Product: PAUL
Team: Group 6

Abstract
In our fourth demonstration, we will present a hardware implementation that can be controlled using a user-friendly web-based UI. We will also present our plans for the commercialisation of PAUL and some of the challenges we have faced with our hardware implementation.

1. Project plan update

1.1. Demonstration Goal:
We are aiming to have a Hardware implementation that can be controlled using a user-friendly web-based UI.

1.2. Milestones
The milestones each sub-team has worked towards for this demonstration were as follows:

- Software and Simulation Team:
  - 1.5 Simulate Robustness
    - Success Criteria: ensure PAUL is robust and secure during work and for various pole diameters, capable of performing work under conditions with minor vibrations.
    - Milestone Outcome: **Partially Achieved**
- Web Development Team:
  - 2.3 Build a fully functioning front-end
    - Success Criteria: a fully-functioning UI that controls PAUL's movements and cleaning actions.
    - Milestone Outcome: **Partially Achieved**
  - 2.4 Complete Marketing Website
    - Success Criteria: a complete website for the entire project.
    - Milestone Outcome: **Partially Achieved**
- Hardware Team:
  - 3.6 Testing
    - Success Criteria: tests based on functions provided by the UI should run successfully and resolve any integration issues between Web-based UI and hardware.
    - Milestone Outcome: **Partially Achieved**
- Project Management Team:
  - 4.1 Prepare for Demo 4
    - Success Criteria: Prepare content to present live at the Q&A.
    - Milestone Outcome: **Achieved**
  - 4.2 Complete Demo 4 Report
    - Success Criteria: has LaTeX report/video finished and peer reviewed by all members.
    - Milestone Outcome: **Achieved**
  - 4.3 Write User Guide
    - Success Criteria: a fully-written user guide that can be followed by people unfamiliar with our project.
    - Milestone Outcome: **Achieved**
  - 4.4 Commercialisation and Marketing
    - Success Criteria: research on the target market, and commercialise the project.
    - Milestone Outcome: **Achieved**

See table 1 for a task breakdown. We made a number of minor changes to the original plan for this demonstration, but ultimately the changes made facilitated us having a compelling product to demonstrate to industry judges. We decided against focusing on simulating robustness as we originally planned it, to instead redirect our focus more on conducting market research. Milestone 3.6 was not fully achieved as we continue to work to resolve some hardware issues. We do intend to continue work towards this milestone next week with hope to present it at the Industry Day next Friday. We intend to submit an updated video next Thursday if we manage to resolve these issues. We will go into detail on the hardware issues we faced in the Hardware section. Milestones 2.3 and 2.4 are currently delayed due to ongoing testing. With expected completion of the marketing website set for tomorrow.

1.3. Group Organisation
Ultimately, for this demonstration we were satisfied with our current structure of sub-teams. We found that the work of the Software and Simulation team was largely completed and so members worked toward goals on their other teams. Overall, our teams focused especially on Commercialisation features and research for this demonstration.

1.4. Commercialisation
PAUL is cleaning robot which will employ its UV light to clean high-touch point poles on trains. PAUL will operate alongside professional cleaners to support them by disinfecting the areas most likely to cause them harm as current research suggests that UV robots are not always effective when utilised to clean entire rooms(Cresswell & Sheikh, 2020) whereas effectiveness increases substantially when used to support existing professionals (Miller, 2020). Currently, each pole will employ their own PAUL to achieve disinfection. In future we leave open the possibility of expanding PAUL's functionality to allow for operation during transit. Currently, PAUL will only operate when there are no humans in the area, at the end of a given route. Our market research emphasises a number of key points, firstly, Covid-19 is highly susceptible to irradiation with ultraviolet light (Heilingloh, 2020). Secondly PAUL overcomes traditional problems with UV cleaning because of the design decisions we have made, such as limiting the cleaning area, maintaining a constant distance and light intensity. Finally, PAUL is the only robot on the market which will provide this functionality at its price point, costing only £381 to produce, with other robots selling for around £40,000 e.g. (Hipac) (UVD-Robotics). Ultimately we see the next steps in our journey to be two fold. Firstly, starting to develop relationships with procurement officers at train companies operating in Scotland e.g. Scotrail, Crosscountry, etc. Secondly, starting negotiating with suppliers in order to minimise our dependency on any given supplier and improve our negotiating position when buying in bulk whilst minimising production downtime.

