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Waterloo

Department of Mechanical and Mechatronics Engineering

Smart Cane

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Executive Summary

With the considerable number of visually impaired individuals in Canada and the high likelihood in them falling when taking independent trips, there exists a need for a more reliable solution for navigation. The proposed solution aims to improve the traditional white canes by adding the ability to detect obstacles and guide to safer paths, while still being intuitive to the user. This is achieved by using electromechanical sensors, such as a stereo camera and LiDAR. A vibration motor to provide haptic feedback, and a directional motor to allow automatic directional changes to steer the individual away from any obstacles. This design fulfilled the criteria and constraints determined beforehand, such as being portable, reliable against misplacement, having a long battery life, and comfortable during use.

While the final design was being built into a prototype, multiple modifications were made to the mechanical, electrical, and software and control subsystems by testing it against its desirable outputs and offering an alternative solution in an iterative approach. An engineering analysis was conducted while facing problems during its testing and debugging phase, such as calculating how to better center the mass of the enclosure in its relative position on the cane. The results of this analysis were used to make necessary changes to the parts used, which led to updates to the detailed design. Significant consideration was taken into the construction and manufacturing process such as how to complete unit and integration tests for the software and electrical components and the electrical and mechanical subsystems in the most efficient way. Upon completing the prototype, an extensive amount of effort was made for commissioning and fine-tuning the product with the goal of making the user experience as seamless as possible. Finally, the prototype and its subsystems were tested in multiple indoors, and its performance was evaluated against the established criteria and constraints. The final prototype was presented to the general audience at the Mechatronics engineering symposium.

1.0 Introduction

1.1 Background

The motivation for this project comes from the statistics that in 2019, 1.2 million Canadians were reported to have some form of visual impairment [1] and it was found that visually impaired were 70% more likely to fall [1] and were 50% less likely to take independent trips [1]. With the limited functionalities of traditional white canes and how they rely on the user to control the cane, visually impaired people are more susceptible to getting injured in their travels.

1.2 Needs Assessment

There exists a need for visually impaired people to be able to confidently take independent trips using a white cane without having to worry about injuring themselves.

1.3 Problem Formulation

The problem defined for this project is the lack of functionalities in traditional white canes, and to add functionalities to help the visually impaired people navigate to safer paths.

1.4 Constraints and Criteria

The criteria that a potential solution should ideally be able to provide feedback, be portable, be reliable against misplacement, be structurally able to support against falls, detect obstacles, and be comfortable during use.

Constraints were derived from the needs analysis and criteria. The constraints of the potential solution include that the weight must be less than 4 kg. The manufacturing cost must be less than $1000 for it to be affordable for its targeted audience. Another constraint is that the battery life must be at least 8 hours, which is particularly important considering the cane is used for travels. Lastly, the system must be able to detect obstacles within 5 meters and provide appropriate feedback to the user.

1.5 Design Review

The design involves a mechatronics feedback system for obstacle detection. A smart cane is proposed where a white cane is retrofitted with the addition of an omnidirectional wheel, gear motor, enclosure, electrical sensors, battery, and a microcontroller. Additionally, a vibration motor will be attached to the handle where the palm of the user would rest. A python script running on a Raspberry Pi 3 would use the data collected from the RPLiDAR A1 sensor and the OAK-D Lite camera to detect obstacles and help the user navigate. This device would provide haptic feedback via the vibration motor attached to the handle. The vibration motor would emit different vibration patterns depending on the state of the cane. The cane has an omnidirectional wheel at the end of the cane to provide an automated directional change both in detection and avoidance. While audio feedback was originally proposed, time constraints prevented the team from implementing it. Computer vision model from the stereo camera was also a significant aspect of the software subsystem of the project that while able to detect crosswalks and people, did not detect red light with high accuracy, hence better planning for the dataset needed to be done into the future. Additionally, the wheel mounting needed to be more user-friendly and designed to ensure accommodation for visually impaired individuals of different heights. Currently the omni-directional wheel, if tilted too high, would not touch the ground, and hence would not provide steering when obstacles are detected. The IMU was not fully integrated due to time constraints. The prototype design significantly lacked accessibility to the inside of the enclosure, which made debugging and replacing wires extremely time consuming once fully assembled.

2.0 Final Design

2.1 Original Design

2.1.1 Overall Design of the Smart Cane

The design includes an electromechanical enhancement to a traditional white cane with the addition of a LiDAR, stereo camera, microcontroller, vibration motor, and omnidirectional wheel. The cane operates in a sweeping mode when uninterrupted. It autonomously moves side-to-side to ensure there is no obstacle in the way of the user. If the cane detects an obstacle, it will steer the user into an open path. If the obstacle is both to the left and right of the individual, the cane will stop powering the wheel. The cane also provides haptic feedback to the user; a constant vibration when it detects an obstacle and a pulsing vibration when it sees a stop sign. There is an additional push button placed at the handle which will pause the cane from sweeping but is not shown in Figure 1. The overall design of the Smart Cane can be seen in Figure 1.

