ROCO507: Advanced Robot Design And Prototyping.

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1 Abstract

This report displays the creation of Traybot. It incorporates the design process as well as simulation to present the proof of concept. The Traybot is a logistics robot which is to be used in healthcare, its primary function is to deliver food or oral medication to a patient in quarantine. A secondary function is to filter and clean air with an inline air filter. This report will cover the mechanical components for each key part of the design, such as linear actuators, belt drives and the system incorporated into the wheelbase. Justification will also be given for all the decisions made during the design process.

2 Introduction

The British Medical Journal recently published a report stating that "hand-mediated transmission is a major contributing factor in the acquisition and spread of infection in hospitals, and such transmission can occur directly via hands, or indirectly via an environmental source"[1]. Furthermore, it has been found that hand contamination with MRSA occurs as often when healthcare staff touch contaminated surfaces as with direct contact with an infected patient [2]. An approach to reducing these healthcare acquired infections (HCAIs) could be to find better methods of decontaminating frequently touched surfaces. However, it also raises the question "is it possible to reduce the number of surfaces which need to be touched by multiple people?". In this work, we seek to explore this possibility by designing Traybot, a robot capable of completing routine hospital logistics autonomously.

3 Literature Review

The concept of using autonomous robotic couriers within hospitals is not new, an early implementation was trialled in 1991 [3]. Named Helpmate, the authors produced a mobile platform which relied on a fusion of structured light, ultrasound and contact bumpers to navigate whilst avoiding collisions. The robot could be dispatched using a screen and keypad, and upon arrival at its destination payloads were manually unloaded. The use of a voice output system to narrate robot behaviour was considered crucial in gaining acceptance within the hospital. Although great potential was shown, the authors concluded that future developments would benefit from advances in sensing and processing technology.

A similar concept was more recently reported in 2015: the hospital mobile platform [4]. Additional power management features were included, such as regenerative braking and autonomous changing via a docking bay. To provide the manoeuvrability needed to avoid collisions in a hospital setting several drive systems were considered. Omni-wheels were rejected due to noise concerns raised by the hospital staff, and a differential drive with four powered wheels was chosen. Since the platform was required to move packages between defined stations, a laser range finder was used to map and localize the platform within its environment. As with the Helpmate, items had to be manually loaded and unloaded. The authors noted that their system could also be appropriate for use in other sectors such as mail delivery and grocery shopping.

To this date, we are unaware of any logistics robots that have been trialled transporting items in a hospital setting without requiring human contact for loading or unloading. However, this capability has already been implemented in other sectors.

//Need's review of logistics robot that picks up things

4 Design Process/Implementation

From the start of the project many ideas/mechanisms of the Traybot have evolved or changed completely over time. In order to achieve the functionalities of the Traybot specific goals had to be met. These goals include; creating a mechanism which allow the robot to move vertically in order to reach to different table heights, create a tray mechanism which retrieves as well as dispenses trays, create a wheelbase which can cope with a smooth floor surface but will also allow the robot to be as agile as possible and finally to create a simple air filtration system.

The design process of each component would evolve based on feedback given through the preliminary and critical design review (PDR/CDR). Each component would also be improved based on research, as well as alternative methods used in previous applications.

4.1 Vertical mechanism

In order to raise the main body of the robot which would then allow access to a variety of table heights a mechanism with precision is needed. The initial idea was a scissor lift mechanism seen on many forklifts, it is a simply idea which is compact, robust and reliable. This initial idea was soon changed due to a centre of mass issue. If the robot were to be extended to its maximum height then the centre of mass will shift causing the robot to become unstable and could cause it to possibly tip over. This is highly undesirable and can be a safety issue to patients and hospital staff. After evaluation of the scissor lift method we decided to change to a rack and pinion linear actuator, this will give the torque required to lift the Traybots main body which houses the trays as well as the air filter. Positioning one in each corner will remove the previous issue which the scissor lift mechanism had as the centre of mass will only shift vertically by a slight amount. Other methods such as lead/ball screws have also been researched but were not chosen due to the lack of rigidity compared to a rack and pinion. A lead/ball screw option also create a screw whip issue, this is were vibrations occur due to high speeds over long axis. This causes a inaccuracy, which for precision work is undesirable. Other reasons for using a rack and pinion method are because of higher reliability in harsher environments and extremely efficient transfer of power compared to lead/ball screw method.

