LTUS

May 2, 2006

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

Re: ENSC 440 Post-Mortem for a High-Rise Window Cleaning System

Dear Dr. Rawicz:

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

The post-mortem details the current status of the proof-of-concept device, deviations from the original design, and recommendations for future developments. It also looks at the actual timeline and budget of the project in comparison to estimated timeline and budget in the project proposal document. Lastly, individual team members will reflect on their participation with the project.

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: Post-Mortem for a High-Rise Building Window Cleaning System

Post-Mortem for a High-Rise Building Window Cleaning System

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Submitted to:	*School of Engineering Science* *Simon Fraser University*	
	Dr. Andrew Rawicz	CEO and CFO
	Mr. Steve Whitmore	CIO and VP HR
Issued date:	May 2, 2006	
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Revision History

Date	Rev.	Description	Contribution	Approved
May 2, 2006	1.0	All content and formatting complete	Altus	T.C.

Abstract

Altus Technologies has created a proof-of-concept device for a high-rise window cleaning system. Taking four months from initial concept to implementation, Altus technologies examines the current state of the proof-of-concept device, including differences from the original design. Other than reductions in the scale and complexity of various subsystems of the device, the major deviation was the sensors and feedback for the cleaning module, which was not implemented. Otherwise, all major designs were implemented and followed closely to the design specifications.

Altus also looks at future developments for the project, areas of improvement, and evaluates the budget and timeline. Finally, each team member reflects on his experience working on the project.

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Glossary

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
Mobility Module	Part of the system that allows for the cleaning module to move to another surface or area of the building.
PLC	Programmable Logic Controller

1. Introduction

In April 2006, Altus Technologies created a proof-of-concept device for a high-rise window cleaning system. The goal was to design and implement an automated system which cleans the exterior surfaces of buildings without the use of window cleaning professionals directly at the cleaning site. The system consisted 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.

This document evaluates our proof-of-concept device and our overall process from concept to implementation, including deviations from the original timeline and budget. It also looks at future developments and recommendations for improvement, and finally, individual reflections from each team member of Altus Technologies.

2. Current State of the Device

2.1. Overall System

Figure 1 shows the originally proposed system diagram and Figure 2 shows the actual system diagram implemented for our proof-of-concept device.

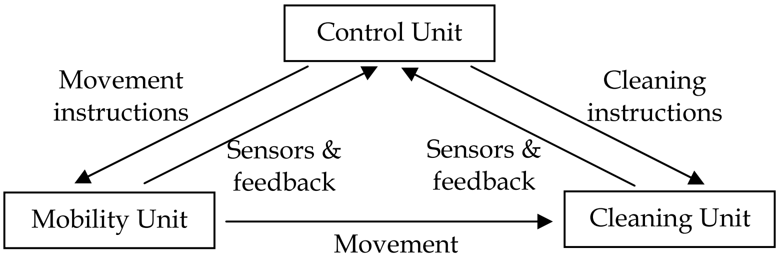


Figure 1: Originally proposed system diagram

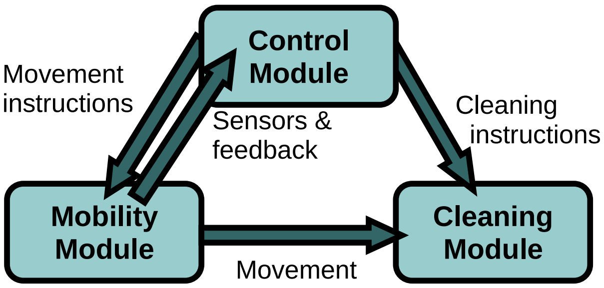


Figure 2: Actual system diagram of proof-of-concept device implemented

As you can see, sensors and feedback from the cleaning module to the control module is non-existent in the final implementation of the proof-of-concept device. This was due to cost and time considerations, and we felt that other modules were more crucial to the proof-of-concept device than implementing sensors and feedback intelligence to the cleaning module.

Figure 3 shows the final proof-of-concept device.