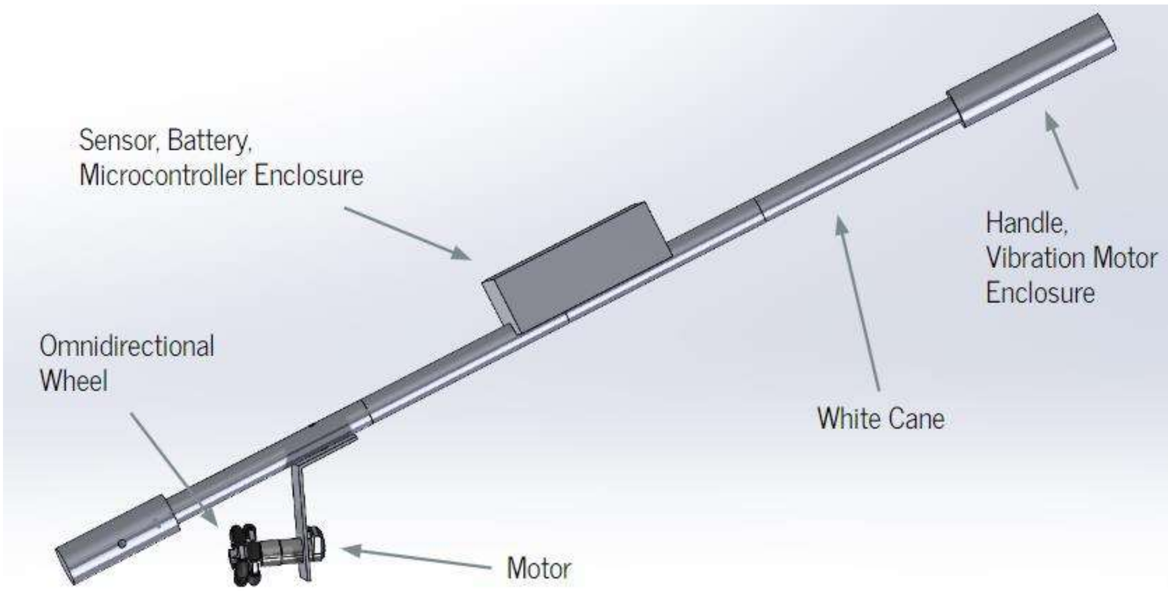


Figure 1 Original Design of Smart Cane [1]

Table 1. Brief Justification for Component Selection [1]

Part	Selection Reason
Slamtec RPLiDAR A1	Cheapest Lidar found at with decent specs (8000hz polling rate, 12m distance)
Raspberry Pi 4B	2 USB 3.0 ports for LiDAR and stereocamera, 40 pin GPIO header
Luxonis Oak-D-Lite Camera	Cheap camera solution with depth perception and object detection
BHI 160B IMU	All around cost-effective IMU
VCLP0820B004L Vibration Motor	All around cost-effective vibration motor with low power consumption
JGA25-370 Geared Motor	Selected based on the torque requirement calculated.

Note that the model for the Raspberry Pi listed in Table 1 is 4B, which was the intended model used, however due to unexpected failure on the Pi 4B, the project migrated to using the Raspberry Pi 3 instead. If available, the Raspberry Pi 4B is preferred over the Raspberry Pi 3.

2.1.2 Software Design

2.1.2.1 Object Classifications

Luxonis OAK-D Lite stereo camera was used for object classifications of traffic lights, crosswalks, and stop signs. It used the YOLOv5 model for image recognition as the model had higher accuracy than other image processing models. It also had higher FPS compared to other models. For the final presentation, the pedestrian red light was replaced with a stop sign that the stereo camera should detect from within 5 meters. Roboflow was used to train the model and OpenVINO to deploy a deep learning model using an inference engine which was particularly useful to build a model for the zebra crosswalk. To avoid false positives of detecting stop signs during sweeping motion, a threshold was implemented to flag stop signs.

2.1.2.2 Object Detection / States

The Slamtec RPLiDAR A1 was used as the main component for object detection. Only the data points detected within $180°$ of the fronts of the cane were used to compute the current state of the cane. With no obstacles detected, the cane operates in sweeping mode. In sweeping mode, the cane periodically makes a sweeping movement from side to side between $[-30°, 30°]$. If an obstacle is detected while in sweeping mode, the cane would exit sweeping mode, and steer the user towards an open path by determining if there are free pathways on either left or right. If there is no such path, the cane will no longer guide the user and the user will experience resistance from the cane to stop.

2.1.2.3 Haptic feedback

Additional haptic feedback was added to provide more direct feedback to the user. A vibration motor was attached at the handle of the cane where the palm of the user would rest. The vibration motor emits different vibration patterns depending on the mode. When an obstacle is detected, a constant vibration is used. Whereas if it detects a stop sign, a pulsing pattern is used.

2.1.2.4 Overall Design

With the subsystems explained above, the following flowchart shown in Figure 2 can be used to describe the overall system. All systems are controlled by a Raspberry Pi 3 board. SLAM is not implemented in the actual prototype and is included as a future recommendation in section 4.2.1. Likewise, the audio feedback is also included in section 4.2.3.

