# FINAL REPORT :

# SYNTHESIS REPORT

Autonomous Window Cleaner for High Buildings

**AUTOWIND**

Proposal N“ : CR 117991

Contract N“ : BRE2-CT93 0889

| | |
|---|---|
| Author | V Papantoniou, Cybernetic Technology |
| Date | }5.03,96 |
| Status | Confidential |

# C. Synthesis Report

(Non-confidential for publication)

## 1. Title, Author names and addresses

**AUTOWIND CR 1179-91 (CRAFT Project)**

**Cybernetic Technology B**
**ROBOSOFT** F
**CRIIF** F
**TECPISA** E
**RIGUAL** E
JOMY B
**CALSA** E

Contact Person: **Dr V K Papantoniou**
Cybernetic Technology
Rue Limauge 131050 Brussels B
Tel 322 5241071 Fax 3225240031

## 2. Abstract

The AUTOWIND project had defined as a main goal the prototype-integration of an operational cable-suspended platform to be used in cleaning and maintenance tasks currently performed by human workers,

The main objective of the project has been to provide a cost-efficient solution: guaranteeing security and quality of cleaning work.

Regarding the cleaning procedure, the initial aim towards the automatization of the existing manual glass-cleaning procedures. including injection of water/solvant, brushing/wiping and eventual further injection of water/glazer, has been directed towards the system that would guarantee maximum quality of the results.

## 3. Introduction

The use of transparent materials in modem high buildings imposes cleaning/maintenance operations currently done hy human specialised workers, who are often exposed to important risks. Consequently, the cost of the operations is actually very high and for that reason the market remains restricted.
In order to provide a solution to this problem, the AUTOWIND project has aimed at the development of a low-cost ," reliable, safely remote-operated window/glass surface cleaning system.

The project succeeded its main goal of proving the feasibility of a prototype-integration of an operational cable-suspended platform, demonstrated window-panel cleaning tasks on a real building facade.

The system is self-contained from a water and solvant point of view and requ· res only an electrical power supply line, The design of the system eliminates water leaks and the L sed water/ solvant is locally recycled and can be re-employed for further cleaning cycles.

Theses aspects contribute to the environmentally-friendly approach for system design, while cm the same time they permit to have a very light suspended system (150 kg), the ·efore minimizing the required infrastructure for the building.

The system is tele-operated through visual feedback and wireless communicatio: ı link, on the basis of an extremely simplified user interface. The programming software includes suppc rt of graphic displays, washing parameters. etc.

The quality of the cleaning procedure has been given important focus during t'ıe development effort. The chosen innovative technology gives cleaning results similar to the one s obtained by human workers, a fact that is seldom in automatic cleaning systems. The cleaning meth‹ xd consists of injecting high-pressure water and solvant in a restricted area while creating a local vacu urn envelope in a way that the water is not spread around. Practically 100% of the sprayed water/sol vant is recovered with this method.

# 4. Technical description

As a first step. the research project dealt with an investigation of the cleaning pr‹ ›cedure. with the objective to approach the "human-like" way. in order to obtain a quality comparable of th: one from human labour. The technology of the cleaning tool has been investigated in depth. Towards this direction, ROBOSOFT proposed an interesting idea concerning the cleaning procedure: A tool compr sing a tape of a cleaning tissue. mounted in a way to circulate continuously. The operating part would t ıen perform the cleaning. remaining in contact with the window panel. while rotating around a thin roller. Simultaneously. other parts of the tissue would be induced with solvant or water. while other parts would be dried as well as cleaned through a self-contained tank. in a continuous way. The idea was intere: ting, since it could lead to a solution of several problems: Problems occurring with brushes (they are bul! y, they become dirty very fast) as well as wipers (they leave leaks. need to be dried often and use a lot of w: iter).

Other interesting aspects of the proposed idea were the enhanced agility of the :leaning tool (a thin roller can have access to window panel angles etc) as well as the foreseen *economy* in solvants and water which could lead to a higher autonomy of the overall machine for a given weight.

