COST-EFFECTIVE ROBOTS FOR FAÇADE CLEANING

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Abstract: In the last years, several robots for building façade cleaning have been designed and some prototypes have been developed. However, most of these robotics systems are too expensive to be introduced in the market or are only able to cope with very simple completely flat glass façades. Funded by the European Commission, a consortium formed by several European enterprises and research institutions is developing a semi-automatic low cost robotic system that is able to cope with the cleaning tasks of most of the existing large building façades. The robotics system is semi-automatic because one single human operator is necessary to supervise the robot task and to perform simple operations. However, this operator, located at the ground, increase the security of the cleaning task. The main specifications for a marketable robotic façade cleaning system are presented and after that, a first description of the proposed robot is presented, showing the concept of the system and the control architecture.

Keywords: Automatic Façade Cleaning, Climbing Robots, Cleaning Robots.

1 INTRODUCTION

Nowadays the number of buildings with large glass or flat façades is increasing all over the World. These façades must be periodically cleaned with manual procedures that supposed high cost and risk for the workers which have to develop their work under heavy conditions. Although the cleaning cost depends a lot on several factors as the façade characteristics, the cleaning periodicity or the total surface to be cleaned, the cost per square meter, in Europe, varies between € 4 for flat glass façades and € 18 for jalousies and difficult structures. The average cost is € 7-8 per square meter. A typical building of 12.000 m^2 supposes a total façade cleaning cost of € 100.000 and this task is usually done every year. The use of an automatic or semi-automatic cleaning system can lead to around 60% savings over existing practice. In the cleaning of a single building, a saving of the order of € 50.000 will be possible, for example.

Automation and robotics technologies allow environmentally friendly façade cleaning, helping to reduce the cost of these tasks. Additionally, these systems overcome the current worker safety problems associated with difficult and dangerous access, contributing to a zero injury and fatality working practices [1].

Because of the increasing number of high-rise buildings and large glass façades and the resulting problem of safe and effective cleaning, a lot of effort has taken place in the last few years to develop automated cleaning systems. The majority of systems conceived and developed thus far are in Japan [2] and Europe [3]. The first automated cleaning systems for high-rise building were used in Japan in the middle of the 80's. These systems were mainly designed for use on specific buildings. For safety purposes or in order to guide the robot's movement on the façade, they often required additional construction such as guidance rails to the façade.

During the last 10 years, there has also been a lot of effort towards the development of such façade cleaning systems in Europe. These systems, like the Japanese developments, were designed for specific buildings. The practical application of the systems mostly failed because of either a weak safety concept, poor cleaning quality, required additional construction to the façade, or simply due to expensive initial or operating costs. At this time, there is only one known system that is in practical operation. That is the automatic system for the cleaning of the vaulted glass hall of the Leipzig Trade Fair, Germany, which was developed by the Fraunhofer Institute IFF, Germany [4]. It must also be added that this system is only applicable to this particular building.

Funded by the European Commission, a consortium formed by several European enterprises and research institutions is developing a semi-automatic low cost robotic system that is able to cope with the cleaning tasks of most of the existing large building façades.

This system is with minor changes adaptable to the largest possible number of buildings with homogeneously-designed façades. Additional constructions to the façade such as guide rails or scaffoldings are avoided or made unnecessary. The requirements for the control and sensor concepts are very specific, because the proposed robotic system is able to operate under adverse conditions such as changing weather conditions.

2 SPECIFICATIONS FOR A MARKETABLE ROBOT FOR FAÇADE CLEANING

To design a marketable and successful automatic façade cleaning system, it is necessary to provide a reliable, simple and economically efficient machine. The performance objectives may be summarized in:

- The total cost of the system must be under $ 75.000
- The system must be small (much less than 100cm x 80cm).
- The machine must master usual obstacles such as window frames
- One person must be able to handle the system
- Water and detergent must be recovered avoiding spilling
- Time to complete the cleaning of one square meter of flat glass façade should be less than 4 minutes.
- The system must be suitable for buildings with conventional installations

Many of the existing façade cleaning robots can only climb and clean completely flat glass window façades. However, most of existing buildings have homogeneously-designed façades but not completely flat. In many building there are not very complex obstacles, such as windows frames, that can be overcame by a not very sophisticated robot, allowing covering a very wide range of buildings with a single design.