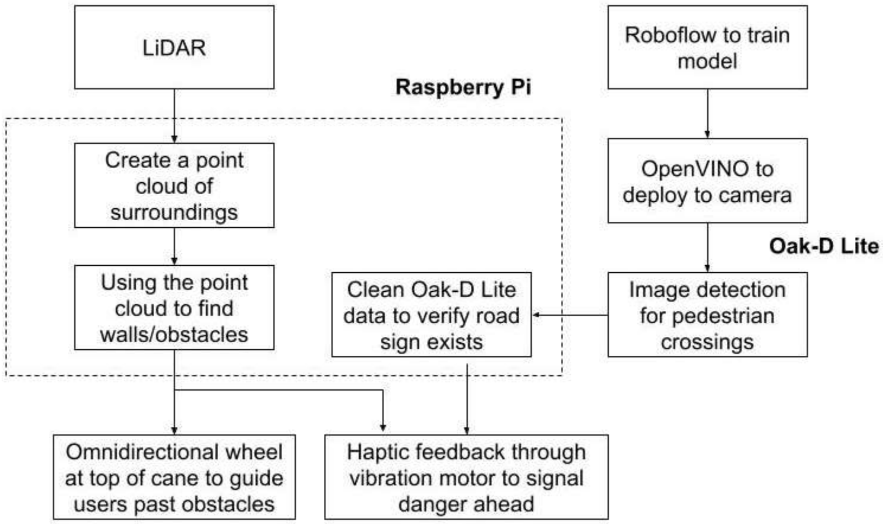


Figure 2. Software Architecture [1]

The algorithm automatically starts on boot using systemctl service, which would ensure that the script is running or re-runs itself in case of a program crash. It was noted that the RPLiDAR started its motor as soon as it was given power, which resulted in difficulties determining whether the algorithm was initialized and running or not. To mitigate that, an LED light was added to indicate that the algorithm was running.

2.1.3 Electrical Design

2.1.3.1 Raspberry Pi 3 and Breadboard

The Raspberry Pi 3 was the main board of the entire system with the Jetson Nano not being used. All electrical components used by the cane were controlled by the Pi through GPIO pins bridged with the breadboard. The LiDAR and the camera were the only components that were directly connected to the Pi via USB ports.

2.1.3.2 Gear Motor and Motor Driver

The motor driver Neuftech L298n was used to control the gear motor JGA25-370 attached at the end of the cane. The gear motor required minimum of $6V$ operating voltage. The Raspberry Pi 3 can only provide up to $5V$ thus, an external power source of an off-the-shelf $9V$ battery was connected to the motor driver as power source. The motor speed was controlled by the Raspberry Pi 3 through PWM and direction signals.

2.1.3.3 Omnidirectional Wheel and Mount

The omnidirectional wheel was mounted as seen in Figure 3. The mount was 3D printed to be friction fitted onto the cane strong enough to resist the torque from the directional motor.

Figure 3. Omnidirectional Wheel and Motor Mount

2.2 Deviations from the Original Design

2.2.1 Mechanical Modifications

The main mechanical functionality of the Smart Cane was maintained from the original design. However, two main differences were implemented as issues were identified after the first prototype was made. The first prototype's main enclosure can be seen in Figure 4.

Figure 4. Initial Enclosure Prototype

The first problem was that the main enclosure was top-heavy in its center of gravity, meaning that the cane would naturally sway to orient the main enclosure downwards. This was problematic as the LiDAR sensor and the OAK-D camera needed to be placed at the top-front. The solution to this problem was a redesigning of the main enclosure such that the center of gravity of the Smart Cane is bottom-heavy while also having a top surface where the LiDAR sensor can be placed, as seen in Figure 5. This balanced the enclosure as the center of mass was closer to the cane.

Figure 5. Final Prototype Fully Assembled

The second design problem that was identified was the method of fixture of the main enclosure to the cane. Since this project is intended as a mechatronics enhancement of a normal white cane, the method of fixture of the main enclosure should be non-permanent. The solution to this problem that was implemented was a flexible 3D printed tube that was friction fitted onto the cane and the main enclosure at the same time.

2.2.2 Hardware Modifications

After the original design, a new product was discovered that can fulfill the requirements of the Jetson nano, for much cheaper. The OAK-D Lite was found to have built-in color, stereo cameras for depth sensing, as well as built-in hardware to accelerate machine learning algorithms for image processing. This could not only replace the expensive Jetson Nano, but also the camera, and the Lidar. Unfortunately, when tested it was found that the camera was insufficient for obstacle avoidance as there are major artifacts for depth perception, especially with uniform wall and floor colors. After thoroughly testing the hardware in various environments, it was decided that Lidar should be primarily used for obstacle detection, and the OAK-D for image recognition.