2. Technical details

2.1. Hardware
The work of the hardware team for this demo has been focused on resolving issues that we have found with our Hardware prototype. We have worked with the Front-End team to create scripts that can control PAUL from the Web UI. Our main objectives for this demo were to fix the LED light issues, find a more compact way to store

Milestone	Task/Aspect	Member
1.5	Conduct friction tests	Stirling
	Add scene to simulation	Jim
2.3	Write scripts to control raspberry pi	Jim, Naman
	Make Password Authentication	Jim, Naman
	Research and Implement Scalability features	Jim, Gagan
2.4	Complete Marketing Website	Gagan, Yasmin, Zhiqi
3.6	Fix LED issues	Daniel
	Attach LED into UV casing	Pablo
	Fix Motor Stalling	Daniel
	Fix wheel Drive Shaft Issue	Pablo,Daniel
	Redesign UV Casing	Pablo
	Test Redesigned UV Casing	Pablo, Daniel
	Install Components into consumer box	Pablo, Daniel
	Reinforce Bumper Sensors	Pablo, Daniel
	Research into public transport power	Daniel
4.1	Prepare for the Q&A on Wednesday	Daniel, Stirling, Gagan
4.2	Demo Report & Video	Daniel, Gagan, Pablo, Stirling
4.4	Write User Guide	Daniel, Pablo, Gagan
	Pitch Video Script	Daniel,Stirling, Gagan
	Pitch Video Editing	Daniel
	Market Research	Stirling
	Gather.io page and poster	Daniel

Table 1. Contributions of each member towards tasks

our control components and then test the control of PAUL from the Web UI. However, after installing our control components into the consumer box we encountered some major hardware issues. These hardware issues took up more of our valuable technician time to resolve than we hoped and unfortunately despite our best efforts we were unable to have a working hardware prototype ready for this demo. In this section we will detail the progress we did make and how we are working to resolve the hardware issues we currently have.

1. **Research into public transport power**
   To assess how our system could be powered on public transport we conducted some research and spoke to the technicians. The most easily accessible way to power PAUL would be to use the power sockets used for charging passengers phone and laptops, companies such as Scotrail are increasingly adding more power sockets to their trains (Scotrail). In our current setup we use a battery pack and power bank to power our system as the Motors require a different input voltage than our other components. To avoid damaging components we would have to voltage converters to step the voltage down from the 240V outputted by a standard UK plug. We could see this being as feasible option if our system was to be deployed onto public transport.
2. **Fix LED Issues**
   We are using a LED light strip to simulate the UVC light on our hardware prototype. We encountered issues when we attempted to add the code to our controller as one of the dependency libraries used by the LED must be run with root privileges on the Raspberry Pi and one of the dependency libraries for the motors cannot be run with root privileges due to the way the libraries are set up. To resolve this issue we created a separate Python script to activate the LED light. To activate the light the from the Web UI this script can be called using an ssh script created by the Front-End team.
3. **Install Components into Consumer Box**
   After having the final prototype assembled we noticed that its wiring was causing issues, the wires kept on adding noise to the IR sensors and dragging PAUL down the pole. We then discussed with the technicians that using and external box with all the required circuit boards would be more efficient. Hence, the Battery Pack - 8xAA Batteries, motor Board, encoder Board, USB Hub, Phidget 888 Sensor Board, Raspberry Pi and the USB Power Bank, were place in the Consumer Box and directly connected to PAUL's casing components through a wire arm.