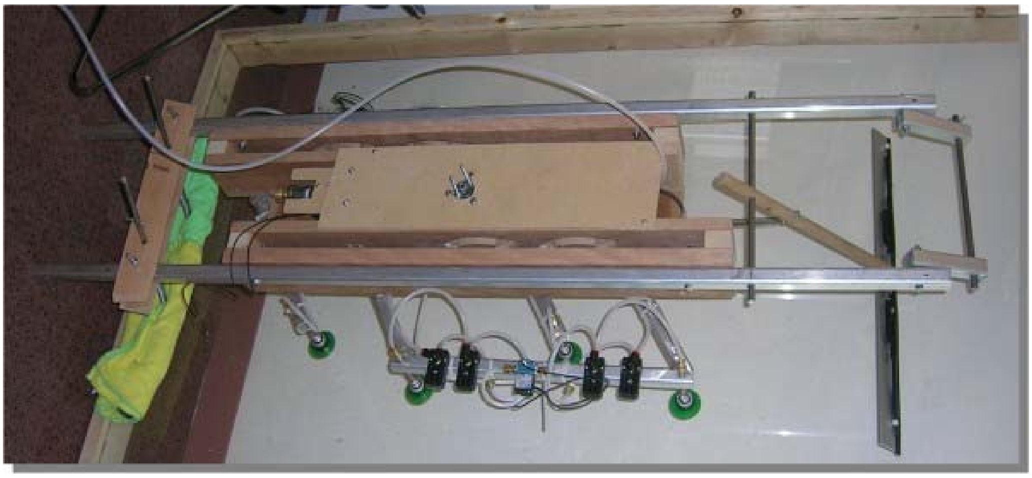


Figure 3: Final proof-of-concept device

The overall physical structure and layout followed quite closely to our original design outlined in the design specifications document. Almost all of the major components in the design was realized, including the use of a pneumatic and vacuum system, a cabling system, and down-climb stepping system for the mobility module, and a PLC for the control module.

Implementation of the various subcomponents of each module of the system has deviated from the original design, and these differences will be discussed in the following subsections.

2.2. Mobility Module

2.2.1. Pneumatic and Vacuum Subsystem

Following our original design, eight PIAB FC-50C polyurethane suction cups were used to implement the pneumatic and vacuum subsystem. These cups are mounted on the aluminum legs of the down-climbing stepping system, along with springs to act as level compensators to allow the suction cups to automatically adjust to different window frame depths, and to cushion the impact when the aluminum legs are deployed onto the windows. Eight PIAB X10A6 Venturi vacuum pumps were used to service each cup. The suction cups and vacuum pumps are shown in Figure 4 and Figure 5:

Figure 4: Suction cups with level compensators

Figure 5: Pneumatic and vacuum subsystem

The alternating deployment and release of the suction cups on each aluminum leg allows for the down-climb subsystem to function properly by ensuring the system is securely anchored to the window at all times, all the while allowing the legs to walk down the window surface.

Finally, a Porter Cable compressor with a maximum ability to supply 150 psi was used to power the vacuum pumps. The power of the compressor allowed for very efficient functioning of the suction cups, and large suction was easily achieved, firmly adhering our system to the window.

2.2.2. Down-Climb Subsystem

This subsystem consists of two components – the aluminum frame legs and wooden climbing paths. Round-edged aluminum beams are used to construct the legs due to it's rigidity and strength. The legs are then locked to the main body of the cleaning module via curved wooden paths. Wheels and plenty of lubrication was used to ensure smooth traversal of the aluminum legs along the wooden paths. Finally, gravity, and the functioning of the pneumatic and vacuum subsystem allowed the down-climb subsystem to function effectively. Figure 6 shows the construction of the down-climb subsystem in our proof-of-concept device:

Figure 6: Aluminum legs and wooden paths of the down-climb subsystem

2.2.3. Rooftop Anchoring and Cabling Subsystem

A Power Fist electric winch capable of pulling a 2000 lbs load is used for the cabling subsystem. The winch is coupled to a winch controller connected to the PLC of the control module, and is used to change the actual height of the cleaning module relative to the building. Figure 7 shows the electric winch used:

Figure 7: Electric winch for cabling subsystem

A 12 V DC battery is used to power the winch. This battery is also used to power the PLC, and the battery, winch, and PLC are intended to be mounted on the rooftop of the high-rise building the device is being implemented on.

Unfortunately, we were not able to test our device on an actual rooftop, and our secondary option of testing our device on a 13 ft scaffold with two 6 ft by 12 ft demo windows also eventually failed to realize. We ended up testing our cabling system using one of our demo windows. As a result, the rooftop anchoring part of the subsystem was scaled down. The winch was mounted to a thick and durable metal board and anchored to the floor using counterweights. Figure 8 shows such a set-up:

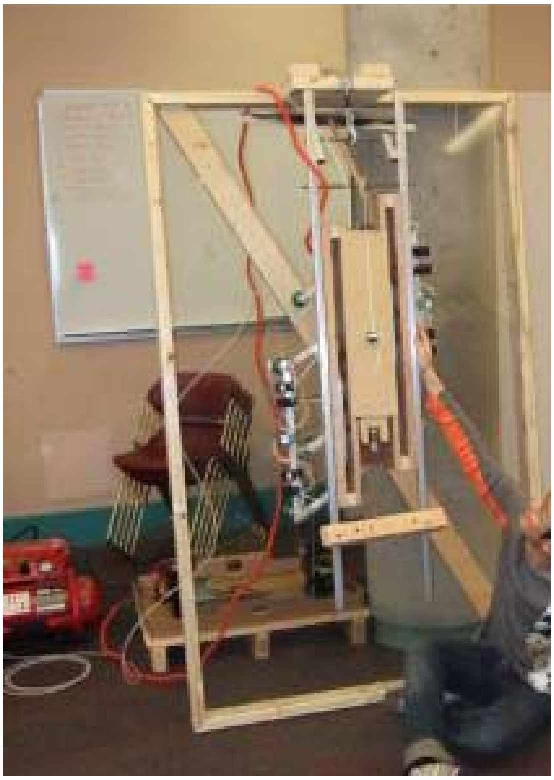


Figure 8: Testing the anchoring and cabling system

2.3. Cleaning Module

2.3.1. Liquid Cleaning Agents and Containers

Our focus of the proof-of-concept device was on the mobility and control module. Therefore, due to time constraints, we abandoned to implement the use of sophisticated liquid cleaning agents and containers for the cleaning module, although it was originally planned for in the design specifications. Instead, we opted for a simple hose connection to the cleaning module to feed water, and potentially a already mixed solution of cleaning liquid and water, to the cleaning apparatus. This served our purpose of demonstrating the proof-of-concept device.

2.3.2. Cleaning Apparatus

A microfibre mop with an internal water-permeable tube is used at the bottom of the cleaning module to clean off dirt and debris on the window. Water is fed to the water-permeable tube to soak the microfibre for effective cleaning. This is shown in Figure 9:

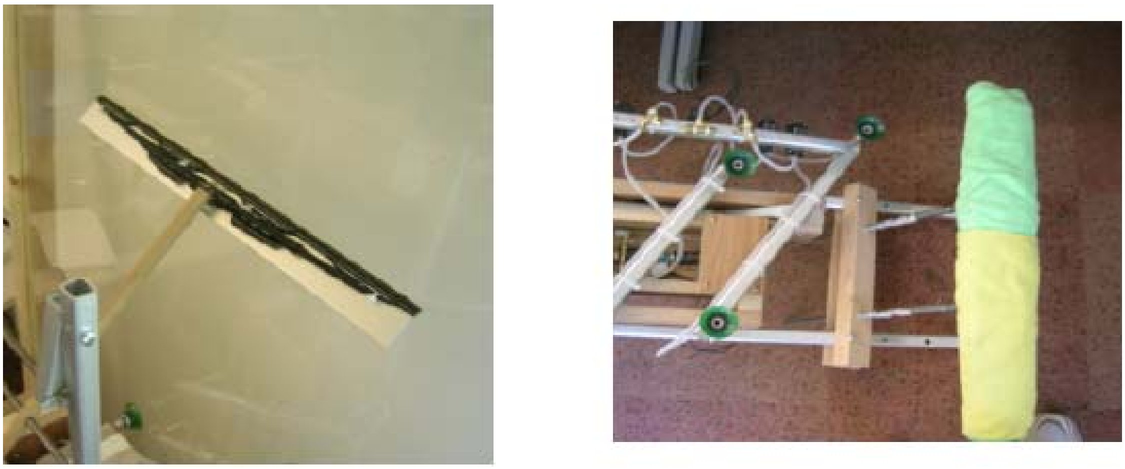


Figure 9: Squeegee and microfibre mop of cleaning module

Although the microfibre mop is very effective in cleaning small amounts of dirt, dirt will accumulate as the mop traverses over long distances, and will have to be replaced or washed regularly during deployment of the system. This is a severe disadvantage compared to the original design of using a sponge or towel roller that continuously replaces it's surface with clean towel by rolling out unused towel and rolling in the used portions.

After the microfibre mop wets and cleans the window, a squeegee is used to eliminate excess water and ensure no watermarks are left on the window surface. This is implemented using a 22-inch windshield wiper, which we found to be quite effective in doing its job. An aluminum flap is attached to the wiper to allow the apparatus to easily traverse over window frames, as shown in Figure 9.

2.3.3. Cleaning Procedure

A cleaning apparatus deployment motor is used to deploy and retract the cleaning module. For our proof-of-concept device, a windshield wiper motor is used for this purpose, and is mounted in the centre of the cleaning module. String is tied to the output of this motor with the other end tied to the squeegee and microfibre mop. Springs are also attached to both cleaning apparatus, so that the default position for both apparatus is to put pressure on the glass surface. The windshield wiper is controlled by the PLC, and once activated, attempts to wind the string to pull the squeegee and microfibre mop away from the surface of the glass. Operating the motor in the reverse direction releases the cleaning apparatus towards the glass. This procedure is needed for the initial deployment of the system so that the suction cups can reach the window and activate before the cleaning apparatus puts pressure on the glass. It also allows for troubleshooting by retracting the cleaning apparatus if the mobility module isn't functioning correctly.

The deployment motor can be seen as the metallic bolts sticking out in the centre of the device in Figure 3.