2.2.3 Software Modifications

A few modifications were needed for the computer vision functionality. Firstly, YOLOv5 was used instead of YOLOv4 as it was more performant which significantly reduced latency. Moreover, multiple models were used concurrently as YOLOv5 did not have enough object detection capabilities for crosswalks and pedestrian lights (green and red). Upon demonstrating the final prototype, since there were very few pedestrian light datasets to train a model, the traffic light detection was replaced with a stop sign detection. While green light worked with a high accuracy, the real-life environment did not predict red light with a similar accuracy. An additional model was also trained to detect road signs and the nature of the road sign itself, such as if it indicates dangerous conditions or a yield sign, however for simplicity it was removed as a key component of the computer vision functionality.

For navigation, SLAM was not used with LIDAR and IMU. The updates turned out to be much too slow with pre-existing libraries, and the development time for creating a performant SLAM implementation was unfeasible. This is because the obstacle avoidance requires a somewhat high refresh rate (>5Hz) for the algorithm, as the cane moving back and forth means that the location of the cane is continuously and rapidly changing, and there would be too much error with slow refresh rates. A low refresh rate (<1 Hz) would also make avoiding moving obstacles such as humans nearly impossible. Testing multiple off the shelf SLAM algorithms written to run on the Raspberry Pi, a refresh rate over 0.7Hz was not possible to achieve, as the code is meant for slower systems and is running as a python script on a Raspberry Pi 3.

After the setback with SLAM, it was decided that the best move going forward would be to have a much simpler feedback algorithm that senses the obstacles directly and keeps the cane a certain distance away from the obstacle with a simple feedback controller. This approach, even with unoptimized python code could run at about 8Hz, exceeding the requirements that were set out.

2.3 Construction/Manufacturing

2.3.1 3D Prints

The bookable 3D printing service available on WATiMake was used to 3D print all the enclosure, the wheel mounts and the standoffs. Overnight sessions were booked to print larger pieces such as the enclosure, while daytime bookings were used for smaller prints. The small 3D printed standoffs were chosen as the mechanism to hold electrical components such as the Raspberry Pi and the breadboard in place. The reason for using standoffs as opposed to having the electrical component locations explicitly guarded by the 3D printing model was due to the high inaccuracy of the 3D printer. The initial enclosure had all its dimensions in almost unusable accuracy and tolerance, and thus it was necessary to come up with a more dynamic solution for securing electrical components. Having flat surfaces within the enclosure and super-gluing the standoffs in desired places allowed for dynamic allocation of electrical components.

The final enclosure was designed in a such way that all components except for the LiDAR and the OAK-D Lite camera are placed in the lower half of the enclosure, making the enclosure bottom heavy. Doing so allowed the enclosure to use its weight to center itself while the cane is moving sideways. The enclosure was pressure fit onto the cane.

The wheel mount was also pressure fitted onto the cane. The mount was printed in two parts, one to support the gear motor, and another to support the wheel from the other end.

2.3.2 Electrical Components

All the electrical components were powered by the Raspberry Pi 3 which can provide up to $5V$ with the exceptions of the OAK-D Lite camera and the gear motor. The gear motor required a minimum of $6V$ and was explained in section 2.1.3.2. The OAK-D Lite camera could have been powered by the Pi, however, to reduce unnecessary current draw on the Pi, a Y-split cable with USB-C for power and USB-A for data transfer was used for the OAK-D Lite camera. The OAK-D Lite camera was powered directly by the power bank, which also powers the Pi.

The RPLiDAR was connected to the USB-A port of the Pi with a microUSB cable, and the OAK-D Lite camera was connected to the Pi's other USB-A port with a USB-A 2.0 cable. The rest of the electrical components were connected using a combination of male-to-male, female-to-male, and female-to-female jumper wires. Soldering was done on the gear motor, vibration motor and the push button to connect the jumper wires. The soldered ends were secured with electrical tapes. The gear motor, vibration motor, and the push button were then connected to either the handle or the end of the cane through multiple jumper wire connections from the enclosure. The connections between jumper wires were taped down to secure connectivity, then firmly secured to the cane using zip ties. In the future, better wiring methods will be explored both for functionality and aesthetics.

2.4 Commissioning

Once all the subsystems were tested and the whole cane was fully assembled. The cane was taken into the hallways of Engineering 7 building for real-life testing. The cane was tested with the user's eyes covered to mimic visual impairment. The overall correctness of the system was commissioned first. That is, the cane correctly navigated the user to safer paths. Afterwards, all feedback systems were carefully examined for fine tuning. Examples of fine tuning include sweeping angle, sweeping speed, vibration patterns, and wheel speed and accelerations when changing directions.

2.5 Testing and performance

2.5.1 Testing

Testing was completed on a per system basis before all systems were joined together for full testing. The computer vision functionality was tested with datasets of images with pedestrians and crosswalks via Roboflow before being assembled. The crosswalk was trained using over 100,000 images; however, the pedestrian street sign was trained with only 3000 images. After assembly, a printed off real-life sized stop sign was used for testing.