3 CONCEPT OF THE ROBOTIC CLEANING SYSTEM

Existing façade cleaning robots are too complicated and/or too expensive to be introduced in the market. Moreover, most of these robots are not appropriate to cope with a wide range of façades, and those who have competitive costs are only able to clean completely flat glass surfaces.
All the high buildings use commercial carrier systems that support a gondola that moves on the façade for manual cleaning. One or two operators are needed for this task. Based in the existence of the carrier system on the building roof, the proposed robotic system uses it to reduce the costs of the vertical and horizontal movements. The system uses a commercial carrier with minor modifications for movements in axes X and Y (Figure 1).

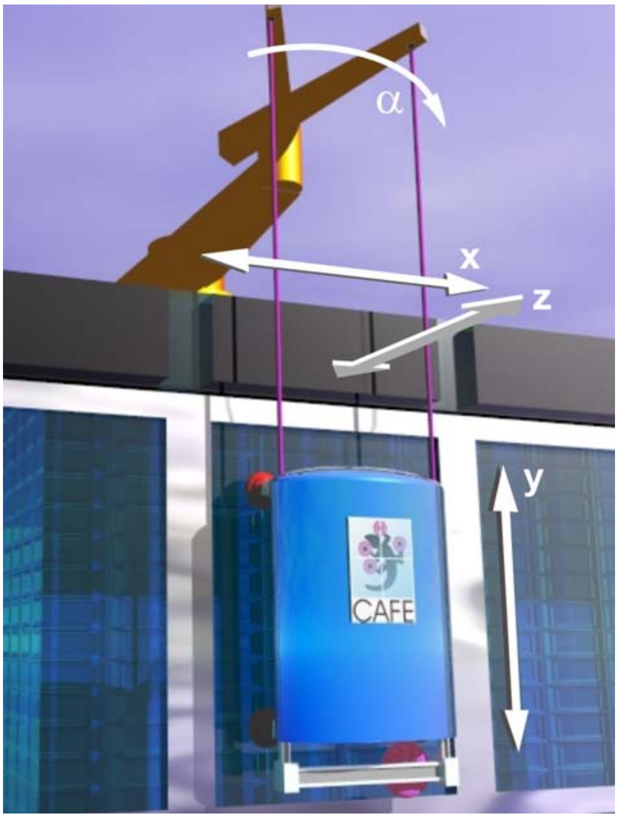

Figure 1. Façade cleaning robot concept

Completely autonomous systems result too expensive for the market and the proposed system has been designed to perform the cleaning task in a semi-automatic way. This means that many of the tasks will be performed in a completely autonomous way, however, because of security and economic considerations, a human operator will permanently control the robot operation.

The operator will be physically situated on the ground below the robot. In normal operation, he will be in charge of starting and stopping the robot action and changing the robot from one column of the façade to the following. It is not foreseen that the operator actuates during the cleaning of a façade column while in normal operation. He must only take actions in case of errors or emergency situations.

The robot cleaning system has been decomposed in four different modules (Figure 2):

- Cleaning Module (CLM)
- Kinematics Module (KM)
- Carrier Module (CaM)
- Control Module