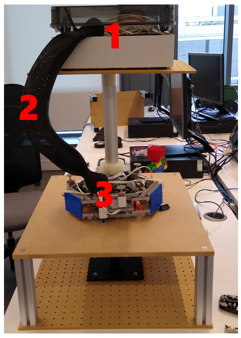

Figure 1. Consumer Box (1), Wire Arm (2) and Pole Climber (3).

4. **Reinforce Bumper Sensors**
   After attaching the bumper sensors and testing the prototype, we noticed that they kept on falling off. We then decided to use Lego EV3 touch sensors, which can be easily and securely mounted onto our Lego robot's casing. The technicians attached these with lego fixings. The following test runs demonstrated that the touch sensors are now more securely positioned.
5. **Attach LED into UV Casing**
   The main issue we faced when attaching the LED strip into the UV casing was its length (60cm), too large for it to fit inside of the module, so the technicians issued us a shorter strip (20cm). This could fitted inside the UV casing and be ravelled around the Pole twice, however this added friction in the system which would stop PAUL from going up, when then decided with technicians to redesign the UV module.
6. **Fix Motor Stalling**
   During one of the lab sessions the technicians reported to us that that it appeared that one of PAUL's motors appeared to be stalling when started. To check if this was the case we asked them to remove PAUL from the pole to allow us to see the behaviour of the motors when started. We activated the motors and the technicians were able to identify the motor which was stalling. Since, the Lego NXT motors we use are standard issue kit from the technicians we were able to quickly replace

the motor. The Lego case meant that replacement process was simple and did not require disassembling other parts.

7. **Fix Wheel Drive Shaft From Disconnecting**
The technician who originally created the Lego case design (based on our CAD design) was able to identify some of the weak points on the LEGO case which caused it to fail to climb the pole. The connections between the motors and the wheels were a major weak point and he was able to reinforce these connections using more LEGO components. However, we were unable to fix all the weak points on the LEGO casing in time for this demo but we intend to continue this task next week.
8. **Improved case design**
Previously our prototype had to be slid onto the pole from above, this would cause trouble for our use case as it needs to be fitted onto a public transport pole, which usually are fixed in place so they cannot be disassembled. Hence, we decided with technicians to make one of the side sheets from the casing mobile. The panel can be unclipped and PAUL then fitted into the pole.
9. **Redesign UV Casing**
The first model of the UV casing was too slim which made it difficult to fit the LED strip inside, also, the rods that attached it to PAUL case had no mobility, these problems made for PAUL impossible to climb upwards. After discussing with technicians possible ways to solve this issues, we decided to redesign the UV module. Making a bigger model with a hole to fit in the LED strip and we also remade it into two slices for it to be bolted directly around the pole and not having to slide it in. The rod's threaded holes were also moved closer to the ends to allow for more mobility on the fixings.
10. **Test Redesigned UV Casing**
After redesigning UV casing to allow the LED light to be installed properly we carried out a test case to ensure that PAUL could still climb properly. This test took place on the 16/03/21 (just after the last demo) and we were successful in getting PAUL to climb the pole. However, after installing the components we ran into a series of issues which meant we were unable to have a working hardware prototype for this demo. These are the issues we encountered when conducting tests on PAUL on each date and the steps we took to resolve them.
16/03/21: Issue: In tests 1 and 2 the pins on the Python LED library did not match the pins on the Raspberry Pi. Solution: edited pins in Library to match our Raspberry Pi setup which was described to use by the technicians.
22/03/21: Issue: The technicians reported that motor appeared to be stalling. Solution: Removed PAUL from the pole and started the motors again. The technicians were then able to identify the stalling motor and replace it with a new one.
23/03/21: Issue: The short gap between the UV casing and the pole caused more friction. Solution: Shortened legs on UV casing to reduce friction in the idea that having the UV casing positioned in a lower position would reduce the friction.
24/03/21: Issue: Short gap between UV casing and pole continued to cause more friction. Solution: New UV casing with more space between pole to allow reduce the friction.
25/03/21: Issue: Motor connections kept coming loose when PAUL started up. Solution: The technicians identified the weak points on the connection and improved the drive shaft design.
26/03/21: Issue: Wire arm put a lot of pressure on one side of PAUL causing imbalance. Solution: Attempted to balance by using elastic to hold arm to reduce pressure on one side.
We will give a breakdown of the test results in the Test Section.