On the other hand. very soon after the beginning of the project, another different approach has been engaged from TECPISA/CALSA/RIGUAL also including the construction of several experimental prototypes.

An experimental tool-displacement set-up for extensive cleaning tests has been constructed by CRIIF . The importance of the cleaning tool performance having been recognised by all p ırtners, the consortium has decided to proceed with cleaning tests further than initially planned, by fixin g the maximum admissible cleaning tool weight to 100N and by leaving the parallel development of the t\ /o cleaning tool approaches free to continue until month 12.

Concerning the platform on which the cleaning tool will be mounted, the initial idea was to have it stabilised against the area to be cleaned and a tele-operator to pre-define thrc ugh video-image (or other sensing means) a working panel for the machine to perform. The ' nachine would then generate brush/wiper trajectories for optimal and safe cleaning.

This principle has been followed towards integration, Apparently it represents the best possible way to control the cleaning procedure. while continuous cleaning or tactile-ha sed cleaning can be compromising to quality aspects.

Another important objective of the project was the definition of optimal cable-suspension means, chariot driving units and robust horizontal and vertical motion remote control systems. At the very early stage. an "aeronautic" approach has been engaged. aiming to the integrat on of a system as light as possible. in order to avoid cost increase of the required infrastructure.

The adaptability of the stationary hardware (guiding rail on roof. power supply lines etc) for varying types of buildings represented a major design criterion. together with the possibilities to minimise the cost of the installed infrastructure per building in a way to minimise the necessary initial investment.

The project also aimed the development of sophisticated. sensor-based adaptive platform-technology for the stabilisation. adherence and mobility of the autonomous cleaning unit against the glass-surface of the building. in away to obtain efficient and user-friendly wireless tele-operation.

Furthermore. the research objectives included design optimisations for speed of the system during operation and modular "washing unit" design for rapid washing-container 're-charge" during operation.

# 5. Results

## *1. General design approach for the projected system*

The general design approach for AUTOWIND has been the "aeronautic" system consideration rather than the "industrial machinery" consideration

Cybernetic Technology, with established experience in light-weight, mobile robotics design. insisted in the minimisation of the weight of the suspended system as a means to bring down both infrastructure and main system costs

As a result. the mechanical design focused on '-flexible'" structures. while the various hydro-electric systems (water-pressure pumps. vacuum pumps. compressors. etc) have been chosen with great consideration on their power/weight performance.

## *.2. Optimisation of the washing tool by TECPISA, RIGUAL, CALSA*

As a first step. the research project dealt with an investigation of the cleaning procedure, with the objective to approach the "human-like" way, in order to obtain a quality comparable of the one from human labour. The technology of the cleaning tool has been investigated in depth. Towards this direction, ROBOSOFT ' proposed an interesting idea concerning the cleaning procedure: A tool comprising a tape of a cleaning tissue. mounted in a way to circulate continuous%'. The operating part would then perform the cleating. remaining in contact with the window panel, while rotating around a thin roller. Simultaneously, other parts of the tissue would be induced with solvant or water, while other parts would be dried as well as cleaned through a self-contained tank. in a continuous way. The idea was interesting, since it could lead to a solution of several problems: Problems occurring with brushes (they are bulky, they become dirty very fast) as well as wipers (they leave leaks, need to be dried often and use a lot of water).

Other interesting aspects of the proposed idea were the enhanced agility of the cleaning tool (a thin roller can have access to window panel angles etc) as well as the foreseen economy in solvants and water which could lead to a higher autonomy of the overall machine for a given weight.

On the other hand, very soon after the beginning of the project, another different approach has been engaged from TECPISA/CALSA/RIGUAL also including the construction of several experimental prototypes.

An experimental tool-displacement set-up for extensive cleaning tests has been constructed by CRIIF The importance of the cleaning tool performance having been recognised by all partners, the consortium has decided to proceed with cleaning tests further than initially planned, by fixing the maximum admissible cleaning tool weight to lOON and by leaving the parallel development of the two cleaning tool approaches free to continue until month 12.