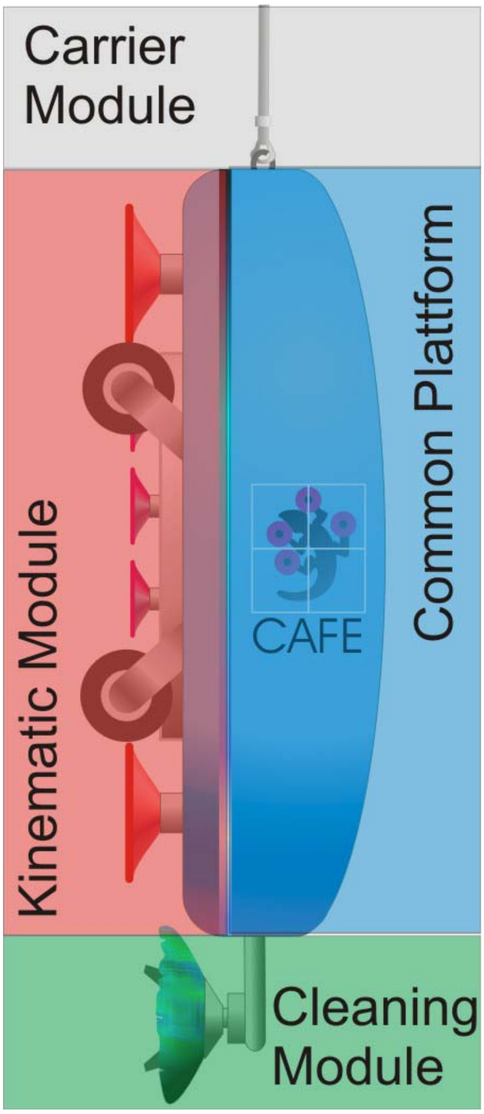

Figure 2. Arrangement and interconnections of the hardware modules

The Cleaning Module is in charge of the actual façade cleaning. It mainly consists in a cleaning mechanism and a positioning system. The façade cleaning mechanism is the part of the Cleaning module that is in contact with the façade and that mechanically carries out the task of cleaning. This mechanism is able to clean flat, glass surfaces and does not have the task of cleaning framework between glass panes. The cleaning is carried out using only water (little or no additives or cleaning agents) that is sprayed onto the glass. A brush that is in contact with the façade mainly forms the cleaning mechanism. This mechanism also has the task of sufficiently sealing off the area that is being cleaned, to ensure that the water used during cleaning does not drip down the façade during cleaning and, when necessary, so that it is possible to recover the used water for a water-recycling system. The quality of the seal is has been taken into consideration during the design phase and plays a large role in the cost of the system. The cleaning system is able to clean up to between 3-10mm away from a window pane. The cleaning head is shown in Figure 3 and the positioning system of the Cleaning Module is shown in Figure 4.

Figure 3. Cleaning head

The Carrier Module is responsible for moving and positioning of the cleaning system into the working position. This coarse positioning is realized by a vertical (Y), and horizontal (X) movement, as well as a movement in an orthogonal direction (Z) to the buildings surface for a coarse adjustment of distance between the cleaning head and the windows.

It is installed on the building rooftop and moves over rails or on a concrete path (guided along the parapet), holding and providing motion to the cleaning and kinematics modules by means of cables. While the cleaning robot might be moved from one building to another, the carrier system will generally stay on the building rooftop.

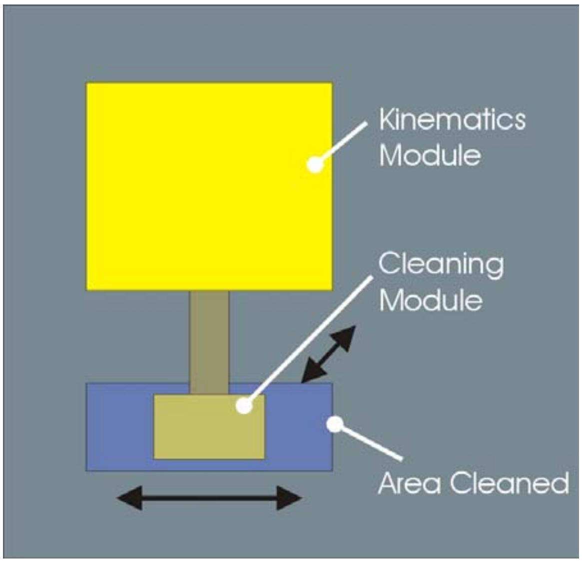

Figure 4. Positioning system of the Cleaning Module

The carrier must position the kinematics and cleaning modules on the façade at the beginning and between cleaning operations. The carrier positions the cleaning and kinematics modules in the X axis through its movement along the rooftop. The vertical motion and positioning in the Y axis is transmitted by the winding or unwinding of the cables. The adjustment of the distance to the wall Z is obtained by controlling the angle α (see Figure 1).

The carrier must also be able to bring the kinematics and cleaning modules down to the floor or hoist and deposit them on the rooftop in order to perform maintenance operations, refill cleaning water or even lay those on a vehicle on ground to be transported somewhere else.

Further the carrier is responsible for installation and supply of energy as well as other necessities for the Kinematics and Cleaning Module. There are not external wires and so, the Common Platform support wires are also in charge of the energy supply. This is done by introducing small wires inside the support wires.