2.2. Software

The work of the software team was primarily focused around supporting our case for commercial viability. We ensured to complete any remaining tests which we had planned and ensured that previously implemented functionality continued to operate as expected. Whilst ensuring that we were well positioned to begin deployment of our Web UI. Members split their time assisting other teams in achieving their goals, especially in regards to market research and commercial viability.

1. **Conduct Friction Tests**
We met with the Webots expert to discuss the optimal way to implement and test friction within the simulation as a result of the feedback given at our last demonstration. Results can be found in the Evaluation section.
2. **Add scene to simulation**
As we have now decided to use our simulation to show how we ultimately expect PAUL to work, we created a train scene for PAUL to operate in. Although this environment is not as realistic as we had hoped, Webots only provides assets for template scenes e.g. the factory and office scenes. As far as possible we reused these assets as we did not determine it to be an effective use of time to create our own train assets.

2.3. Web User Interface

1. **Authenticate users in login page**
We added a login feature to the Web UI in order to demonstrate the future potential for scaling. We use an SQLite database and store usernames with hashed passwords created using the Werkzeug python library. This allows us the user to securely login to the sign in to the control panel. However, our team is still aware of some security vulnerabilities which can compromise our data, such as SQL Injection. Our team is currently working on this.
2. **Accessibility Extensions**
The team implemented several accessibility extensions to our control panel. We implemented vibrations to provide visual feedback to users, and added magnifiers to aid readability. These changes are in line with the Web Content Accessibility Guidelines (WCAG) and were all implemented using Javascript. We also divided our settings pages into two parts - one for accessibility and one for the control panel for ease of navigation. We made this decision as a result of feedback from our client at the last demo.
3. **Marketing Website**
This week we wrote the content for our marketing website, we started by migrating different content from our earlier demo reports and plans. Then we moved to writing new work aiming at our users. We have finished most of it but plan to add to it after this demo, and aim to complete it tomorrow on 30th.
4. **Research and Implement large-scalable features**
Our team researched different techniques to scale our system efficiently, scaling our systems goes hand-in-hand with commercialisation of our robt, and allows us to efficiently grow our robot when demand increases substantially. We used Amazon Web Services' EC2 service to try out our program on the cloud, and built images to horizontally scale them on command. We also considered other options such as Heroku and Microsoft's Azure but ultimately decided to use AWS, considering the agile protocol.

3. Evaluation

3.1. Hardware Testing

LED Light Test The objective of this test was to ensure that our LED light functioned correctly when activated. To activate the LED light had to run a Python script with root privileges. The success criteria was to ask the technicians to check the light was turned on, then send us a picture of the light and asked the technicians check the light was turned off. The test was considered successful if the LED light was activated when the script was run and then deactivated when the script was run again. We also checked the picture the technicians sent us to ensure that the light was a colour which was similar to the colour emitted by LED light.

Date	Test #	Success
19/03/21	1	×
	2	×
	3	×
	4	×
	5	√
	6	√

Table 2. LED Light Test Results

Conclusion: Tests 1 and 2 were unsuccessful as the Python script failed to activating due to conflicts with the motor library. Tests 3 and 4 were successfully in activating the LED using the library but the colour was not similar enough to look like UV so the tests were considered unsuccessful on that a basis. Tests 5 and 6 were successful as we were able to activate the LED and have the colour look similar enough to UV light.