Concerning the platform on which the cleaning tool will be mounted, the initial idea was to have it stabilised against the area to be cleaned and a tele-operator tool predefine through video-image (or other sensing means) a working panel for the machine to perform. The machine would then generate brush/wiper trajectories for optimal and safe cleaning.

This principle has been followed towards integration.

The final design of the optimised wiper, including independent, linear actuation of the upper wiper Made for better cleaning finishing of the lower window frame, has been presented by CALSA/ RIGUAL /TECPISA. The system has required extensive testing and optimisation, regarding:

- water / solvant injection elements : A large variety of injectors have been tested, in order to find the most suitable for the application
- water/ solvant pressure: a high-pressure 900 W pump has been installed. ! replacing the low-pressure pump used in the previous (12-month) prototype
- additional degree of freedom for the upper wiper blade: a pneumatically actuated additional degree of freedom has been installed in order to facilitate the finishing of the lower part of the window frame. without leaving any trace of humidity on the glass. This last tool design modifies the previous two fixed wiper blades, using the upper one provided with a possibility of individual displacement towards the glass surface. In that way, at the bottom of the tool trajectory, (when the tool is at the bottom of the window frame). the main body of the tool is retrieved from the glass pane' while the upper wiper remains in contact. The upper wiper then operates alone during the last par. of the tool trajectory, performing a passage with simultaneous vacuum aspiration of the last water drops remaining on the panel. In that way, there are no water-drops left on the panel after the end of the passage,

Other details comprise elements to automatically seal the dirty water tank to avoid leakage during motion. while conductivity sensors control the operation and give warning about low pump pressure due to overload of filter. A cycle of 8 to 10 hours has been estimated for cleaning the filters

### 3. *Integration of the X-Y table and stabilising appendages by CyberTec*

Cybernetic Technology has finished the integration of the selected design solution for tool displacement X-Y table and the platform stabilisation appendages, comprising the retractable articulated system

The distance of the platform from the building has been fixed to 600 mm

Concerning the light displacement system for the washing tool, a rail guided system using toothed belts and X-Y displacement 1400 x 800 guideways has been used. The system is dimensioned for minimum weight (25 kg) and can afford elastic deformation during operation.

The displacements are operated by compact 10OW/ 200 W DC motors, driving toothed belts on customised rail-guides. An important effort has been concentrated in the design and integration of this guiding and driving system, since the lightest commercially available tables represented a mass 4-5 times more important than the proposed solution.

Another important objective of the project was the definition of optimal cable-suspension means, chariot driving units and robust horizontal and vertical motion remote control systems. At the very early stage, an "aeronautic" approach has been engaged, aiming to the integration of a system as light as possible, in order to avoid cost increase of the required infrastructure.

The adaptability of the stationary hardware (guiding rail on roof, power supply lines etc) for varying types of buildings represented a major design criterion, together with the possibilities to minimise the cost of the installed infrastructure per building in a way to minimise the necessary initial investment.

The project also aimed the development of sophisticated, sensor-based adaptive platform-technology for the stabilisation, adherence and mobility of the autonomous cleaning unit against the glass-surface of the building, in a way to obtain efficient and user-friendly wireless tele-operation.

Furthermore, the research objectifies included design optimisations for speed of the system during operation and modular "washing unit" design for rapid washing-container "re-charge" during operation.

## *4. Integration of the upper platform elements and suspension unit by Jomy*

JOMY integrated a light horizontal bridge with 5m opening and 7 m height, for an admissible load of 2000N, from which the washing unit will be suspended.
The horizontal displacement of the structure is operated with a stationary DC motor. actuating the structure motion through a toothed belt transmission. The vertical displacement is operated by a standard 6mm cable- mounted 12V DC motorised trailer unit.

Concerning the detection of the absolute position of the horizontal displacement chariot on the rail and the length of the unrolled cable, necessary for the estimation of the machine location in front of the facade, an angular position sensors in the displacement motor will be used. A free pulley equipped with an angular sensor will also be used for the estimation of the unrolled cable length.