The Kinematics Module establishes contact between the cleaning head and the window pane. This contact is necessary for generating a reaction force of the cleaning head against the window pane. The presence or absence of the contact is controlled by the system controller accordingly to nominal and non-nominal situations.

In nominal situations the contact must be established during the entire cleaning task and hoisting operation. The break of contact can induce serious problems like bumps towards the facade caused by oscillations of the carrier. In case of this non-nominal situation a safety module must be activated in order to avoid oscillations.

The role of the Kinematics Module is:

- To establish a stable contact with the facade.
- To keep the common platform apart from the facade surface at a constant distance (required for the cleaning).
- To follow vertical movement of the platform ensuring stable contact with the surface during the motion as well as during the cleaning (horizontal movement of cleaning module).
- To redirect platform in the surface plan (compensation for vertical motion deviations).
- To protect the facade and platform during lifting, i.e. during carrier movements, from possible damages (humps, caused by oscillations, wind etc.).

The term Control Module refers to the general architecture of the control systems of al the modules, and encompasses the concept for controlling each individual system.

The basic operation cycle is shown in Figure 5.

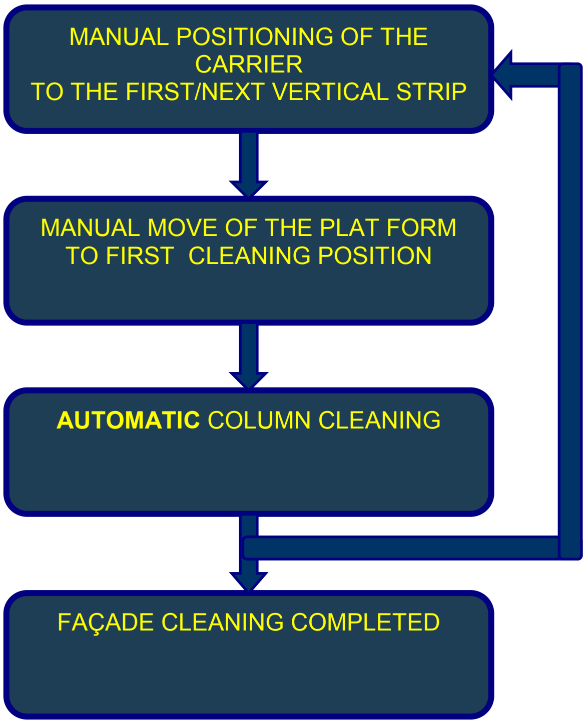

Figure 5. Basic operation cycle

4 CONTROL SCHEME

The cleaning task has been decomposed into different actions that must be performed simultaneously by the different robot modules. The control module is in charge of the synchronization of all this tasks (Figure 6).

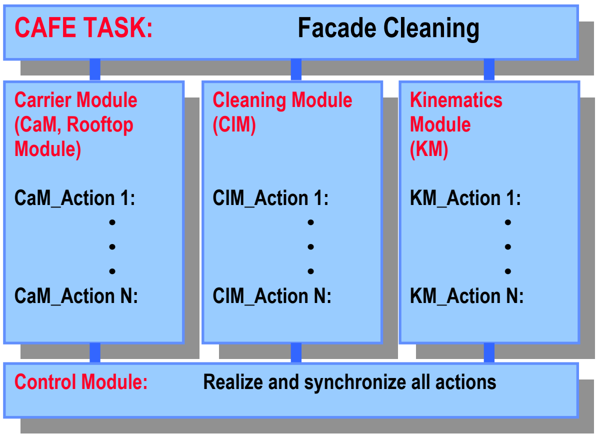

Figure 6. Decomposition of the cleaning tasks into modules/actions

It has been implemented a hardware decentralized and a software centralized control architecture, as appears in Figure 7. This architecture is considered more appropriate for the control system than a decentralized one.

This configuration reduces the total cost of the system and simplifies the integration.

The Control Module (physically located on the robotic Common Platform), the Carrier Module (for safety reasons) and the Operator Interface, include their own microprocessor based computer.

However, wire connection between the Control Module and the Carrier Module is not possible, while obviously the same happens between the Control Module and the Operator Interface. To solve this problem, a wireless communication (Ethernet WIFI 802.11b) has been established. The safety of this communication is critical and it has been guaranteed by a watchdog system. In case of failure of the wireless communication, all the system adopts a safety position and can be recovered manually from the Carrier Module Control. The communication scheme is shown in Figure 8.

