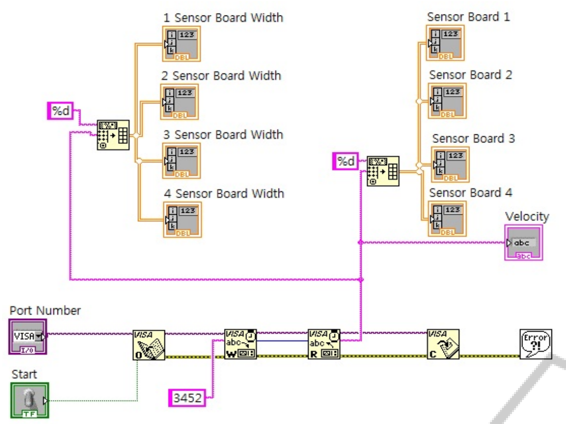

Figure 6: Client-side user interface.

Additionally, the time to reach 500mm was identified as 6.480 seconds. This conforms to regulation KS F 2594, as suggested.

$$Length = (330mm)+(306mm)=636mm \tag{3}$$

$$Width = (306mm)+(322mm)=628mm \tag{4}$$

The setup for the experiment was in an indoor environment, with the client PC within 10 meters of the test device. Therefore, the ZigBee wireless network was able to deliver the requirement bandwidth without problem. In the event of increased client to test device distances, routers can be inserted into the network to relay the data. So we can transmit the measured data to office in long distance away. Therefore we can apply this device even if it is needed long distance measure.

5 CONCLUSIONS

In this paper, an automatic concrete fluidity measurement system using a wireless sensor network is presented. The performance of the proposed device was compared with the conventional fluidity measurement technique, as described in the KS F 2594 specification. To reduce measurement variability, the proposed device utilizes an automatic laser scanning mechanism with a computer controlled timer. From the resultant data, concrete fluidity can be more reliably calculated. Furthermore, the measurement data can be logged, for future statistical analysis. While vision systems possess the fidelity required for concrete fluidity measurement, they lack the robustness required for field use. The proposed system takes advantage of a wireless sensor network coupled with a robust laser sensing system for use in a potentially dusty and humid environment. Future research on the proposed device includes the implementation of smaller laser detectors to improve detection accuracy, and the development of a graphical user interface for improved user ergonomics. Additionally, a consistent method for slump cone removal will allow for uniform initial conditions.

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