2.3.4. Physical Framework of Cleaning Module

Two long aluminum beams are mounted on either side of the cleaning module, which serves as the supporting framework of the entire cleaning module. This can be seen in Figure 8.

2.4. Control Module

2.4.1. PLC and Sensors

The brain of the control module consists of the Omron CPM-1A programmable logic controller, as shown in Figure 10:

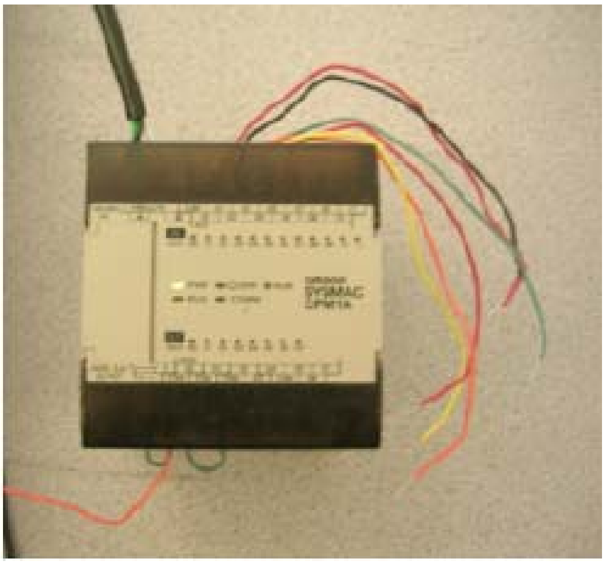


Figure 10: Omron CPM1A PLC

Actuating three solenoid valves, a deployment motor for the cleaning module, and the cabling subsystem of the mobility module, was controllable via PLC ladder logic implementation.

The aluminum legs of the down-climb stepping subsystem of the mobility module are monitored by two proximity inductive sensors. This is possible because the bulk of the device's body is constructed out of wood and the material of the legs is aluminium. This allows the proximity sensors to have accurate detection of the leg position. However, the proximity sensor was positioned too high on the leg movement to allow flexibility in leg traversal timing.

The current system lacks motor control logic in the PLC to allow the deployment motor of the cleaning module to wind both ways to facilitate automatic deployment and un-deployment. Currently, the deployment and un-deployment requires manual reversal of electric current to the deployment motor. Improvements in this area will allow our system to perform much closer to what is required by our function specification.

2.4.2. User Interface

Simple push buttons with labels were used as the user interface to the entire system. These push buttons were used to interface with the PLC, controlling deployment of the cleaning module, cabling movement, and the pneumatic and vacuum subsystem. This was deemed sufficient for our proof-of-concept device, as the focus was on functionality and not usability of our system. Issues of usability would be addressed in the commercial version of our device.

2.4.3. Resource Management and Delivery

Two solenoid valves are used to control the flow of compressed air. By turning on and off the compressed air flow to the four vacuum pumps on the left and right legs of the down-climb stepping subsystem of the mobility module, we were able to control which leg achieved suction and which leg disengaged at specified times. One more solenoid valve is used for water control. By pre-limiting the flow rate of the water, the solenoid valve just functions as an on/off switch for the water flow to start and stop the performance of cleaning operations. Due to budget constraints, the solenoid valves used were not of sufficient specification for usage with water and were susceptible to corrosion if used for a long period of time. This problem needs to be solved in subsequent revisions of the system.

3. Future Developments

3.1. Overall System

Certainly, looking at Figure 1 and Figure 2, sensors and feedback can be implemented for the cleaning module for more effective cleaning, and to allow operators to monitor progress. The overall system can also be made more robust by ensuring all parts are waterproof, and multiple feedback systems can be built into the overall system for physical and signal monitoring of all components of the system.

Because of the modularity and adaptability of our system, there are many other potential applications for our device other than high-rise window cleaning. One example is for surveying building exteriors for cracks and damage, and even replacing the cleaning module with a high-power x-ray to examine concrete fractures in buildings.

At this point, Altus Technologies has decided to not continue development of the high-rise window cleaning system due to the enormous time and resource commitment such continued development would require. However, we recognize the vast potential our project has to offer both as a learning experience and as a real-life product beneficial to society.

The rest of the subsections below describe future developments that can be made to specific areas of our device.

3.2. Mobility Module

Future developments of the mobility module involve improving the pneumatic subsystem, the down climb subsystem, and the rooftop anchoring and cabling subsystem. Currently, the pneumatic system consumes too much air in order for the suction cups to achieve suction. This high air consumption is due to the fact that the vacuum pumps use the Venturi effect to achieve vacuum, which wastes a large amount of air. Improvements could be made by utilizing suction cups that physically change its volume to achieve suction instead of ones that rely solely on vacuum. Another option to decrease air consumption would be to choose better vacuum pumps that are more efficient, meaning pumps that achieve more vacuum with less air consumption.

