February 20, 2006

Dr. Andrew Rawicz
School of Engineering Science
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Burnaby, BC
V5A 1S6

Re: ENSC 440 Functional Specification for a High-Rise Window Cleaning System

Dear Dr. Rawicz:

The attached document, *Functional Specification for a High-Rise Building Window Cleaning System*, outlines the requirements of our proposed device. Our goal is to design and implement a computer-automated window cleaning system for high-rise buildings to eliminate the dangers of having manual labour do the cleaning from a high vertical distance.

Our functional specification provides a detailed set of requirements for our high-rise window cleaning system. Specifications are listed for both our proof-of-concept device and the system intended to go into production. We will be using those specifications to guide our design phase of development.

Altus Technologies consists of five SFU undergraduate engineering students with expertise and experience in both technical and management backgrounds: Tommy Chiu, Howard Lee, Kelvin Mok, Li Ng, and Hubert Pan. Feel free to contact us by phone at 778.892.3432 or by e-mail at altus-ensc440@sfu.ca if you have questions or concerns.

Sincerely,

Kelvin Mok

Kelvin Mok
CEO
Altus Technologies

Enclosure: Functional Specification for a High-Rise Building Window Cleaning System

Functional Specification for a High-Rise Building Window Cleaning System

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Submitted to: *School of Engineering Science*
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Revision History

Date	Rev.	Description	Contribution	Approved
Feb 01 2006	0.1	Draft	K.M.	--
Feb 05 2006	0.2	Added Content	H.L. / L.N.	--
Feb 07 2006	0.3	Added Content	H.P. / T.C.	--
Feb 15 2006	0.4	All the written content is merged	T.C.	--
Feb 20 2006	1.0	All the formatting is completed	K.M.	K.M.

Executive Summary

Currently, almost all window cleaning for medium to high-rise buildings are done manually by workers on a cleaning platform or with a simple cable. Employing professional window cleaners to clean high-rise buildings has numerous fundamental flaws. First and foremost is the high risk of injury or death caused by the sheer height, strong winds, and isolation of the work environment. Another issue is the high cost associated with hiring window cleaners due to the salary and high insurance costs, and the expensive equipment.

The current demand for high-rise buildings is ever increasing, due to urbanization and a growing population. It is difficult to have affordable window-washing personnel trained to work in an increasingly dangerous environment, and it is also very challenging for architects or developers to design giant structures that takes into account the safety of the window-washing professionals. Altus Technologies seeks to eliminate the disadvantages associated with employing window cleaners by developing an automatic high-rise window cleaning system that would be controlled by an operator at the roof or base of the building.

Development of our high-rise window cleaning system will occur in two phases. We will first seek to create a proof-of-concept system with the following key features:

- development costs of less than CDN $2000
- cleans the exterior building surface for a vertical distance of up to 5 m
- removes debris such as pieces of grass and leaves stuck on the glass by natural means, spider webs, wet soil, thick dust, and obvious watermarks

The second phase of development will be our design that would go into production, and has the following key features:

- functional on buildings up to 200 m in height
- moves the cleaning module horizontally for a length of up to 60 m
- removes fingerprints, all watermarks, and bird excrement, in addition to the cleaning capacity listed for the proof-of-concept device
- minimizes the environmental impact caused by the use of water and detergent through a waste management system

The first phase of development will be completed in April 2006.

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Glossary

Beaufort Scale	A scale of wind strength definitions and damage potential
Cleaning Module	Part of the system that does the actual cleaning of the building surface
Control Module	Part of the system that allows for user input and system monitoring
CSA	Canadian Standards Association
Day	Period in which the outdoor luminance level is between 1K lux to 100K lux.[1][2]
FCC	Federal Communications Commission
ICWA	International Window Cleaning Association
Mobility Module	Part of the system that allows for the cleaning module to move to another surface or area of the building.
Night	Period in which the outdoor luminance level drops below 1K lux.[1][2]
Removal	To reverse the setup procedure into a package that can be carried away from the rooftop to ground floor by one person in one trip.
Setup	To rigidly anchor the mobility module to the building and to make sure all connections between the control module, mobility module, and control module are properly installed.

1. Introduction

The high-rise window cleaning system is an automated system which cleans the exterior surfaces of buildings without the use of window cleaning professionals directly at the cleaning site. The system consists of three modules: the cleaning module, which cleans and washes the building exterior, the mobility module, which allows for movement of the cleaning module across different surfaces, and the control module, which allows user input to control both the cleaning and mobility modules. The system will be developed in two stages, with the first proof-of-concept stage scheduled for completion by April 2006, and further development in the second stage to create a system for commercialization and mass production.