The button control, the haptic feedback and the omnidirectional wheel were tested by checking if the desired behaviour is observed based on the state of object detection. Both feedback systems were correctly set up and wired without being on the cane itself. Once all of the systems were fully tested, the final product was fully assembled and tested in a real-life scenario by trying to navigate hallways with eyes covered.

2.5.2 Performance

For computer vision, the green light was predicted with 88% accuracy, the red light was only predicted 45% of the time. This was deemed insufficient and replaced with a stop sign for the final presentation. The cane could have performed better had the Raspberry Pi 4B not burned and was used as the main controller instead of a Raspberry Pi 3.

Upon testing the original criteria and constraints of the prototype, most were satisfied. The weight of the cane was roughly 3 kg, the budget was well under $1000, the length of the cane upon extension was over 1 meter, the LiDAR and the stereo camera were both able to detect obstacles within 5 meters, upon optimal environment conditions such as lighting, and the smart cane can support a weight of over 65 kilograms. The battery life also lasted far more than 8 hours as the power bank lasted over multiple days of testing with one full charge.

Overall, the performance of the final product was satisfactory. It correctly navigated users to safer paths and gave correct and proper feedback under different situations. The final prototype did not meet all the criteria as desired. While the cane was still portable, a few of the joints needed to be taped together to allow the wheel to move with the handle as otherwise, it would rotate up to a certain length of the cane with some of its rotation being lost in the joints. This also translated to the reliability against misplacement criterion being not fully satisfied as the white cane could not be fully retracted to easily fit into bags. The ability to detect obstacles is directly incorporated into the design, both with the LiDAR and stereo camera, as is the means for feedback of obstacle detection information to the user. The comfort during use criterion is considered satisfied due to this design being very similar to the traditional white cane, which is the most used aid for the visually impaired. Moreover, there is no additional action required by the user to operate the cane other than simply holding the cane. The vibration and stop button are conveniently located at the handle so the user can be given direct feedback and have control over the cane. This will allow an intuitive transition for the users. Lastly, the battery life criterion is satisfied as it lasted much longer than 8 hours.

3.0 Schedule and Budgeting

3.1 Schedule

The project schedule from the beginning of January is shown in Table 2.

Table 2 The schedule [1]

WBS	TASK	START	END	DAYS	% DONE
1	**Manufacturing**		-		
.1	Make electrical component enclosures	Mon 1/09/23	Mon 1/16/23	8	100%
.1	Assemble motors, enclosures, and wheels onto white cane	Mon 1/16/23	Mon 1/23/23	8	100%
	Redesign and 3D print main enclosure	Tue 3/07/23	Tue 3/14/23	8	100%
.1	**Commisioning**		-		
.1	Verify constraints of the prototype	Mon 1/23/23	Mon 1/30/23	8	100%
.1	Make adjustments to the prototype if some constraints not met	Mon 1/23/23	Mon 1/30/23	8	100%
.1	**Testing**		-		
.1	Verify combination of computer vision and lidar sensor works	Mon 1/30/23	Mon 2/06/23	8	100%
.1	Verify feedback on the wheel, handle, and audio works	Mon 2/06/23	Mon 2/13/23	8	100%
1	Make a test course for testing use cases	Mon 2/06/23	Mon 2/13/23	8	100%
.1	Experiment on test course and improve prototype based on results	Mon 2/13/23	Mon 3/13/23	29	100%
.1	Experiment on test course with new main enclosure mounted	Tue 3/14/23	Tue 3/21/23	8	100%
.1					
1	**Detailed Design and Engineering Analysis**		-		
.1	Research Specific Mechanical Parts	Tue 11/01/22	Mon 11/07/22	7	100%
.1	Research Specific Electrical Parts	Tue 11/01/22	Mon 11/07/22	7	100%
.1	Research for Specific Software Design	Tue 11/01/22	Mon 11/07/22	7	100%
.1	Detailed CAD of Design	Mon 11/07/22	Mon 11/14/22	8	100%
.1	Detailed Mechanical Design	Mon 11/07/22	Mon 11/14/22	8	100%
.1	Detailed Electrical Design	Mon 11/07/22	Mon 11/14/22	8	100%
.1	Flowchart of all Software Methods to be used	Mon 11/07/22	Mon 11/14/22	8	100%
.1	Mechanical Analysis of Design	Wed 11/09/22	Wed 11/16/22	8	100%
.1	Electrical Analysis of Design	Wed 11/09/22	Wed 11/16/22	8	100%
1	**Report Video and Symposium**		-		

.1	Work on Final Design Report		Tue 3/28/23	Mon 4/10/23	14	100%
.1	Work on Promotion Video		Thu 3/02/23	Thu 3/09/23	8	100%
.1	Work on Symposium Poster		Thu 3/16/23	Mon 3/20/23	5	100%

3.2 Budget, Projected and Actual Cost

3.2.1 Budget

The expected expenses for the prototype are summarized in Table 3.

