

# AN EXPERIMENTAL STUDY OF AUTOMATIC CLEANING TOOL AND ROBOT FOR FAÇADE IN HIGH-RISE BUILDINGS

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**ABSTRACT:** Due to the development of construction technology, there is a considerable increase in the number of skyscrapers in the world. Accordingly, there are rapid growing requests about maintenance systems such as cleaning, painting, and monitoring the processes of facade in high-rise buildings. However, it is extremely dangerous working the walls of high-rise buildings, and crashes from buildings have accounted for large proportion of constructional accidents. An alternative solution must be developed with the commercialization of automatic robot systems. For the last decade, interest in developing robots for cleaning and maintenance in facade of high-rise buildings has continuously increased. The use of automatic robot systems can be expected to reduce accidents and decrease labor costs. In this paper, we propose a new kind of cleaning mechanism. We have designed and manufactured various cleaning tools and robots for different types of facades with economic commercialization. The cleaning cycle, size, and intensity will be determined by economic constraints as well. The final goals are to design and manufacture tools and robots that can clean facades efficiently and rapidly even in dangerous places. The cleaning tool systems consist of nozzles, brush rollers, and squeezers. Furthermore, these tools and robots perform each process utilizing the systems of built-in guide types and gondola types for building maintenance. The performance of the proposed cleaning tools and robots is evaluated experimentally; however additional study should be necessary for safer and more stable commercialization.

**Keywords:** *Cleaning Tool, Robot, Maintenance, Building Façade, Gondola, Built-in Guide*

## 1. INTRODUCTION

The construction of skyscrapers with 100 stories and over has been consistently carried forward across the world, and in Korea buildings with 60 stories and over are actively constructed as well. Modern buildings are becoming larger and high-rise as scientific technology develops, and this trend is going to continue.



Fig. 1 High-rise building projects in Korea

High-rise buildings that beautify urban landscape are expected to incur significant amount of cost in the aspect of construction as well as of maintenance. Moreover, dangerous tasks are carried out by various workers in construction industry due to the labor intensive nature.

The current maintenance work on the exterior walls of high-rise buildings is mostly done with conventional rope and gondola, which is the cause of frequent safety accidents and falling productivity. Especially, as the number of high-rise buildings with irregular shapes increases, the safety accident rate during the maintenance work of exterior walls increases each year, and most of the accidents lead to death. The industrial disaster along with the old age of skilled labor is expected to bring about





future imbalance of demand and supply of construction workers. The automation of construction industry is an essential measure for decreasing industrial disaster and resolving the imbalance of construction worker demand and supply.

In this research, a fundamental research has been conducted for drafting and commercializing an automation tool that is carried in the robot system of gondola and built-in guide method, which can perform cleaning.

**2. RESEARCH BACKGROUND**

According to the statistics of industrial disaster from Korea Occupational Safety and Health Agency, death in construction industry continues to take place as the death toll reached 631 in 2006 and 669 in 2008 among accidental deaths in the entire industry. Deaths caused by fall account for 48.9%, which is the highest rate, of all the accidental deaths in the construction industry in 2008 [1].

Table 1 Causes of the crash in the classic work

Classic Work	Accidental Case	Causes
		<ul style="list-style-type: none"> <li>▪ Irregular shape of building</li> <li>▪ Tangled rope</li> <li>▪ Sudden gust</li> </ul>
		<ul style="list-style-type: none"> <li>▪ Crash against building</li> <li>▪ Breaking of wire</li> <li>▪ Unfit posture</li> <li>▪ Bad equipment</li> <li>▪ Heavy weight</li> </ul>

The main causes of accidents during the conventional work on the exterior walls of buildings are, as is expressed in table 1, breaking of rope and wire that hang on the high-rise and unfit posture as well as falls caused by various winds that exist between buildings [2]. Especially in case of high-rise buildings located in inner city, industrial disaster may take place due to the factors such as tangled

ropes that are caused by eddies and sudden gust of wind breaking out among buildings [3,4].

**2.1 Present State of Cleaning Work in Korea**

Currently there is no development of automated robot system for cleaning the exterior walls of high-rise buildings and the related research is also insignificant in Korea.

Among the cleaning methods carried out for exterior walls of high-rises in Korea is to clean by a worker in a cage of a gondola that is connected to the top of a building. However, use of gondola is quite often impossible due to the esthetic structure of the tops of the buildings as well as the irregular shapes of recently-built buildings that are constructed with design element.