The down climb subsystem is where most of the innovation of our device lies. In order to power the aluminum leg frames by pure gravity and let from correctly traverse down the window, we designed, with special geometry, the walking path for the legs to travel. Although the path is in working condition, it sometimes allows the leg to travel in the wrong direction. For example, when a leg falls down, it is suppose to fall down from behind, but sometimes actually falls into the front path. Future developments on the down climb path include installing one-way locks such that the legs cannot travel backwards into the path that they came from, and thus, eliminating the problem of a leg entering the wrong path. A second improvement to the down climb path would be to totally change the geometry of the path. The current design contains an offset between the two steady states. In other words, the top and bottom positions do not line up vertically. This offset could introduce unwanted instability and is one of the factors contributing to the legs entering the wrong path.

Finally, implementation of vertical electromechanical actuators for the cabling subsystem can allow upward movement and finer control in the downward movement of the cleaning module. It will also increase the versatility of our system because the leg's vertical movement will not be dependant on a fixed path anymore. Implementation of horizontal moving actuators will also allow the machine to move sideways, and reduce the amount of time spent on redeploying the machine.

3.3. Cleaning Module

A waste and water management system and be employed to enhance the cleaning capabilities of the device. Used water can be sucked back into the module, filtered, and reused to conserve the amount of water needed. Also, dirt and debris removed by the system can be collected and removed from the cleaning apparatus to ensure effective cleaning.

The most common dirt on high-rise windows is bird excrement. Our current proof-of-concept device does not have the capability to remove dried or sticky bird excrement, and the cleaning apparatus must be redesigned to allow for this function. Further enhancement of the cleaning module can also be done to allow for greater versatility in dealing with an array of dirt and debris.

3.4. Control Module

Much more can be implemented to improve the reliability and expand the capability of the control aspect of the system. Additional sensors can more closely monitor the movement of the aluminium legs of the down-climb stepping subsystem, allowing enhancement in efficiency and reliability. Air pressure sensors, along with vacuum pumps with non-return valves can conserve air consumption and also more reliability in suction locking. Allowing for variable speed in the cabling system of the mobility module will also enable much greater flexibility and usability of the system

Lastly, a camera along with a sophisticated image processing system can help to make sure that windows are cleaned properly. Algorithms for the PLC can also be revised so that the cleaning module can revisit or dwell on difficult-to-clean spots on the window that are detected by the system, drastically improving the cleanliness level achievable by the cleaning module.

4. Budget and Timeline

4.1. Budget

Table 1 compares the initial estimated cost with the actual cost of the proof-of-concept device. The items in red are items not used in the final design, while the items in blue were required by the final device but were not considered in our initial planning stage.

Table 1: Expense breakdown

Item	Estimated Cost	Actual Cost	Notes
Sensors	$150	$73.71	
Actuators	$400	$14.99	
Mechanical parts	$500	$527.19	Pneumatic parts such as suction cups and valves
Personal computer	$0	-	Not used
Microcontroller and PC interface	$0	$204.65	PLC
Electronics	$200	$195.9	Battery and winch
Web Cameras	$80	-	Not used
Cabling	$240	$14.81	Pulley
Compressor	-	$534.66	
Material and Coupling	-	$576.55	Wood, metal, screws, bolts, air-couplings
Miscellaneous	$230	$221.39	Cleaning tools, garden hose, other minor items
Total	**$1800**	**$2363.85**	