2.1. Scope

This document describes the functional specifications for the high-rise window cleaning system. This set of requirements fully describes the required functionality of the proof-of-concept device and partially describes the production device. The listed requirements will guide our design process of our high-rise window cleaning system, and will be traceable in our design document.

2.2. Intended Audience

This document is intended for design specialists at Altus Technologies to guide the design and development phase of the project. Members of the design team will use it to ensure their design meets the requirements set out in this document, while the project manager will use it as a means to measure project progress and performance. The testing team will use it to verify the functionality of the system, and finally, marketing and sales personnel will use it to develop preliminary promotional material.

2.3. Convention

Each functional requirement will be indexed according to the following convention:

[R*xy*] requirement description

where ***x*** is the requirement number, which is unique to every requirement, and ***y*** denotes the stage of production the requirement is applicable to, which can be of three options:

a denoting that the functional requirement is only intended for the proof-of-concept device, or

b denoting that the functional requirement is only intended for the production device, or

ab denoting that the functional requirement is intended for both the proof-of-concept and production device

To make this document easy to follow in our first stage of development, the functional requirements intended only for the production device is coloured in blue.

2. System Requirements

Functional requirements applicable for the overall system are listed in this section.

2.4. System Overview

This subsection describes the overall system block diagram that illustrates our concept. Figure 1 shows the three parts, the mobility module, the cleaning module, and the control module, and how they interact.

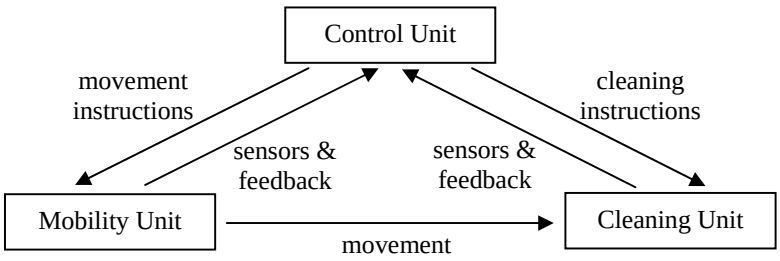

Figure 1: System Diagram

As shown in figure 1, the control unit sends instructions to the mobility unit to control the mechanical movement of the mobility unit, which in turn determines the movement and position of the control unit. The control unit also sends instructions to the cleaning unit to control the cleaning operation. The mobility and cleaning units in turn send sensor data and other types of feedback back to the control unit for processing and operation monitoring.

2.5. General Requirements

[R1a] The proof-of-concept system shall cost less than CDN $2000 to produce.

[R2ab] The system design shall be modular, meaning that the whole system is composed of sub-modules.

[R3ab] The system shall be able to clean windows.

[R4ab] The system shall be able to clean automatically once deployed.

[R5ab] The system requires human monitoring and supervision.

[R6ab] The system shall not be built into the building.

[R7ab] The system shall be deployed at the building before cleaning, and be

removed from the building when cleaning is complete.

[R8ab] The product shall have an aesthetic appeal to it.

[R9b] The system must be capable for mass production.

[R10b] The system must not violate ICWA I-14.1 Window Cleaning standards, where applicable.[3][4]

2.6. Physical Requirements

[R11ab] The maximum weight of the entire system shall be 40 kg to allow it to be moved up to the building by manual labour and the use of trolleys and lifts.

[R12a] The modules of the system must to be able to fit in an average elevator, with the floor size of 1.3 m by 0.8 m. [5]

2.7. Power Requirements

[R13ab] The power supply shall be sufficient enough to allow for all modules of the system to work at the same time.

[R14a] The system shall acquire electric power from an AC outlet operating at 120V and 60Hz.

[R15b] The system shall acquire electric power through a CSA approved adapter.

2.8. Environment Requirements

[R16ab] The system shall be able to function with winds up to 38 km/h. [6]

[R17ab] The maximum movement of the cleaning module from the maximum tolerable wind speed described in the requirement above shall be 0.01m.

[R18ab] All modules shall be able to withstand a physical shock equivalent to a free drop from 0.5 m above ground or less, on a concrete surface.

[R19ab] The system shall be able to withstand impact from all directions with force stated above.

[R20ab] The system shall be able to operate between an external temperature of 0 °C to 40 °C.

[R21ab] All modules shall be water resistant. It shall be able to function despite splashes of rain, detergent, or wastewater. However, the system shall not be required to withstand water pressure (ie. the modules do not have to

function when submerged underwater).

[R22ab] FCC - (1) this device shall not cause harmful interference.

[R23ab] FCC - (2) this device must accept any interference received, including interference that may cause undesired operation.