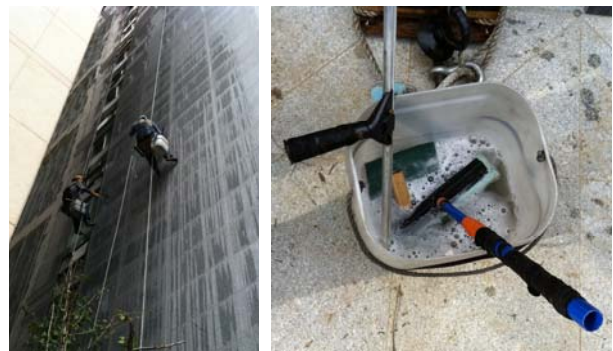


Fig. 2 Cleaning work and tools in high-rise building

As for the exterior wall cleaning of common high-rise buildings, conventional ropes, as is illustrated in the figure 2, are mostly used. The worker cleans as he comes down while being suspended by a rope that is fixed on the rooftop of a building. The cleaning work is mostly conducted in a team of two persons, and when the worker reaches the bottom of a building as a certain area of work has progressed, he moves back to the initial position on top of the building to proceed with the work. The cleaning water for cleaning the exterior walls is supplied from the building, and the worker cleans with cleaning tools.

The cleaning tools that are used are the vacuum compressor for holding the body on the exterior walls and the sponge tool that cleans while supplying the detergent, and the rubber squeezer that lastly wipes the moisture, as is illustrated in the figure 2. Adjunctively, plastic pieces or

blades of knives are used to remove the foreign substance that has adhered on the wall.

**2.2 Present State of Maintenance Work in the World**

The research on the construction robot for maintaining exterior walls of high-rises is being actively conducted with advanced countries like Japan and Germany as the center.

The general shapes of exterior wall maintaining robots that have so far been developed are divided into three kinds: a robot system that uses a gondola installed on top of a building, a robot system that uses a guide rail and a mullion installed on the exterior wall of a building, and a robot system that performs the work by utilizing self-moving mechanism. The examples of exterior wall maintenance robots that have been developed up to now are summarized in the table 2 [2].

Table 2 Developed construction robots in the world

		
Inspection The US	Inspection The UK	Moving Hong Kong
		
Monitoring Japan	Painting Japan	Cleaning Germany
		
Cleaning Germany	Cleaning Germany	Cleaning Germany

As for these construction robots for exterior inspection, cleaning, and painting, complete automation has not yet

been achieved and the scope of work is restricted as well due to the variety of working methods for various building shapes.

**3. DEVELOPMENT OF CLEANING TOOL**

Cleaning process performed by a worker is generally comprised of three tasks that follow. The cleaning water supplied from the interior of a building and the detergent carried by a worker is sprayed on the exterior wall by a sponge tool. Next the detergent on the exterior wall is wiped with the cleaning water and lastly the moisture is removed by a rubber squeezer that is like a wiper for a windshield. When the contamination of the exterior wall is slight as in the pre-delivery inspection, sometimes only the cleaning water is sprayed without the detergent and finished with the rubber squeezer.

The following automated cleaning tool has been invented by utilizing the above cleaning process.

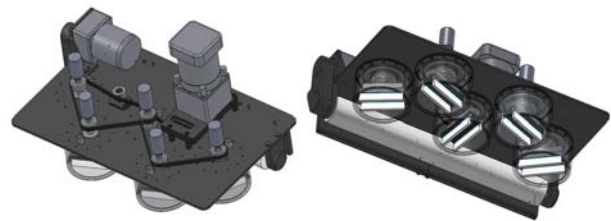


Fig. 3 General drawings of cleaning tool

The automated cleaning tool illustrated in figure 3 is comprised of a nozzle, brush roller, and squeezer as a result of the analysis of the actual cleaning process that the worker performs [5]. The width of cleaning is designed to be 500mm, and the height is designed to be 350mm or under for the ease of attachment to the carrying robot system.

A lot of office buildings constructed recently are constructed with curtain exterior wall, which is prefabricated wall with ease of construction [3]. The kinds of curtain walls can be classified by appearance, quality of the material, structure, and constructing method. In order to apply this tool for cleaning on these curtain walls, the quality of the material that is used should be closely considered because some of the metal curtain walls can be corroded by using the acid or alkaline detergent. Moreover,

as the tool for cleaning should be driven by a separate moving equipment such as a guide rail or gondola system, the optimization of weight is essential for actual application to a building. For this reason, most of the parts in this cleaning tool that is invented are those made of anodized Al6061 and acetal to help to reduce the weight.

### 3.1 Composition of Cleaning Tool

Nozzle part is a device for spraying the detergent and the cleaning water. As for the cleaning process that is performed manually by a worker, large amount of cleaning water is sprayed for cleaning and the retrieving system has not been contrived. Especially in case of highly contaminated exterior walls, acid or alkaline detergent is sprayed with high pressure and additionally the counteragent and the cleaning water is sprayed, which makes the amount of water used large and the economy disadvantageous not to mention the environmental pollution.