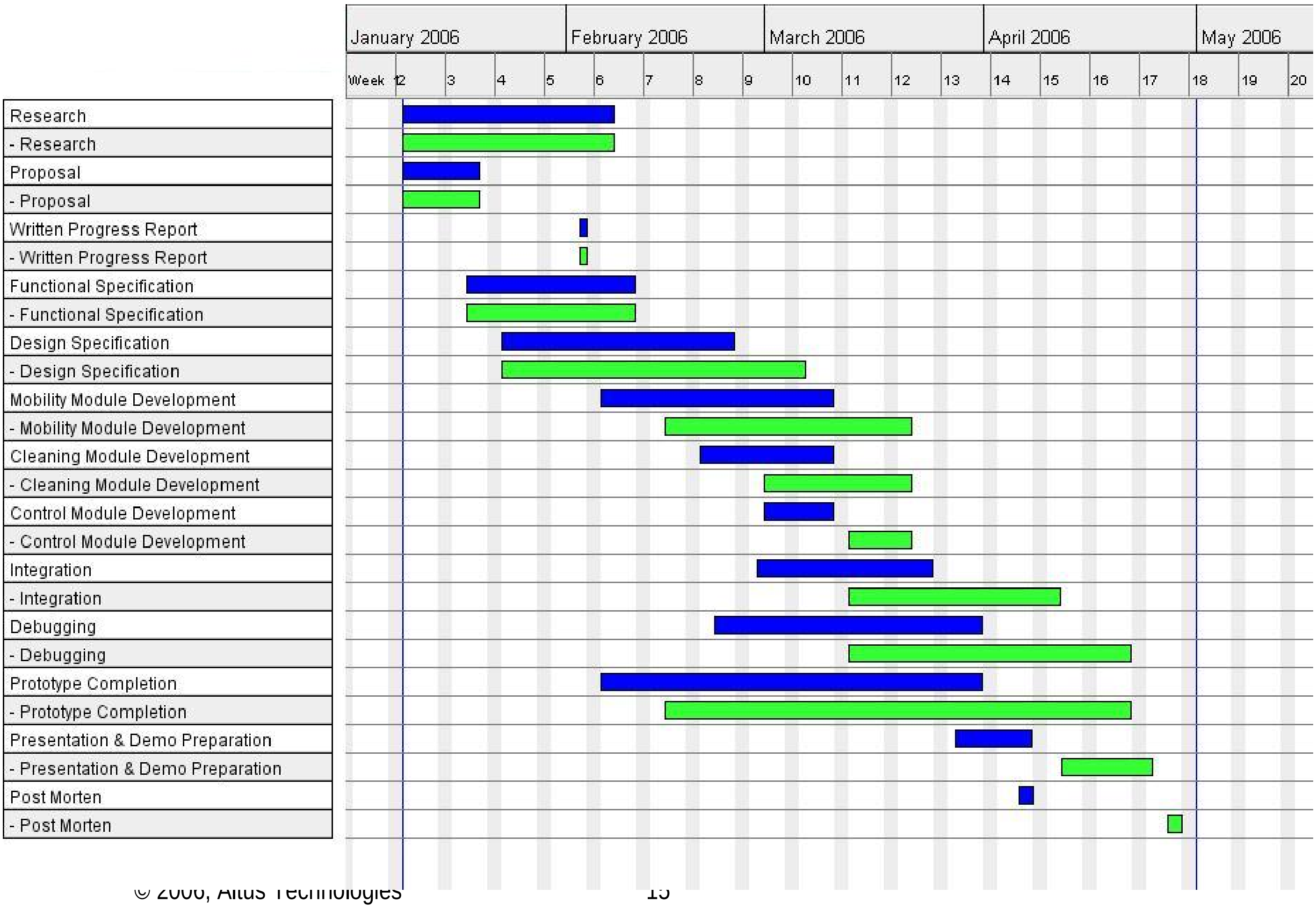
In the planning stage, we thought that sensors, actuators, and cabling would be the most expensive items in our spending and that the material cost would be the least. However, it turned out that we over-estimated the cost of sensors, actuators and cabling, and these items only attributed 5% of the total expense. On the other hand, the material cost, including coupling, was extremely high and attributed 24% of our total expenditure.

Originally, we thought that we could use materials from the inventory of one of our team members, but we found that he did not have suitable materials for constructing certain parts of our device, such as the aluminium leg frames and steel beams. In addition, we modified our design in the building process, which forced us to buy more material to rebuild certain parts. Another expensive item that we did not consider in our planning stage was the compressor. One of our team members had a compressor that we originally thought we could use. Unfortunately, when we finished building the pneumatic system, we found that the compressor did not deliver enough airflow and pressure for sustaining the pneumatic and vacuum subsystem of the mobility module. Hence, we had to buy a brand new compressor which became 23% of the total expense. Although we correctly estimated the cost for pneumatic parts and the electronics required for building the cabling system, the total expense was much higher than estimated due to the cost for materials and the high cost of the compressor.

4.2. Timeline

A Gantt chart comparison between the initially planned schedule for our project and the actual timeline is shown in Table 2:

Table 2: Gantt chart comparison of planned timeline (in blue) and actual timeline (in green)



In the beginning, we strictly followed our schedule, and there was no delay in doing the research and writing both the project proposal and functional specification. However, we spent an extra week in preparing the design specification due to difficulty in finding parts that fit our designs.

Since there is a delay of one week in our design stage, this propagates into our development. The individual modules were completed on March 22nd, and took eleven more days than the original planned completion date of March 11th. In addition, we spent an extra ten days for debugging the whole system, which pushed the completion of the final proof-of-concept device to April 22nd.

Individual Reflections

4.3. Tommy Chiu, COO

Working on this project was definitely an amazing experience! First and foremost, it was very interesting work with four other students to simulate a start-up company, and to design and implement a piece of technology from scratch. The scope and magnitude of this project is definitely not like anything done previously in other courses.

It was also interesting that our team chose a project that was highly mechanical and hands-on in nature, an area which none of us were extremely familiar with. Nevertheless, we persevered and ended up learning a lot about woodwork, metalwork, and other hands-on technical knowledge.

This project also taught me a lot about documentation, and the steps involved in writing project proposals, functional specifications, and design specifications. All of us also got a lot of practice on how to do professional presentations to sell a product.