/// add pictures of scissor lift mech and linear actuators

4.2 Tray mechanism

The tray mechanism has a few different part which have been developed and added over time. The first mechanism needed is one in which extends the tray, the second is the tray mechanism which allows efficient delivery and collection of trays. The first concept was to create a belt drive that spans the width of the tray and a forklift tray mechanism which moulds to the shape of a square tray. This was a good first concept but had a few issues which needed to be improved in order to make is more efficient. The first issue was the yaw orientation of the tray itself. If the tray is sitting at an awkward angle when being collected then this creates a meshing problem. To over come this a more symmetrical tray was created, this was the shape of a disk which had a small flat lip which could be used to support the try when it is being collected. The belt drive was also replaced as when fully extended the weight which sits a the furthest point from the robot could cause a jamming issue. This was replaced with a rack and pinion method as is rigid enough to cope with heavy trays when fully extended and is incredibly precise. This rack and pinion would sit on rails which guides the tray mechanism in and out of the robots main body. So when the tray mechanism is extended the negative mould would scoop up the tray and therefore the tray would be retrieved. The next problem was a reliability issue, if the tray were to be overloaded at the far end then it would tip and fall out of the tray mechanism. This called for an adaption of the tray shape and the mechanism itself. At this point another problem was also spotted, the rack and pinion was a great method to extend the mechanism however the rails which would guide the tray mechanism would limit the reach to just outside the robots main body.

These problems were overcome with a bit of ingenuity. Firstly the tray mechanism, an embedded rim was placed on the tray which allowed it to be hooked onto when sitting inside the tray mechanism. When the tray is seated correctly a servo motor rotates a small horn which locks the tray into place. A curved rail has also been added which extends around the lip of the tray to give it extra support, for scenarios where the trays load sits outside of the centre point. As for the extension and recall of the tray mechanism, this was changed to a telescopic design and the initial idea of using a belt drive was reused. A linear guide bearing rail is used on each side of the tray mechanism and is what connects the tray mechanism to the main robot body. These highly precise and rigid rails use linear bearings which are designed to utilise the motion of rolling elements which are perfect for high load cases. The block on these linear rails then attach to a aluminium extrude which guides the carriage plate which is connected to the tray mechanism. The linear rails and carriage plate are moved forwards and backwards via individual belt drives each powered by a stepper motors.

/// add pictures of the tray design at different stages

4.3 Wheelbase

4.3.1 Initial considerations

The robots mobile base needs to satisfy many requirements. It must fit within a footprint of around 0.5m squared, to permitting navigation though narrow corridors. It must be highly manoeuvrable, as the wheelbase is used to align the tray mechanism. To keep the overall centre of mass low, the wheelbase must be of minimal height, and house heavier components such as the battery.

To provide maximum agility, only holonomic drivetrains were initially considered. A powered castor vehicle (PCV) [5] drive was originally intended, but rejected due to the complexity of additional steering motors and concerns about stability when specifying a new vector of motion [5]. The use of an omni-wheel drive was also explored. However, this approach forbid the use of inflatable tyres, losing advantages they provide, such as better grip and an inherent suspension. These factors, in addition to the previously discussed noise concerns, prompted us to reevaluate whether a fully holonomic drivetrain was essential. We concluded that a simple differential drive could adequately balance our various requirements. Although lateral movement is denied, zero radius turns and the use of conventional tyres is possible. Another benefit is that this drivetrain is already commonly accepted within hospitals for electric wheelchairs. Subsequent design of the mobile base used these as a starting point, with two powered front wheels and two idling castor wheels at the rear.

The computer aided design (CAD) package Solidworks 2016 was utilized for modelling of the mobile base. Figure 1 shows an early design, 30x30mm RS-Pro aluminium extrusion provides an easily assembled rigid framework. Toothed belts couple DC motors to the driven wheels, allowing for quiet running and the possibility of regenerative braking. Custom components, such as mountings and pulleys are designed for manufacture by fused deposition modelling (FDM) 3D printing.

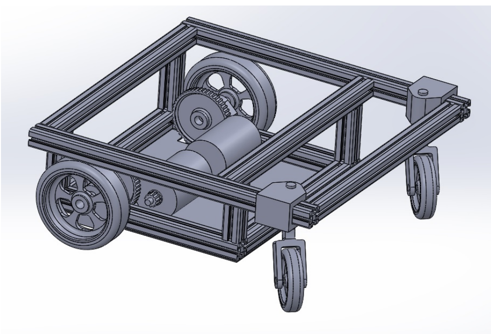

Figure 1: Early mobile base design

A safety issue become apparent: the back-drivable drivetrain presents a risk of uncontrolled motion in the event of power failure.

4.3.2 Final design

The final design is shown in figure 2, and uses dimensionally accurate purchasable components, which are specified in the appendix. To solve the back-driving safety issue, the use of a worm reduction was considered instead of a belt drive, but the addition of a dedicated fail-safe braking system was preferred. This gives the advantage of allowing back-driving during normal operation. Highlighted in blue, the fail-safe brake acts directly on the tyres, so that the base can still be bought to a stop in the event of a belt failure or a wheel becoming decoupled from its pulley.