In the initial stage of this research, a method was contrived, in which a nozzle installed with a bearing is revolved by reaction from spraying the cleaning water, and the straight-lined brush attached to it is revolved for cleaning. However it was impossible to carry enough amount of cleaning water due to the heavy weight of the whole system.

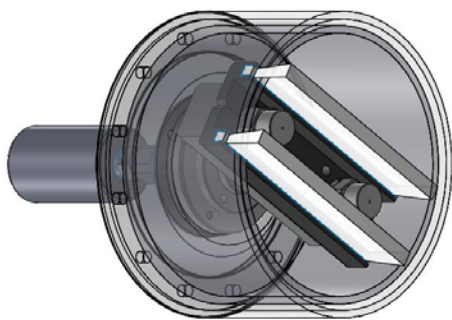


Fig. 4 Detailed drawing of nozzle parts

The nozzle part designed by this research is comprised of five segmentalized nozzle devices. Each nozzle device is connected by a timing belt and a timing pulley, and through the power of the motor, two nozzles are revolved that are installed inside to spray the detergent and the cleaning water. In order to reduce the weight of the whole system

and the amount of consumed water, spraying the cleaning water is performed with a spray shape.

As is illustrated in figure 4, the primary cleaning is performed by straight-lined brush being revolved that is connected to the nozzle as each nozzle is revolved. Each nozzle case is comprised of an inner case and an outer case that have step of 3mm, and is contrived to retrieve the water and the detergent that has been used for primary washing between two cases by using vacuum.

Brush roller is positioned at the end of the nozzle and performs an additional cleaning task for the remaining contaminant that is left after the primary washing task by the straight-lined brush in the nozzle part. Brush roller is also driven by a motor. Various materials such as polypropylene and nylon are applied to the brush so that it can cope with chemicals such as acid or alkaline detergents. Generally nylon material can be used with alkaline detergent, and polypropylene material can be used both with acid and alkaline detergent.

Rubber squeezer is installed at the end of the cleaning tool and cleans lastly the remaining water and the detergent on the exterior wall to finish the cleaning work. Retrieving device is additionally designed at the front of the squeezer to additionally retrieve the cleaning water and the detergent, which maximizes the retrieving rate of the cleaning water.

### 3.2 Additional Research on the Variable Brush Roller

The brush roller that is presented in 3.1 is of the structure of all-in-one cylinder that is driven by a motor. On the exterior walls of a building, a lot of structures such as window frames exist. The cleaning robot system that is currently developed does not realize the complete automation, in which the structures such as these can be wholly recognized for cleaning task. A complicated control system should be constructed to detect these parts that exist on the exterior walls of a building, which leads to the weakness in terms of productivity due to the cost rise and the slow-down of working speed.

In this research, a variable divided brush roller has been designed additionally that can actively cope with the structures such as window frames [6].



Figure 5 is an example of a variable divided brush roller, in which segments are divided according to pneumativity. The brush roller is divided into circular plate rollers of uniform thickness, and an axis is built inside that has a manufactured pneumatic pipe. Using this, pneumativity can be applied selectively onto certain parts of a brush roller. If a divided circular plate roller that is not applied with pneumativity comes into contact with structures on the exterior walls such as window frames, it can respond naturally according to the shapes of the structures as is illustrated in figure 5.

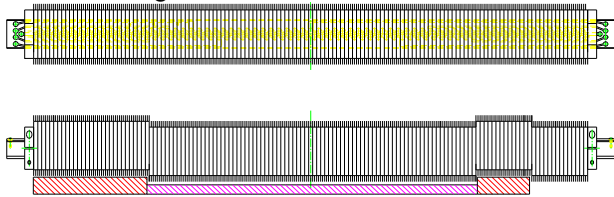


Fig. 5 Design of variable partition brush roller

In case of highly contaminated exterior walls, the efficiency of cleaning can be maximized through adherence of high pressure by enlarging the pneumativity on the whole that is supplied to the brush roller.

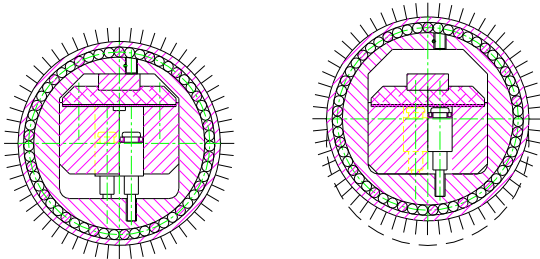


Fig. 6 Sectional view of variable partition brush roller

The cross section of the divided circular plate roller is illustrated in figure 6. A variable divided brush roller is naturally driven by multiple balls that are positioned between the inner roller and the outer roller as the cleaning work proceeds. It has the advantage of decreasing the power supply and the weight since it is not forcibly driven by a motor.