This project catered to both my interests in engineering and business, combining both hard skills required in the engineering profession and the soft skills required in business management and marketing.

4.4. Howard Lee, CTO (Hardware)

Two key tasks performed by me for the project was the mobility module design and special parts sourcing. Both were very challenging because I had no previous experience.

The mobility module was had very mechanical design. Despite being in systems engineering, I must admit that my mechanical academic background is rather weak and did not provide much real help in the design process. Most design choices and solutions to problems were mainly based on intuition, experimentation, and research. This turned out to be an excellent chance to realize and practice this method of problem solving. I believe that in a real work environment, such techniques are at least as valuable, if not more valuable, as knowledge acquired from textbooks and lectures.

Another challenging part of the project is part sourcing. I was left to determine what parts will fit our needs, and where and how to acquire them. Many simple parts like springs were a lot more difficult to obtain than imagined. Specialty equipment like vacuum systems required knowledge in the functioning and specifications of those components before correct purchasing decisions can be made. My familiarity with shipping and online ordering did allow most parts to arrive in a predictable manner. However, last minute realizations of the necessity of certain components previously unplanned created a huge hassle and multiple bottlenecks for our schedule.

The biggest problem about the project is the experimental nature of many parts of the system. Being heavily mechanical based and tightly constrained by the budget, a detailed plan was not possible and many of the most ideal parts could not be obtained. However, it is also the experimental nature and lack of knowledge that forces us to further develop our problem solving skills.

Last but not least, it was a valuable experience to be able to work in a group setting, giving first-hand insight not only to internal group dynamics, but also to external-relations management. We often sought the help of external parties to allow us to realize the project, but it was also those external parties that introduced major setbacks.

4.5. Kelvin Mok (CEO)

Finally, it is over! The past twenty weeks have definitely left a mark in my memory. I had run through the whole cycle on figuring out an idea or concept, to constructing a prototype at the end. It has been a remarkable experience. I am really fortunate to have the opportunity in working with four other amazing individuals; with their dedication, expertise, and effort, I would say this project is a true success.

I can break this long, rewarding development process into three distinct phases: initialization, functional specs and design spec, and realizing the prototype. After the completion of every stage, it felt like the hardest part of the project had just gone by. Yet, there were more challenging tasks ahead of us.

During the initialization phase, which started in early November, the biggest challenge was to land on a feasible idea and a powerful group. In terms of finding teammates to join our group, it was a difficult task because we were looking for individuals who possessed skill sets that would complement what was already in the group. In addition, I wanted to pay attention to the personalities of the potential participants to minimize team dynamic issues that might arise. Fortunately, we came across two bright, enthusiastic students who possessed all the desired attributes, plus a desire to finish this project before the next semester started.

We tried extremely hard to do whatever it took to complete the project on time, on budget, and on spec. So at the beginning, we had weekly meetings to keep the group up to date with what's happening. First, it felt like all the good ideas we came across had already been implemented by someone else in form or another. And for some reason, we seemed to be very mechanically inclined because most of the ideas revolved around a final product, rather than a problem statement. Until that lecture about finding a problem statement from Professor Whitmore, we were, in my opinion, lost. We saw that the proposal deadline was creeping towards us, day by day, and we started to get a little impatient. I was delighted when I heard that everyone in the group agreed that there was a better way in window washing. The proposal was quickly drafted shortly after that, and one of the first problem was solved!

The creation of the functional spec and design spec were actually quite straightforward. It all came down to just work, and it was manageable. I guess one of the bumps we came across in design spec was how exactly the windows washing system will be anchored to the building glasses or walls. Using suction cups was one of our first ideas, and later turned into our final solution.

There were many uncertainties in finalizing the design spec at that time because we did not even know if suction cups that met our requirement existed in the market. If we chose the wrong approach, it would be quite time consuming to make all the modifications to the system. We took the chance and went for a system with a cabling system and suction cups. The biggest obstacle in this phase was finding the right parts to do the right job. Our goal was to use all off-the-shelf, reliable components. However, it was often the case that a very complicated approach would land in our brains, distancing us from other simpler alternatives. I think this mindset is caused by our previous experience and education, mainly from school, where practical hands-on work is less of a focus. A solid example would be employing the winch at the rooftop to enable vertical movement of the cleaning module. The first thing that came to my mind was building a mechanism that included a heavy-duty motor, gearbox, pulleys, cables, and a brake-disc. An off-the-shelf item already existed in this case, but I did not realize at first. This brings home again what really counts is the idea, not the material.

Finally, we came to the implementation stage. By far, the most difficult task in the whole project was sourcing the components. For an undergraduate student who did not have any experience in sourcing parts, it was an extremely difficult, time-consuming task. A solid example was finding the suction cups that would suit our system. At the beginning, we didn't have a clue how controllable suction cups work, ignoring the fact on how to source them. Fortunately, we have come across Skeans Engineering Group, who gave us some education in all the theory behind using suction cups in conjunction with pumps and a compressor. With their guidance, along with our effort and research, we figured out roughly what we needed to make the system work.