Table 3 The budget [1]

Part	Category	Cost (CAD)
Jetson Nano Developer Kit	Hardware	CA$305.09
Slamtec RPLiDAR A1	Hardware	CA$152.79
BHI 160B IMU	Hardware	CA$14.43
Raspberry Pi 3B	Hardware	CA$169.50
IMX219-160 Camera	Hardware	CA$36.16
BHI 160B IMU	Hardware	CA$14.36
VCLP0820B004L Vibration Motor	Hardware	CA$5.45
JGA25-370 Geared Motor	Hardware	CA$3.59
White Cane	Mechanical	CA$67.80
Battery Bank	Electrical	CA$51.92
Total		**CA$821.09**

3.2.2 Actual Cost

The expenses incurred throughout this project can be seen in Table 4.

Table 4. Project Expenses

Part	Cost (CAD)
Oak-D Lite Camera	232.35
Accelerometers	14.68
USB-C Cables	14.38
Micro USB Cable	7.90
Ethernet to USB-C Adapter	10.11
USB-C Splitter	13.55
Motor Controller Module	12.42
Raspberry Pi 4B	214.69
USB-C to USB 3.0 Cable	10.16
SD Card	15.81
HDMI Cable	11.29
Battery Holders with Switch	12.42
9V Batteries	12.78
Power Bank	41.54
3D Print Costs	155.34
RPLiDAR A1 Sensor	158.19
Poster	43.26
Motors	36.70
White Cane	35.00
Omni-wheels	67.44
Total	1120.01

The deviations from the initial budget plan are the removal of Jetson Nano in favor of adding OAK-D Lite camera and the upgrade from Raspberry Pi 3B to Raspberry Pi 4B. It was noted that the OAK-D Lite achieves all that the Jetson Nano can with better performance. Raspberry Pi 4B was chosen as the new main controller over Raspberry Pi 3B for performance and the price difference was well justified. Where possible, the actual model numbers are included in the bill of material in Appendix B.

The total cost was above the budget of $1000. Extra expenses were incurred due to the making of a second prototype, damages to the SD card, and the purchasing of extra parts (an extra omni-wheel, batteries, cables, and other electronic parts). Without these extra expenses, it is expected that a functional prototype could be made under the budget. Note that the list includes a Raspberry Pi 4, which was the main controller being used until the board was burnt. Then, the main controller was replaced with a Raspberry Pi 3.

4.0 Conclusions and Recommendations

4.1 Conclusions

The prototype was successfully built and satisfied the objectives defined by the needs statement and problem formulation. The goal of the project was completed to enhance a regular white cane using mechatronics sensors to help visually impaired people with navigation. This was done with LiDAR technology, computer vision functionality, a vibration motor, and an omnidirectional wheel to aid in steering. Some modifications were made from the originally proposed design in MTE 481, such as the enclosure design to make it less top-heavy, and simple integration with the LiDAR and the stereo camera to establish a proof-of-concept. Upon testing, the feedback systems were correctly set up and wired without being on the cane itself and then all parts were assembled.

The final prototype did not meet all the criteria as planned. This was mostly because it was not foldable since a few of the joints needed to be joined together to ensure the omnidirectional wheel steered the individual away from any obstacle. Nonetheless, the smart cane was still reliable against misplacement, prevented falls, detected obstacles, had a long battery life, and was comfortable during use. The constraints were all satisfied as the battery life was longer than 8 hours, the weight was less than 4 kg (yet greater than 3kg), the total expenses of the entire project were over $1000. However, this was largely due to re-designing and purchasing extra parts due to component failures, and as such the actual cost of all components will be under $1000. Lastly, the cane detected obstacles over 5 meters, and the cane supported a weight over 65 kg.

4.2 Recommendations

4.2.1 SLAM

SLAM can be integrated as it was omitted in the prototype due to the tight timeline and technical limitations. Integrating SLAM along with an IMU will allow Smart Cane to map its location in the surrounding areas. This would be crucial for the next step of the cane, which would be autonomous navigation. If there is a predetermined destination, having a map of the surrounding area from SLAM would be invaluable.

4.2.2 Improved Camera Utilization

The camera can be utilized further. With a more trained and more accurate object detection model, the camera can be used to detect obstacles that are missed by the LiDAR due to the height of the obstacles. Furthermore, depth analysis can be done on the camera to compute distances to obstacles, and feed into the SLAM for a more accurate map of the surrounding environment. Improved road sign detection can also provide more information about the current surrounding environment and the resulting feedback to the user. Outdoor navigation will be possible with improved camera performance.

4.2.3 Hardware and Audio Feedback

Regarding hardware, custom PCB could be incorporated with the enclosure to reduce the weight of the electrical parts. The power bank can also be replaced with battery cells to further reduce its weight, and a better interlocking mechanism should be used to prevent the internal rotations at folding joints. Some other improvements, given more time, would include a better wheel mount to be more flexible with the tilt at which the cane is being held, having audio feedback, and ensuring the system is weatherproof for outside use. Adding audio feedback will allow the cane to provide more meaningful and more detailed feedback to the user, which is especially important as visually impaired people rely heavily on their hearing.