The outdoor demonstrator had been a critical issue for the main proposer, ROBOSOFT, since the beginning of the project. As the different parts of the system are towards final integration stage. the practical details of the demonstrator had to be defined. The technical and security aspects of the platform suspension were a first point of discussion. As initially it was planned to install a roof-mounted rail. the technical feasibility of such an installation had to be examined. in detail. It appeared that. following an expertise performed by Tractel. the roof of the CRIIF building is constructed with a roofing coating material that cannot bear any further loading at all. This fact would permit the rail installation only after the removaf of the roof coating. Such operation would then require extensive isolation works on the roof of the building, involving financial expenses not normally anticipated within the project development. For these reasons, CyberTec proposed to avoid the roof-mounted system in favour of a system directly mounted against the building facade, constructed with two towers mainly fixed on the soil and partly on the facade, on which a bridge holding the rail could be easily attached. The specific location for the installation of the two towers has been defined by CRIIF nearby the dedicated lab where the Autowind experimental prototype is prepared. The two towers made from aluminium profiles were fixed on two concrete blocks and reach a height of 10 meters. An horizontal structure also made from similar aluminium profiles bridges the two towers and support the rail for the Autowind platform.

## *5. Design and integration of the user-interface software and communication link to the motion controller*

The motion controller proposed by Robosoft consists of a VME-format card with 8 axis capacity, generally used in multi-axis *control* in robotics applications

The card has an internal CPU that hosts a resident operating system, Albatros, comprising a number of standard functionalities needed for multi-axis control, such as a real-time Kernel, I/O devices, a generalised PID, trajectory generator, sensor read modules and command interpreter.

The embarked module can *also* carry application programmed down-loaded from a host computer, through C interface libraries, as well as specific tools for downloading (available for PC or SUN-SPARC) based on a OASYS cross-compiler

The user-interface software has been developed by CRIF in a MS Windows environment.

It comprises communication link establishment with the embarked system, graphic display of the application including window frame, washing tool condition, various parameter: such as electro-valves on/off. stabilisers on/off functions etc. The programme permits to the operator to position the washing head to the desired location for the starting of the washing procedure and then to re-position the head to the end location of the cleaning trajectory. The host software then generates the trajectories of the X-Y table motors in order to completely cover the defined w-face and operate all the other required operations such as “washing head out”, “pumps on”, “pumps off’ etc.

The communication link to the embarked system consists of a data link and a video image link. The data link operates at 223.6 to 225 Mhz (programmable) as an asynchronous programmable RS232 interface. at rates of 110 to 9600 baud, with a range of up to 150m. An adaptation of the Albatros operating system for fitting the off-board protocols has been made by Robosoft.

