Development of a Sensor System for Detecting Window Contamination for the Building Maintenance Robot System

Y.S. Lee[a], S.H. Kim[a], J.H. Lee[b], M.S. Kang[c], D.I.SUN[c] and C.S. HAN[d]

[a]Dept. of Mechanical, Eng., Hanyang University, Republic of Korea
[b]Dept. of Mechatronics, Eng., Hanyang University, Republic of Korea
[c]Dept. of Interdisciplinary Eng. Systems, Hanyang University, Republic of Korea
[d]Dept. of Robot, Eng., Hanyang University, Republic of Korea

E-mail: pacheon76@gmail.com, shkim83@hanyang.ac.kr, zjagnswkd@hanmail.net, wowmecha@gmail.com, jeniussdi@naver.com, cshan@hanyang.ac.kr

Abstract –

Because of the increasing number of high-rise buildings and large glass facades and the resulting problem of safe and effective maintenance, many studies have been going on progress to develop automated window cleaning systems in the last few years. But the research has not been going on progress to make decision the additional cleaning through the diagnosis of contaminant degree on outer window before or after cleaning. So, the sensor system is proposed to measure the contamination of building's outer-window in this paper. To check the cleaning performance of the window, it is mounted on a Building Maintenance Robot (BMR) which is automated window cleaning system. For detecting the contaminant level of outer window, the sensor module using the IR sensor is proposed. In order to apply the proposed sensor module to BMR system, the mechanism for the horizontal or vertical movement of the sensor module is designed. To improve the diagnostic accuracy of contaminant level, The Algorithm for position control using the proximity sensor is developed to keep a certain distance between sensor and window at the horizontal mechanism. A method detecting the contaminant level is verified by lab test. To validate the mechanism of the proposed sensor module, the field test is executed with the BMR system equipped with the sensor module.

Keywords –

ISARC Window Contamination; Building Maintenance Robot System; IR Sensor

1 Introduction

The number of new high-rises covered with curtain wall glasses is growing along with the improvements in construction technology, with a corresponding increase in the need for their maintenance, repair, and care [1].

The prevalent building maintenance, repair, and care practices largely rely on the conventional means for external wall care, such as the use of a rope, a gondola, and a winch, which are prone to causing safety accidents. As they are more dependent on human labor compared to other construction processes, the safety accident occurrence ratio is also high among them. Several studies are being conducted on ways of automating the process of providing curtain wall care, such as the building maintenance robot (BMR). Several research institutes and companies, including Nihon Bisoh in Japan and Fraunhofer IPA in Germany, are experimenting with the potential application of building maintenance robots for cleaning external wall glasses [2, 3].

Figure 1. State-of-the-art building façade maintenance System

Those robots, however, simply clean the glasses with a constant pace, without paying attention to the varying extent of contamination of the glass surfaces, which again makes it necessary for human staff to check the cleanness of the glass surfaces after the cleaning as the robots are unable to determine their status. Therefore, studies should be conducted on some sensors that could be used to measure the extent of contamination of a glass surface so as to automate the curtain wall glass cleaning system. In this paper, a module-type sensor system capable of measuring the contamination of a glass surface is proposed. The system uses IR sensors mounted on the curtain wall glass cleaning system to survey the extent of contamination on a glass surface.

2 Sensor Module for Detecting Window Contamination

An IR-sensor-based sensor module was developed to detect the contamination of a glass surface. The sensor module was assembled as shown in Figure 2, by combining the light emitter and receiver of the IR sensor. If the light emitter and receiver of the IR sensor are installed at a 45° angle, respectively, part of the light emitted from the light emitter will pass through the glasses, with the rest being reflected back to the light receiver in accordance with the principles of the angle of incidence and angle of reflection. The amount of reflected and inputted light will increase in clean and transparent glasses and will decrease in contaminated glasses, thereby enabling the determination of the extent of glass contamination.

For the IR sensor module developed by these researchers to accurately detect the contamination level, the sensor should be consistently kept at a regular distance from the glasses. If the IR sensor moves back farther from the glasses, both the angle of incidence and angle of reflection will change, thereby making it impossible to detect the contamination of the glasses. If the IR sensor moves too close to the glasses, the angle of incidence and angle of reflection will change again, thereby making it impossible to detect glass contamination or even causing it to bump onto the glasses.