[R24b] The system shall have a waste management system in order to minimize the impact some of the chemicals, specifically detergent that the system uses.

2.9. Building Requirements

[R25a] The system shall work on building surfaces that are 90 degrees from horizontal.

[R26a] The surface of the building in which the system is deployed must not protrude or have a depression of more than 8 cm, roughly the average protrusion or depression of windows and/or window frames in high-rise buildings.

[R27ab] The system is mountable on buildings with a horizontally flat roof.

[R28b] The system shall work on building surfaces that are 45 to 90 degrees from horizontal.

[R29b] The system is mountable on buildings with slanted roofs (up to 45 degrees from horizontal).

2.10. Safety Requirements

[R30ab] The cleaning module shall be operated on CSA A-440 windows without causing any of the following damage: scratch, tear, crack, fracture or any deformation.

[R31ab] If the cleaning module loses control in the air, it shall not break a CSA A-440 window.

[R32b] All the electronic and mechanic parts shall acquire power from a CSA approved power system and through a CSA approved power cable.

[R33b] There shall be an emergency stop function in which the cleaning module will stop before 0.5 m of free fall, or before the momentum of the cleaning module can cause serious injury.

[R34b] The system shall allow manual disengagement and retrieval of the cleaning

and mobility module as a backup in case of a functional or power failure.

2.11. Usability Requirements

Usability requirements are discussed in this sub-section, which also describes the control, interface and feedback to the user. Feedback is crucial in allowing the user to make accurate decisions and to react to emergency situations during cleaning.

[R35a] The system is operable by humans during the day.

[R36ab] Automatic operation of the system shall only start with user confirmation.

[R37ab] Control and monitoring of operations can either be performed on the ground, inside the building, or on the rooftop.

[R38b] The system can be operated by just two people.

[R39b] The system is operable by humans during both day and night.

[R40b] The system must be able to give sufficient feedback to operators via direct visual feedback to at least one operator and status feedback to at least one operator. They can be the same or different operator.

[R41b] Typical setup time of the system on a building shall take less than fifteen minutes and typical removal time of the system on a building shall take less than fifteen minutes. The short setup and removal time allows for higher efficiency of the system.

[R42b] All modules of the system shall have handle points to allow it to be easily carried, lifted, or moved by humans.

2.12. Behavioural Requirements

The behavior of the system refers to the different states of the system and how the system will react to external inputs in different states. Figure 2 is a behaviour state diagram, which illustrates the different modes of operation the system can have. In the beginning, once the machine is set up on the roof, it will start in idle mode. It can be engaged into park mode, which has the cleaning module anchored to the window. Cleaning can start and be performed automatically once the system is requested to be in the cleaning mode. Cleaning can be stopped and resumed as long as the machine is in the park mode. To retrieve the cleaning unit, it must be disengaged from the park mode. Then it can be moved back up to the roof.

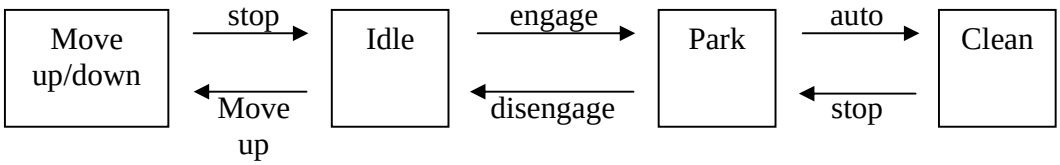

Figure 2: Behavior State Diagram

[R43 ab] The cleaning module shall be able to be parked safely without moving the entire module back to the roof.

[R44 ab] The system shall respond to input within 500ms.

[R45 ab] The system shall always check its state upon power on.

[R46 b] Upon power loss, the system shall be in a parked position.

[R47 b] Clean mode shall be able to resume after being parked for an indefinite amount of time.

[R48 b] The system shall be able to detect obstacles on the building surface and automatically avoid them (eg. open windows).

2.13. Maintenance Requirements

Maintenance requirements outline characteristics of the system that will help ease the troubleshooting, maintenance and repair process. Some of these requirements will also speed up software, hardware and mechanical debugging during the development of the proof-of-concept device.

[R49 ab] Key voltage points shall be easily accessible for maintenance.

[R50 ab] Individual mechanical parts shall be easily detached from the system using standard hand tools.

[R51 b] All internal components shall be able to last 3 years before replacement.

[R52 b] The system shall run a diagnostic test to make sure each component is functioning normally upon power on.

3. Mobility Module Requirements

This section describes all requirements applicable only to the mobility module.

3.1. Safety Requirements

[R53 ab] The cable that supports the cleaning module must be able to withstand a minimum tension of twenty times the weight of the cleaning module.