The video link operates at frequencies up to 7 Mhz. with output power of 10 mW

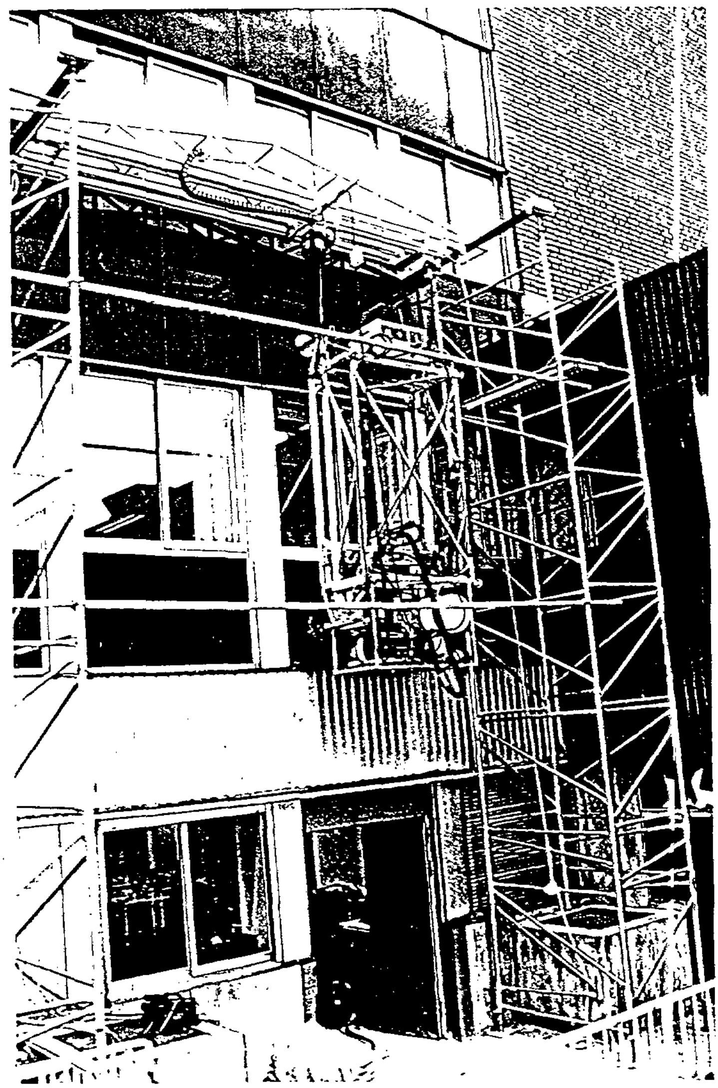
# 6. Conclusions

It can be concluded that AUTOWIND has fully reached its goals, succeeding in demonstrating the feasibility of a teleoperated window-cleaning system, comprising an important number of mechanical. hydraulic, electrical, electronic and software components. The complexity of the required research and overall integration for such a system rates the AUTOWIND project well beyond' he level of the results of a typical project of the CRAFT type.
It is largely expected that industrial versions of the AUTOWIND system will be manufactured and sold in the near future by members of the consortium for a number of cleaning -related applications.

# 7. Acknowledgements

The consortium wishes to thank the Semites of BR-Euram Craft Administration of the CEC for their support in this research, in particular Dr F Sgarbi as the Scientific Officer of the Project and Dr R Cammoun as the Project Technical Advisor. who both contributed with remarkable insight to the research work towards the final successful solutions.

PHOTOGRAPH OF THE COMPLETE PROTOTYPE DURING OPERATION



The photograph shows the AUTOWIND system during operation on the facade of CRIF in Paris

# 8. References

Takashi Shiokawa "Robotization of the Japanese Building Construction Industry" Technical Research Institute, OBAYASHI CORPORATION, Building Construction Dep, Internal Report, May 1992

A Collie "Unusual robots" Industrial Robot, Vol 19 No 4, 1992, pp 13-16

Robatec SA "ROBOT COMET" Commercial Information, Robatec 12 rue de 1' Arcade 75008 Paris France

P Kroczynski , International Robotic Technologies : "The Skywasher" Robotics Engineering Journal, December 1986

J Simpson "Climbing robots break through in the Nuclear Industry" Advance Journal of Robotics , Issue 1, Vol 1 1 .91

S Hirose," Wall Climbing Vehicle Using Internally Balanced Magnetic Unit", Proceedings of the International conference on Advanced Robotics, ICAR 1987

**ARCOW**

Arcow (of the OCS group) stands for Autonomous Robotic Cleaning of Windows. The positioning of the robot over the facade of a building is achieved due to a programmable roof-mounted cradle positioning system. Owing to a tactile. sensor based. datuming head, which determines the window dimensions and the robot's orientation to it. the system is adaptable to a range of window sizes and angles of inclination.
The robot has a single pass wash/wipe head. which sequentially washes. dries and shines the windows. while recycling the environmentally friendly cleaning fluid.
To achieve a higher quality. the robot has some sensors, detecting resistance to the cleaning action by impacted material on the glazed surface. The head then repeats the clean if necessary.
Future possibilities are optical sensors for quantitative assessment of "clean glass", and shaped wash/wipe heads.