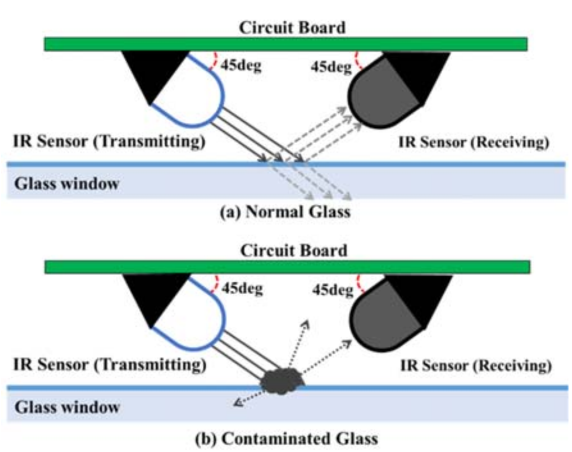

Figure 2. Concept of the IR sensor module

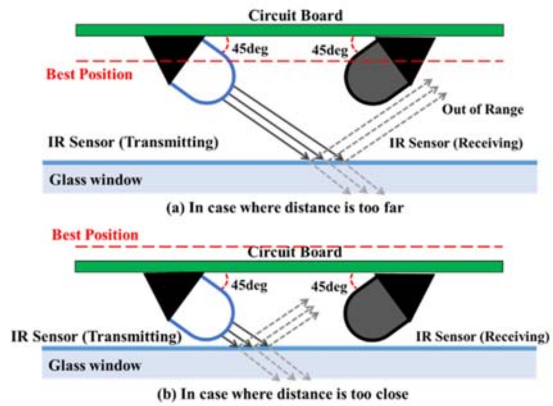

Figure 3. Importance of the distance between the IR sensor module and glass

Therefore, a sensor system with the capacity to maintain a constant distance between the sensor and glasses is required. Chapter 3.1 will introduce a mechanical design for such sensor system while Chapter 3.2 will introduce a control algorithm for the sensor system.

3 Configuration of a Mechanical Design and Control System for Detecting Window Contamination

3.1 Mechanical Design of the Sensor System

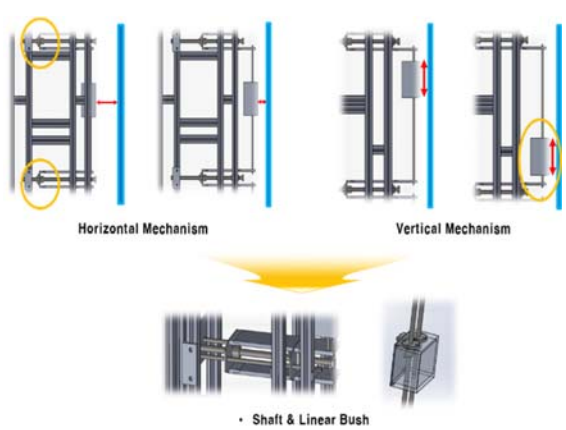

Figure 4. Mechanism design

As described in Chapter 2, a mechanism that maintains a constant distance between a glass surface and a sensor is indispensable for the sensor to possess the specific characteristics required for contamination detection and for improving the reliability and accuracy in the detection of glass contamination.

A guiderail was installed as shown in Figure 4 to enable the forward-backward horizontal movement of the sensor, followed by the installation of a resetting spring equipped with a fail-safe function that enables returning to the default position to prevent a clash between the sensor and the glass surface in case the driving motor is shut off.

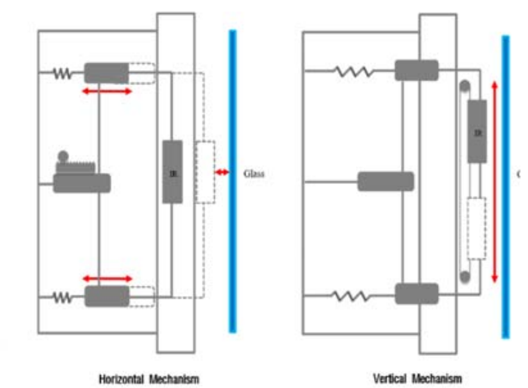

Figure 5. Mechanical design concept

A mechanical design concept equipped with a vertical up-down movement mechanism such as that found in the printer mechanism that was designed to detect the contamination of 1.8m-high large curtain walls using a certain number of IR sensors is proposed herein. Figure 5 shows the mechanical concept that realized vertical up-down movement by employing belts and pulleys.