UV Cleaning Module Test

In this section we will provide a summary of the issues we encountered with our hardware prototype and the steps we took to resolve these issues. The tests were conducted at motor power of 70% power. The objective of these tests was to check that PAUL could climb the pole successfully and perform its UV cleaning function as expected. Our success criteria for each test was to check the video recorded by the technicians and see if PAUL could successfully climb the pole starting at the bottom without slipping back down and stop before it reaches the top. We also checked that the integrity of the UV casing was maintained throughout the test. Conclusion: The last successful test was on the 16/03/21 which was before we installed components into consumer box. After installing the components into the consumer box we faced a range of issues described above which meant we do not have hardware prototype that is able to climb the pole successfully as of this report being submitted. However, we intend to work to resolve these issues next week before the industry day. Note: we discussed the specific issues we encountered on each date in the **Hardware** section.

Date	Test #	Success
16/03/21	1	×
	2	×
	3	×
	4	√
22/03/21	1	×
	2	×
	3	×
23/03/21	1	×
	2	×
24/03/21	1	×
	2	×
	3	×
	4	×
25/03/21	1	×
	2	×
	3	×
	4	×
26/03/21	1	×
	2	×

Table 3. UV Cleaning Module Test Results

3.2. Webots Testing

All of the tests compare a surface type (for the pole) against rubber. The rubber we used for the values provided was Rubber A 60 and we used (Edge) for friction coefficients, with the exception of test 7, for which we used (Mills, 2008). We considered a pass to be successfully climbing and descending the pole 5 times. Tests 1-5 ultimately succeeded without any notable deviation from our expectations. Test 6 however, experienced a slight spin as it climbed, however it was still possible for the entire climb / descent to be completed five times without seriously impacting the time taken. We tested some values between 0.56 and 0.15 and found as we decreased friction, the spin increased until PAUL could not climb the poll at all, as was the case in test 7.

Test	Friction (N)	Surface Type	Pass
1	0.86	Steel	√
2	0.73	Rubber	√
3	0.67	Asphalt	√
4	0.64	Stainless Steel	√
5	0.62	Tungsten Carbide	√
6	0.56	UHMW Polyethelene	√
7	0.15	Ice	×

Table 4. Friction Tests

We are satisfied that PAUL will therefore be able to operate on handrails present within trains. There does exist some risk in the the coefficient of friction being reduced because of water introduced by passengers touching the pole if it is raining outside. But most handrails are made from steel or aluminium - which seems to have a similar frictional properties to steel (Edge) although we could not find an exact value so excluded it from these tests and so even if some reduction was experienced, it would be unlikely to impact the successful function of PAUL in any substantial way.

4. Budget

Table 5 shows our current cost estimate of our Hardware System. All the items except the Metal Pole and Pole Holder were items that are available to all groups and as such our we have only spent £18 of our £200 budget.

5. Video link

SharePoint

Item	Quantity	Cost per item (£)	Source
Raspberry Pi 3	1	30	(Pricelist)
Lego NXT Motors	3	32.39	(Pricelist)
Encoder board	1	10	(Pricelist)
Motor board	1	10	(Pricelist)
Batteries (AA)	8	2	(bat)
Battery Charger	1	20	(cha)
Lego Technic Case	1	6	Estimate
Phidget	1	93.31	(Pricelist)
Sharp Sensors	6	6.22	(onecall)
Bump Sensors	6	4.99	(vex)
Metal Pole (60cm)	1	18	(metals4u)
Pole Holder	1	0.60	(Pricelist)
UV Casing	1	1	Estimate
LED Light Strip	1	6.95	(led)
Wires and Misc	1	5	Estimate
Total		**381.29**	

Table 5. Budget Expenses

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Scotrail. We're investing £475 million in new and better trains for scotland. URL https://www.scotrail.co.uk/about-scotrail/investment.

UVD-Robotics. Uvd robotics. URL https://www.uvd-robots.com/.

WCAG. Web content accessibility guidelines. URL https://www.boia.org/wcag-2.1-a/aa-principles-and-checkpoints.