The three modules physically located in the Common Platform (Control, Kinematics and Cleaning Module) communicate with each other either through a BUS connection with high-level commands. The lower-level processing of these commands is to take place within the individual module.

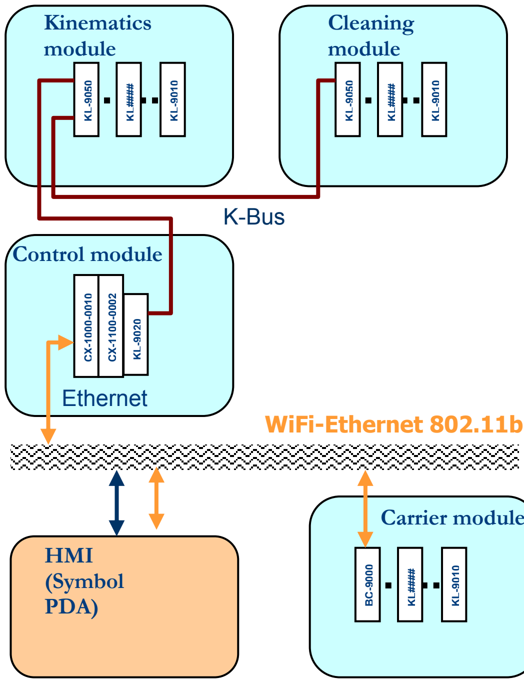

Figure 7. Control Architecture

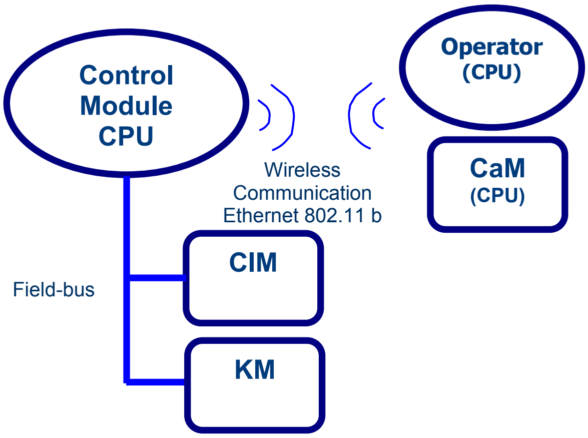

Figure 8. Communications between the modules

5 OPERATOR CONCEPT

There are mainly two options for the operator concept *Human-Machine Interface* (HMI):

- An advanced HMI based on a touch screen (probably with a PC with Win CE) and wireless communication

- o A common HMI with buttons and interrupters

The first alternative will be more flexible and could result very intuitive. The cost is not very high and it will increase the complete system performance. Moreover, HMI based on touch screen will allow different control configurations and possible improvements of the machine in the future avoiding hardware modifications.

As it has been described above, wireless communication will be used between the HMI (operator) and the Control Module CPU that will be physically on board of the kinematics module. Currently, this communication is considered completely safe and the corresponding communication error safety system will be established to guarantee no damage, both the robot and the building, in case of fails in the communication. Other options are not appropriate because it will be very difficult to maintain a connection wire between the operator, on the ground, and the kinematics module, on the building façade.

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REFERENCES

[1] N. Elkman, T. Felsch, M. Sack, J. Saez and J. Horting. "Innovative Service Robot Systems for Façade Cleaning of Difficult-to-Access Areas". Proceedings of the 2002 IEEE/RSJ Intl. Conference on Intelligent Robots and Systems. Lausanne, Switzerland, 2002.

[2] Japan Robot Association (JARA): The specifications and applications of robots in Japan - non manufacturing field. Japan, 1997

[3] R.D. Schraft, U. Bräuning, T. Orlowski and M. Hornemann. "Automated Cleaning of Windows on Standard Façades". Automation in Construction 9 (2000) 489-501.

[4] Elkmann N., Felsch. T., Sack M., Böhme T.: Modular climbing robot for outdoor operations. Proceedings of CLAWAR 1999, Second International Conference on Climbing and Walking Robots, Portsmouth 13.-15. September, 1999, Page 413-419