4.2.4 Early Assembly and Testing

Earlier testing on the final product would have been more useful. This was most evident when the enclosure needed to be re-designed, which prevented some debugging of the other electrical wiring to integrate the omnidirectional wheel to the Pi. If financially possible, backup parts should be ordered in case of unexpected component failures. Lastly, accessibility to the inner components should be checked while designing. With better accessibility, the debugging process will be much more efficient.

4.2.5 Interview Target Audience

It is crucial to collect data from the target audience. Some useful data can be the actual issue they have and their priorities, which can be used as a decision matrix when making an engineering decision such as choosing which functionality to remove at the expense of reducing weight.

5.0 Teamwork Effort

There were no significant deviations from the effort described in the MTE481 report. With the increased workload and having actual components to work with, the frequency of meetings increased as expected. At least one in-person meeting was scheduled during the weekends to work on the project.

Communication was still a big issue where some team members were unreachable over multiple days without an explanation and slowed the progress of the project. However, it improved as the date got closer to the symposium, and the team was able to complete the core work.

As it was for MTE481, all members contributed to all parts of the project throughout the term. Nonetheless, due to the fair distribution of work, and having to meet internal and external deadlines, such as the poster and video, each member had specific areas of the project where they contributed more, and the specific roles of each member are summarized in Table 5.

Table 5. Work Distributions

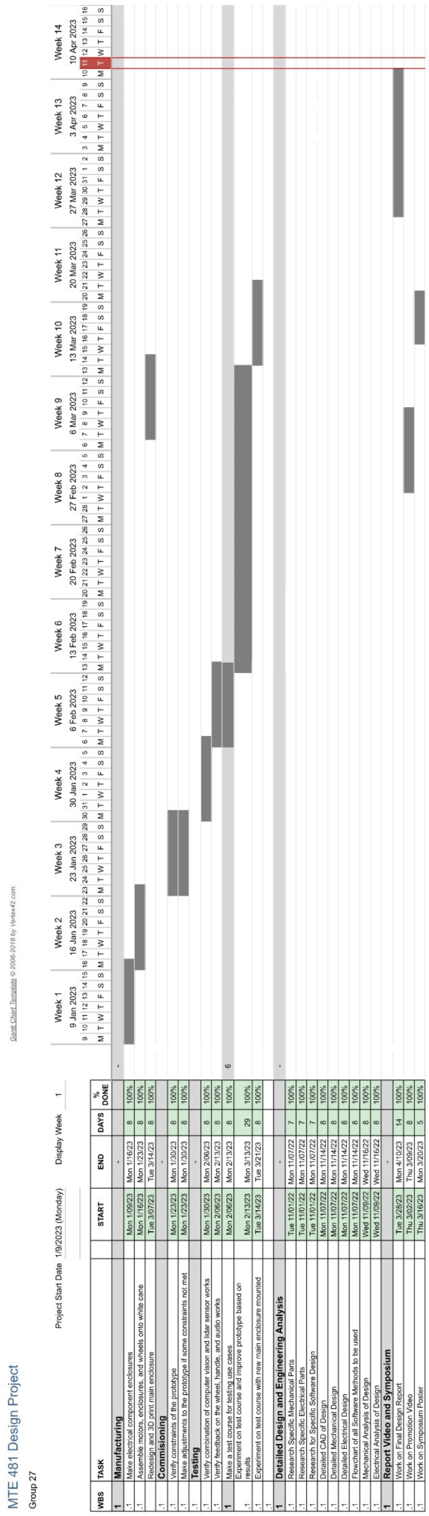
Member	Specific Contributions
Bin Kim	- LiDAR and stereocamera integration with Raspberry Pi - LiDAR software - Promotion Video - Mounting + wiring of omnidirectional wheel - Testing of all subsystems
Hogyun Lim	- CAD + 3-D printing for enclosure and omnidirectional wheel - Mechanical Design - Promotion Video - Symposium Poster Design
Jainish Mehta	- Re-creating website - Blogs, poster - Stereo-camera computer vision functionality (including training of models)
Fahim Shahriar	- LiDAR software - Raspberry Pi, H-bridge, breadboard electrical wiring - Testing of all subsystems

6.0 References

[1] Kim, Y., Lim, H., Mehta, J., & Shahriar, F. (2022). *Smart Cane*.