[R54 b] One backup cable shall be used in carrying the cleaning module.

3.2. Mobility Requirements

[R55 a] The mobility module can move the cleaning module vertically for a maximum distance of 5 m.

[R56 b] The mobility module can move the cleaning module up to a maximum vertical distance of 200 m. (by 2008, the tallest building in Vancouver will be about 200 m. The tallest building in the world is about 500 m, but for our system to function for such a long vertical distance, it will have to seriously be redesigned.)[7][8]

[R57 b] The mobility module can move the cleaning module horizontally for a length of 60 m, sufficient for most high-rise buildings.

4. Cleaning Module Requirements

This section lists functional requirements applicable only for the cleaning module.

4.1. General Requirements

[R58 ab] The cleaning operation is automated once deployed on a flat window surface.

[R59 ab] The liquid containers shall not leak any liquid with under any orientation.

[R60 b] The cleaning module shall be easily attached to another cable if the primary cable fails.

[R61 b] Any solid parts of the cleaning module shall not be easily broken apart under normal operation.

[R62 b] Cleaning tools shall be replaceable to adapt to different working environments.

4.2. Physical Requirements

[R63 ab] The physical size of the cleaning module (excluding the cleaning apparatus) shall be minimized as much as possible, with the maximum allowable dimensions of 2 m X 2 m X 2m.

[R64 b] The shape of the cleaning module shall be an aerodynamic to reduce the effects of wind on the module and minimize unwanted movement.

[R65 b] The external color of the module shall be such that it can be easily seen by the operators, for the sake of safety and clear operation.

[R66 b] The width of the cleaning apparatus on the cleaning module shall vary from 05 m to 2.5 m, the average window width of buildings.

4.3. Safety Requirements

[R67 ab] Chemicals used for cleaning shall be non-toxic and non-corrosive.

[R68 b] When the cleaning module is under parked mode and is left idle, the module shall be mechanically safe guarded from falling down.

4.4. Consumption Requirements

[R69 ab] Enough power shall be delivered to the cleaning module to allow all mechanical and electronic parts in the cleaning module to function simultaneously.

[R70 ab] The cleaning module shall be able to carry up to 5 liters of combined detergent and water, enough to cover an area with a vertical distance of 100 m and a horizontal distance of 2 m.

[R71 ab] It shall be easy to re-fill water or detergent in the water or detergent tanks in the cleaning module.

[R72 b] The flow rate of the detergent or water shall be configurable.

4.5. Cleaning Requirements

[R73 ab] The system only cleans flat surfaces.

[R74 ab] The system can clean glass, marble, metal surfaces.

[R75 ab] The system can remove debris such as pieces of grass and leaves stuck on the glass by natural means, spider webs, wet soil, thick dust, and obvious watermarks.

[R76 ab] The system can continuously clean as it moves down the building surface.

[R77 ab] The cleaning module can stop descending or ascending to do continuous cleaning on a particular spot for surfaces that are particularly dirty or hard to clean.

[R78 b] The system can remove fingerprints, all watermarks, and bird excrement.

[R79 b] The cleaning module can adapt to different window widths by interchanging its cleaning apparatus.

[R80 b] The cleaning module will not leave any residue such as watermarks or detergent.

[R81 b] The cleaning module can detect the material of the surface it is working on and know whether it should clean it or not.

5. Control Module Requirements

[R82 ab] The system shall only have a single set of controls. Therefore, conflicting input from two people are not allowed.

[R83 ab] The status update from the control module shall have a maximum delay of 500ms.

[R84 b] The control module shall prevent the user from inputting hazardous commands by checking the inputs with the operating environment

[R85 b] The control module shall continuously monitor the key parts of the system and shall report to the user immediately if there is any non-functioning component or abnormal stress in the system.

[R86 b] The control module shall have buttons mounted on the system for user input.

6. Documentation and User Training

[R87 ab] A website in English shall be built to market our product and provide brief technical instructions on the operation of the product.

[R88 a] The system shall only be operated under the guidance and supervision of members of the development team.

[R89 b] A quick start guide and a comprehensive manual shall be written and provided both in print form and online, with instructions in English, French, German, Spanish, and Chinese.

[R90 b] The user manual shall be written for an audience with moderate experience in operating large machinery and devices.

[R91 b] Sufficient safety and usage training shall not take more than one business day (8 hrs).

[R92 b] The system shall be operable by personnel with high school education or equivalent level of education and skills.

7. Test Plan

The modular approach to our system allows each component to be tested and verified individually before overall system testing and integration. As mentioned previously in our system requirements section, we have divided our high-rise building window cleaning system into three modules - the mobility module, the cleaning module, and the control module.