The belt-and-pulley mechanism was adopted for the following reasons: (1) it is appropriate for a relatively lightweight and long-distance shuttle movement as the movement entails an up-down movement that is longer than the forward-backward movement; and (2) no positioning control is necessary because the sensor is located in the middle of the up-down movement path.

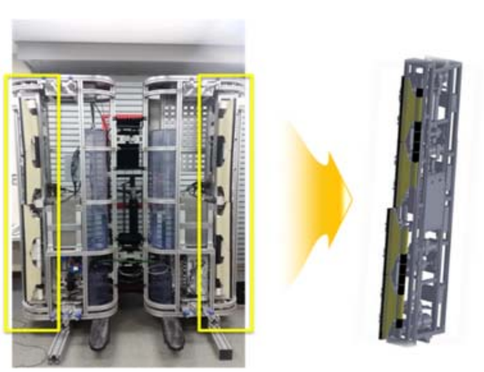

Figure 6. Detachable module-type cleaning tool

As shown in Figure 6, the proposed contamination detector sensor system was designed as a detachable module that can be mounted on the existing curtain wall cleaning robots. The existing curtain wall cleaning robots are designed to remove the contaminants on a glass surface using the cleaning tool mounted on the side opposite the robot's movement (cleaning tools are mounted on the left and right sides of the robot).

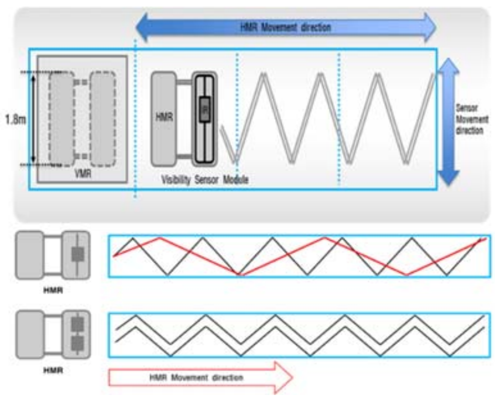

Figure 7. Contamination detection range depending on the number of sensor

The sensor system developed by these researchers was installed on the robot, replacing the robot's right-side cleaning tool. As shown in Figure 7, the sensor system surveys the extent of contamination on a glass surface while the robot installed with the contamination detection sensor moves rightwards, whereas the left-side cleaning tool surveys the cleaned state of the glass surface while the robot is already turning back to its previous position.

The survey range as well as the amount of attainable data from each survey on the contamination of the glass surface can be adjusted as shown in Figure 7, by changing the robot's horizontal movement speed, up-down shuttling speed, and number of sensors.

3.2 Control System and Algorithm for the Sensor System

The proposed system for detecting contamination of a glass surface is composed of eight limit switches, four proximity sensors, four driving motors, and an IR sensor module for controlling the position of the sensor module. Four vertically arranged limit switches and two driving motors control the vertical movement of the sensor module while four horizontally arranged limit switches, along with two driving motors and four proximity sensors, control the horizontal movement.

While the sensor module attached on the belt moves vertically, it measure the contamination on the glass surface at regular intervals. Two proximity sensors capable of detecting the presence of glass are used to enable the sensor module to close in on the glass surface at a regular distance. The proximity sensors with digital output can measure the distance to the glass surface by being mounted on the upper and lower parts of the module at different lengths, respectively. Moreover, the following location-based control algorithm is used to maintain the distance between the sensor module and the glass surface.

The target values in Figure 8 are generated via the following equation:

$$X_{des} = X_{pre} + A * Q_1 * Q_2 \quad (1)$$

where Xdes signifies the target coordinates on which the sensor module will be positioned, Xpre signifies the current coordinates of the sensor module, A signifies the control gain used to change the target coordinates, and Q1 and Q2 signify the output values of the proximity sensor. The initial value of Q1 and Q2 is 1. If proximity sensor 2 detects glass, the value of Q2 changes 1 to 0, and if two proximity sensor detect glass, the value of Q1 changes 1 to -1 and value of Q2 changes 0 to 1. The horizontal movement target value of the sensor module changes in accordance with the values of Q1 and Q2.