7.0 Appendices

7.1 Appendix A. Full Project Schedule [1]

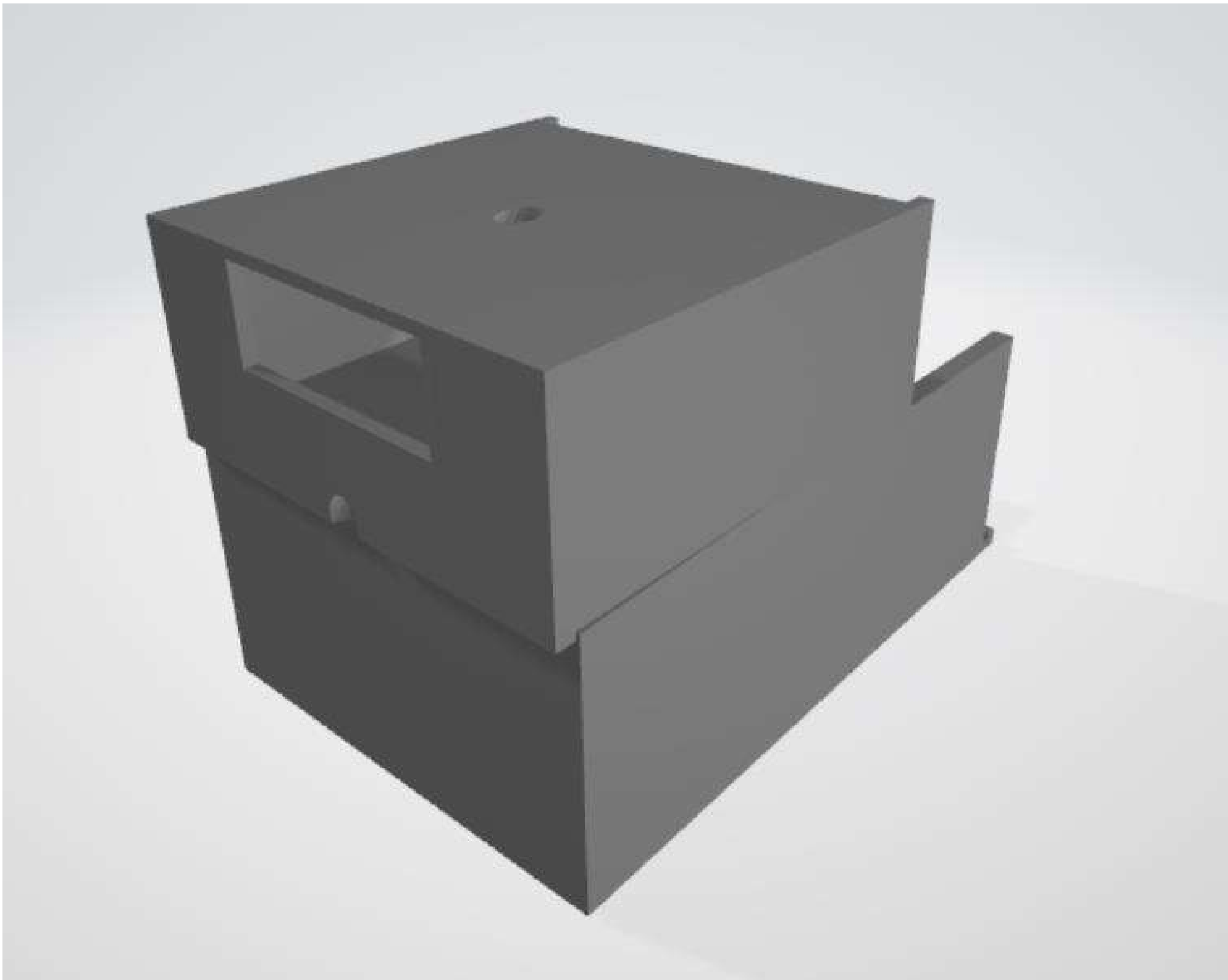


7.2 Appendix B. Bill of Materials

Part Number	Description	Qty	Unit Cost	Cost
392-OAK-D-LITE-AF	stereocamera	1	$232.25	$232.25
CableCreation USB-C Cable	USB-C Cable	1	$14.38	$14.38
UGreen Micro USB cable	Micro USB Cable	1	$7.90	$7.90
JSAUX Ethernet to USB-C Adapter	Ethernet to USB-C Adapter	1	$10.11	$10.11
MoGood USB-C Splitter	USB-C Splitter	1	$13.55	$13.55
L298N Motor Driver Controller Board Modules	Motor Controller Module	1	$12.42	$12.42
256GB Micro SD Card	SD Card	1	$15.81	$15.81
PowerBear HDMI Cable	HDMI Cable	1	$11.29	$11.29
LAMPVPATH (Pack of 2) 9v Battery Holder	Battery Holders with Switch	1	$12.42	$12.42
Amazon Basics 9V Batteries	9V Batteries	1	$12.78	$12.78
ANOIMI PowerBank 36800 mAh	Power bank	1	$41.54	$41.54
Miscellaneous 3D prints	3D prints	9	$17.26	$155.34
Slamtec RPLiDAR A1	LiDAR	1	$158.19	$158.19
VCLP0820B004L Vibrational Motor	Vibrational Motor	1	$4.84	$4.84

114090046 GearMotor	Directional Motor	1	$28.25	$28.25
60MM Double Aluminum Omni Wheel Basic – 14145	Omnidirectional Wheel	1	$67.44	$67.44
VisionU Aluminum Mobility Folding White Cane	White cane	1	$35.00	$35.00

7.3 Appendix C. 3D Render of the New Enclosure



7.4 Appendix D. 3D Render of the Gear Motor Mount

7.5 Appendix E. 3D Render of the Flexible Material