The pneumatic pipe manufactured in the axis that goes through the inside of the divided brush roller prevents the release of pneumativity by gasket and packing. The divided circular plate roller that is not applied with the

pneumaticity is designed to move upward freely as is illustrated in the right-side drawing of figure 6.

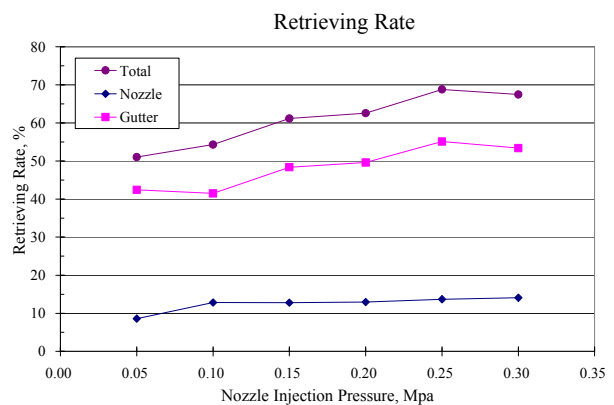
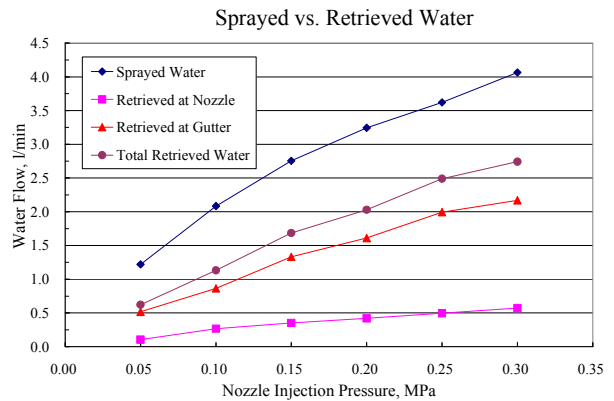
#### 4. EXPERIMENTAL RESULT OF CLEANING TOOL

The experiment was performed to analyze the retrieving rate, and the picture of the experimental setup is shown in Figure 7. This setup consists of a cleaning tool, test bed, and utility system.



Fig. 7 General view of test equipment for cleaning

The measured width and height of the test bed was 1700mm and 700mm, respectively. Six pressures ranging from 0.05MPa to 0.3MPa were adopted in order to examine the effect of nozzle injection pressure. The moving velocity of the cleaning tool was 0.4m/s.



### Fig. 8 Experimental results of retrieving test

Figure 8 presents the sprayed and retrieved water flow upon the increase of the nozzle injection pressure. The sprayed and retrieved water flow was increased upon the increase of the nozzle injection pressure, as shown in figure 8.

When nozzle injection pressure was at 0.25MPa, the maximum retrieving rate of a developed cleaning tool was measured as 68.8%. The retrieving rate of designed nozzle cases was increased gradually with increasing nozzle injection pressure, and the maximum value was 14.1% at 0.30 MPa. However, this is a minor portion of a whole retrieving rate. The retrieving rate of the mechanical gutter was shown to be significantly higher than nozzle cases. In the future, further studies on shapes and sizes of nozzle cases and gutter will be conducted. The effect of vacuum pressure will be investigated experimentally.

## 5. CONCLUSION

This research presented an apparatus for cleaning the exterior walls of a building automatically through analysis of a cleaning work that is performed by an actual worker.

In order to apply this cleaning tool to an actual building, it is essential to have a built-in guide robot system that should be conceived from the designing stage of a building or a gondola method robot system to carry the cleaning tool, or to construct its own moving system. The point that should be considered most importantly in developing the robot system for cleaning exterior walls of a high-rise is optimization of the weight of the entire system due to the peculiarity of the working space. The cleaning tool that has been designed aims to reduce the weight by applying parts of light-weight material. However, the weight of the utility systems such as control system including the power supply part that is carried within the cleaning tool together with water and detergent should be additionally considered in case of skyscrapers.

Although the usefulness of this cleaning tool and utility system has been verified primarily through the experiment of cleaning the window pane, the connection with the moving robot system for carrying this cleaning tool is essential. Additional researches are planned for

optimization of the working speed, retrieving rate of the cleaning water, and applicability of the variable divided brush roller by installing the cleaning tool on the exterior wall of an actual building in the future.

## ACKNOWLEDGEMENT

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