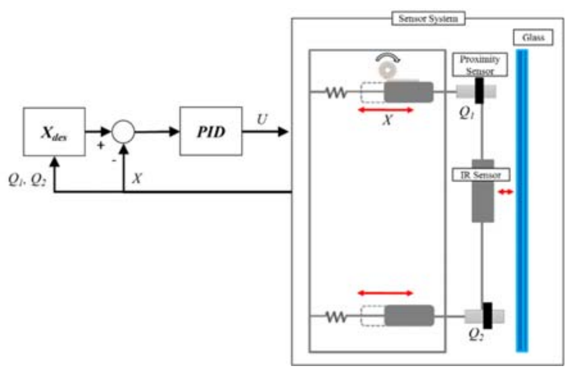

Figure 8. Configuration of the control algorithm

4 Experiment and Result

A field test was performed to drive the sensor system and to detect contamination in an attempt to verify the performance of the proposed system. The proposed system was mounted on a building maintenance robot (BMR), which is an automated window cleaning system.

Figure 9. Sensor system installed on a BMR for detecting glass contamination

The test environment was configured as shown in Figure 10. The experiment was performed in a test building wrapped with 1200mm-wide curtain wall glasses. The BMR robot cleaned the curtain walls twice before the experiment to maintain the contamination of the glass surface at the standard level. An area of the glass curtain wall some 1200 mm behind the initial location of the BMR robot was stained with contaminants before the BMR on which the proposed sensor system was mounted measured the degree of contamination of the glass. The measurement of the contamination was performed at every 3 mm interval since the sensor module embarked on a vertical movement. Over 14,000 contamination data points were measured in the end.

Figure 10. Configuration of the experiment environment

The contamination detection results on the upper and lower curtain wall glasses are shown in Figure 11 and 12, respectively, and a graph indicating the current position of the BMR robot that moved horizontally is shown in Figure 13. The contamination detection results on the upper curtain wall glasses did not show any perceptible change, but values lower than the average output values were observed within the space between 6000 and 9000 msec when the degree of contamination of the lower curtain wall glasses was measured. As such, it was confirmed that those sections whose voltage levels were lower than the average value were contaminated areas. The location of the robot at 6000 msec, where the contamination started, was about 2700 mm, about 1200 mm away from the robot's initial location. The result also shows the location of the contaminated section.

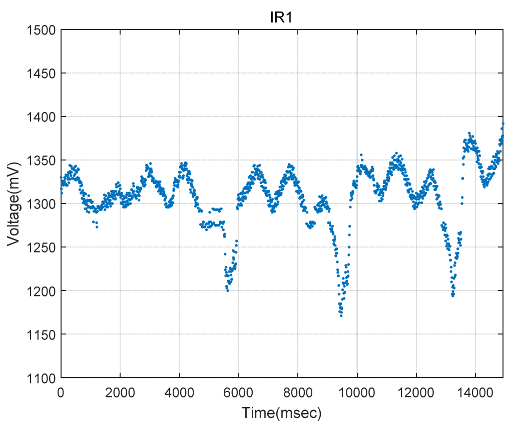

Figure 11. Contamination detection results on the upper curtain wall glasses (IR sensor detection results)

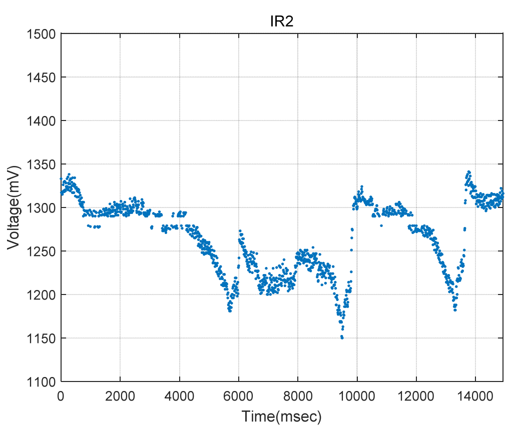

Figure 12. Contamination detection results on the lower curtain wall glass (IR sensor detection results)