However, in the area of pneumatics, as one of the sales associate suggested, "it's like black magic." A lot of trial and error had to take place. However, due to our limited time, we had to order substitutable parts all at once in an attempt to shorten the possible lead time for many of the special parts we ordered. This gave us the opportunity to try out different combinations of the components and see which one fit best to the application.

I found that every large problem was associated with a whole bunch of smaller problems. For example, I never knew nuts and bolts also came in metric size, and ended up spending so much time finding a nut that would fit the windshield wiper motor in imperial size. Another thing we learnt was that the convention in defining the dimension of a piece of wood is counter-intuitive. A "2 x 4" was actually not 2" high by 4" wide when you buy it from vendors.

In this project, I learned to deal with all kinds of people, from our customers (the profs and Tas) to SFU security and facilities management. I think the foundation of our success was built on our ability in dealing with soft systems, i.e. people. Without the help from profs, TAs, facilities management staff, friends, and many various companies, this project would not be made possible. Also, when professor Whitmore mentioned about how good friends could turn into enemies, I did not believe that could be possible. If you asked me now, I would tell you: "It was very close to that point." I am very happy that all my teammates now became my good friends rather than just classmates. This project is definitely be one of the milestones in my 17 years of education. It will probably be something that I will still talk about when I am in my 60s.

4.6. Li Ng (CFO)

We were very ambitious in this project for attempting to design and build a product heavily reliant on mechanical engineering and pneumatics, fields that we had no experience at all. It was a challenging and exciting experience, but at the same time, harsh and difficult. There were always fear that we would not be able to make anything or that we would not be able to find the parts we needed. Yet, with great effort from each member of our team and lots of external help, we were able to finish and test our prototype to prove that our concept and design actually worked.

Our team worked well together. Although there were a few arguments and disputes on some of the design choices, we eventually learned to listen and evaluate each other's ideas and chose the best idea based on advantages and disadvantages of each idea. Everyone in the group always treated each other with respect and everyone worked equally as hard on the project. It was a great team and I greatly enjoyed working with this team.

I learned a great deal about making a real physical product based on a design. It's different when you simply have something on computer that you can make a large number of mistakes and can correct them with no material cost. When building a physical product, much more care is needed, and if you made a wrong cut on your metal beam, the beam could become useless. I also learned a lot about seeking professional help from experts. We would not know which suction cup or vacuum pump to use if it wasn't for the help of Giovanni from Skeans Engineering. Our leg frames of the mobility module would just be pieces of aluminum beams if it weren't for the help of Frank from SFU Facilities Management. We wouldn't even have pieces of glass to demo on if it wasn't for the help of Lee from SFU Facilities Management. Finding the right person to help is what really made our project possible. I would like to thank everyone who spent time and effort to help build our project and I also like to thank my team members for making this such a successful project.

4.7. Hubert Pan (CTO, Software)

When Altus was first formed, we had a difficult time in settling down with a project idea. There were many interesting and crazy ideas being tossed around, and it took a while before we finally decided to work on a window cleaning system. At that time, I felt choosing such an idea was very ambitious; nevertheless, it was fun to design such system because it allowed us not to be bounded by certain technologies, such as those we learned in class, but to have more room for creativity.

During the design phase, I found it is very easy to generate lots of abstract ideas to solve certain problems of the system. However, when I tried to look for parts to implement those ideas, it was hard to find something perfectly suitable. Limited by funding and time, I did not have the courage to obtain expensive parts and had to rely on cheaper alternatives. Sometimes, using these cheaper parts may require a modified design, which may yield more problems to be solved. I think next time when I am designing for something that is totally out of my knowledge field, I would first source out the "abstract" parts before diving right into the details of the design.

What I found to be the most valuable experience is the construction of the system. Although I only worked on small softwood project in my high school, I was able to build a part of the window cleaning system using a variety of wood and metal. In the building process, I made several painful mistakes in the construction that forced me to rebuild certain parts of system from scratch again; however, it helped me become familiar with several common machine tools that I have worked with, and understanding their limitations. This definitely will aid me in the future when I am working on large engineering projects that may require woodwork and metalwork.

5. Conclusion

Our project was a tremendous success, considering restraints in the budget, the team member's initial lack of experience and knowledge required by the project, and the fact that we only had four months from initial concept creation to implementation. Our proof-of-concept device fully illustrated the feasibility of our proposed system, and all major components of our design were physically realized.

With a project of this magnitude, there was plenty of room for improvement, future development, and expansion. We are excited that our project has such enormous potential, especially in other applications such as examining a building exterior for damage, and building surveillance and security.