Our testing team will be focus testing on the modules that are mainly composed of mechanical parts, namely, the mobility and cleaning modules. This is the most critical area of our system, and an area in which most of the knowledge and experience of the team must be focused on for the project to be successful. Therefore, the test cases detailed below are only focused on the primary mechanical requirements of the cleaning and mobility modules, and test cases for other requirements, including the control module are not detailed here. In addition, the test cases below are applicable to the proof-of-concept system only.

7.1. Mobility Module

7.1.1. Test Case 1

Requirement:

Cleaning module must stay firmly on the wall.

Procedure:

Mount the cleaning module on a dry and flat vertical window. Set the module to park mode. Mark the initial position of the module on the window. Exert reasonable pull and push force on the module.

Expected Result:

Module stays on the surface, and does not leave the marked position.

7.1.2. Test Case 2

Requirement:

Move cleaning module vertically for a maximum distance of 5 m.

Procedure:

Mount the cleaning module on a dry and flat vertical window. Initially set the module to park mode. Mark the initial position of the module on the window. Mark the final position by locating a distance of 5 meters directly below the initial position. Set the module to moving-down mode. Stop the module when it reaches

the final position. Set the module to park mode again, and then switch it to moving-up mode. Stop the module when it goes back to the initial position.

Expected Result:

Module travels to final position, and then goes back up to initial position without any trouble.

7.2. Cleaning Module

7.2.1. Test Case 1

Requirement:

Cleaning module performs effective cleaning on a dirty window.

Procedure:

Prepare a clean and dry flat window. Spread dust obtained from a vacuum cleaner and/or chalk from a chalk board on the window. Make sure the window is vertically mounted. Hold the cleaning module at its operating distance from the window. Start the cleaning process and wait for it to end.

Expected Result:

The dust is gone from the window surface, and the window appears to be clean and dry as originally prepared.

7.3. Integration Testing

The final integration for the prototype would be initiated when the control module is complete and the mobility and cleaning modules have passed the unit testing process. Instead of performing the test in a simulated environment, we will be doing the integration testing on a real building surface. The goal for the test is to ensure the modules work properly and is synchronized with each other in a real environment rather than a controlled surrounding. In addition, it also confirms that the system is able to demonstrate the main functionalities outlined in this document.

8. Conclusion

Altus Technologies is determined to tackle the problems inherent in today's high-rise window cleaning industry with our high-rise window cleaning system. The functional requirements set out for our system, especially for our production device, are rigorous and ambitious. This is necessary, since only a top-notch system will be able to satisfy the current high standards in the high-rise window cleaning industry. The requirements set out for our proof-of-concept device, although less rigorous, nevertheless will demonstrate the feasibility of our proposed window cleaning system.

In April 2006, our first stage of development, the design and creation of the proof-of-concept system will be complete, and all **a** and **ab** functional requirements indexed in this document will be satisfied.

9. Sources and References

[1] Wikipedia, *Lux*, 2006. [online]. Available: http://en.wikipedia.org/wiki/Lux [Accessed: February 14, 2006]

[2] Electro Optical Industries Inc, *Candela (cd)*, 2000. [online]. Available: http://www.electro-optical.com/whitepapers/candela.htm [Accessed: February 17, 2006]

[3] Giamberardino, M. 2001. *New Window Cleaning Standard Shines*. BOMA International's Advocacy Advancement Division. [online]. Availabe: http://www.valcourt.net/files/New-Window-Cleaning-Standard.pdf [Accessed: February 17, 2006]

[4] Scotties Building Services, *Safety Regulations and Guidelines I-14.1 Safety Standard*, 2001. [online]. Available: http://www.scottiesbuildingservices.com/pdf/standards.pdf [Accessed: February 12, 2006]

[5] Beyer, R. 1994. Elevators - First Things First. Elevator Advisors Inc. [online]. Available: http://www.elevatoradvisors.com/ [Accessed: February 18, 2006]

[6] Australian Government, *Wind Strength Definitions And Damage Potential*, 2006. [online]. Available: http://www.bom.gov.au/weather/qld/cyclone/windstr.shtml [Accessed: February 08, 2006]

[7] Infospace, *World's Tallest Buildings*, 2005. [online]. Available: http://www.infoplease.com/ipa/A0001338.html [Accessed: February 15, 2006]

[8] Wikipedia, *List of Vancouver's 10 tallest skyscrapers*, 2005. [online]. Available: http://en.wikipedia.org/wiki/List_of_Vancouver's_10_tallest_skyscrapers [Accessed: February 11, 2006]