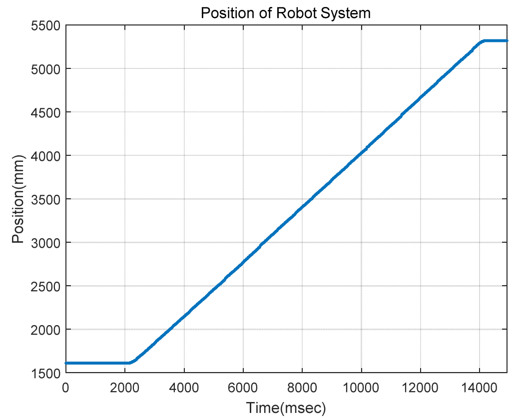

Figure 13. Horizontal movement position of the BMR robot

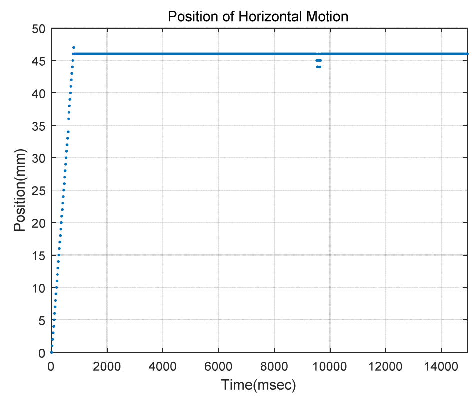

Figure 14. Results of the horizontal movement of the IR sensor module

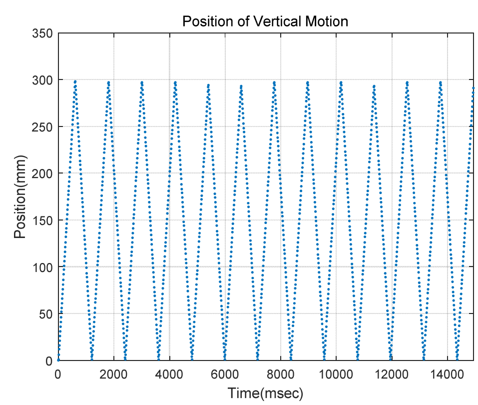

Figure 15. Results of the vertical movement of the IR sensor module

The coordinates of the forward-backward direction of the IR sensor module required for contamination detection are shown in Figure 14 and 15 while Figure 14 shows the results where the distance between the sensor module and the glass surface was kept constant. It was confirmed from the coordinates of the IR sensor module that the proposed system is capable of maintaining a constant distance from the glass surface as well as of detecting contamination in as many areas as possible.

5 Conclusion

In this paper, a sensor system for detecting contamination on curtain wall glasses for the automated window-cleaning robot is proposed. The sensor system for detecting contamination on windows using an IR sensor requires a subsystem that maintains a constant distance from the glass surfaces given the specific requirements of the sensor system. To address this issue, a mechanism that can move forward-backward and upward-downward is proposed herein. The field test results of the proposed sensor system confirmed that a voltage relatively lower than the average of the sensor values gained from detecting a clean glass surface was observed in the sensor signals gained while detecting contamination on a glass surface.

Acknowledgment

This research was supported by the Industrial Strategic technology development program (No.10052965) funded by the Ministry of Trade, Industry and Energy (MOTIE), KOREA and was supported by a grant(14SCIP-B079344-01) from Smart Civil Infrastructure Research Program funded by Ministry of Land, Infrastructure and Transport(MOLIT) of Korea government and Korea Agency for Infrastructure Technology Advancement(KAIA).

References

[1] Horner R. M. W., El-Haram M. A. and Munns A. K. Building maintenance strategy: a new management approach. *The Journal of Quality in Maintenance Engineering*, 3(4): 273-280, 1997.

[2] NIHON BISOH CO. Automatic Window Washers. On-line: https://www.bisoh.co.jp/en/case/washers/, Accessed: 31/03/2016

[3] Hortig J., Elkmann N., Felsch T., Sack M. and Bohme T. The Sirius robot platform for tool handling on large vertical surface. In *International Symposium on Automation and Robotics in Construction* (ISARC2010), 2010

[4] Albagul A., Asseni A., Jomah O., Omer M. and Farge B. Design and fabrication of an automatic window cleaning robot. In *Proceedings of the 9th WSEAS International Conference on Signal Processing*, 2010

[5] Lee S. H., Kang M. S. and Han C. S., Sensor based motion planning and estimation of high-rise building façade maintenance robot. *International Journal of Precision Engineering and Manufacturing*, 13(12):2127-2134, 2012.