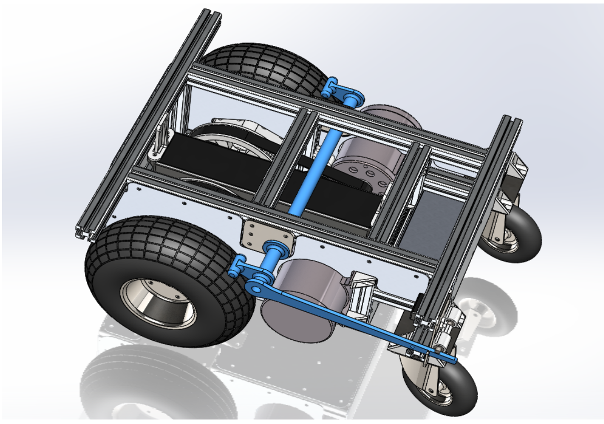

Figure 2: Final mobile base design

Braking force is provided by a powerful tensioned spring hooked on the upper cabinet, raising the pivoting arm. The pivoting arm is secured by a sprung sliding pin, held in place by a small servo, which requires continuous power to prevent retraction of the pin. The system is reset manually by pressing down on the pivoting arm.

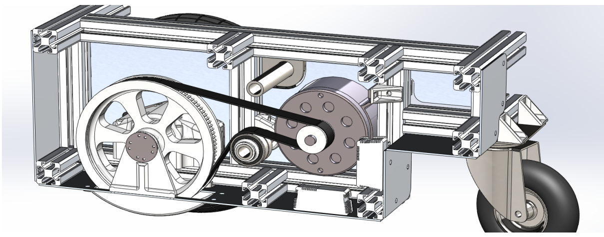

Figure 3: Cross section

As shown in figure 3 belt tension is applied by vertically adjusting a bar which spans the width of the frame. Quadrature encoders give 1200 pulses per revolution of each driven wheel shaft, allowing motion control to within 0.7mm. At peak motor power, the 1:5 belt reductions give 13.9N/m torque at 550rpm for each wheel. This translates to a robot velocity of 7.48m/s, and acceleration of 2.009m/s^2 on level ground, using an estimated total Traybot weight of 106.4kg. As DC motor stall torque is usually greater than peak power torque, the capability for greater acceleration is expected at lower speeds.

4.4 Air filtration system

/// continue here

/// two propeller like fans and small UVC lights. /// changed to v6 circular air filter with two simple cooling fans, then a uvc long light bulb through filter.

4.5 Control and sensing

///neo slam with other sensor /// or teleop?? Rasp-

berry pi 4? run nav stack? act as server wifi multiple user control? distributed?

In this work, our efforts have mainly focused on mechanical design considerations. However, the Traybot is intended to navigate and complete tasks autonomously, so it must be able to perceive its environment. This will be mainly provided by an RGB-D camera. However, we intend to include a 2D lidar, ultrasound, and bumper switches as redundant sensors to permit safe operation under poor sensing conditions. Integration of sensor data with high level software such as simultaneous localization and mapping (SLAM), path planning, and visual servoing will depend on the Robot Operating System (ROS) [7]. Although SLAM incurs a significant computational burden, it can still be made to work well on a Raspberry Pi 2 Model B[6]. More recent models include WiFi and Bluetooth connectivity, in addition to faster processing [8]. For these reasons, we propose the use of an onboard Raspberry Pi 4 for autonomous operation. This may also act as a TCP/IP server, potential allowing remote control and monitoring from several desktop or mobile devices. It's computational burden may also be reduced by adding peripheral microcontrollers for basic tasks such as stepper motor control.

5 Experiments(Methods, Results, and discussion for each)

5.1 Simulation

To verify the practicality of design choices, the physics-based robot simulator CoppeliaSim was used at various stages throughout the project. It was anticipated that reliably securing trays from surfaces would present the greatest risk of project failure. Therefore early trials did not include visual representations of the Traybot, using only basic kinematics and primitive objects to test tray-robot interactions.

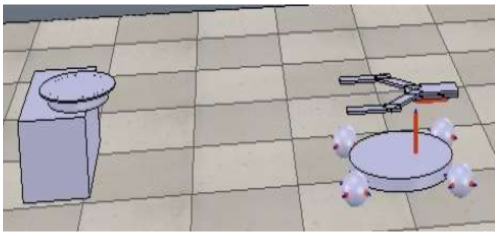

Figure 4: Early simulation

As shown in figure 4, a holonomic drive is used, which gave easy adjustment of the Traybots pose under manual key control. As intended, the use of a circular tray facilitated picking by allowing potential approaches from numerous directions. However, it became obvious that a mechanism was required to lock the trays in place to prevent them from slipping or tilting.

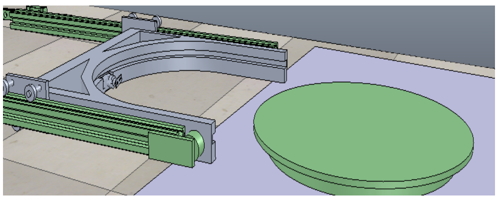

Figure 5: Securing trays

As shown in figure 5, a grasping mechanism was designed using a slot to prevent trays from tilting, with the addition of a clamp driven by a small servo to lock them in place. However, this interface required high accuracy to properly align, and trays were more often pushed away from the Traybot than secured correctly.

The mobile base was updated to use a differential drive, which gave adequate adjustment under manual control, but required more forethought for in obtaining poses since lateral motion is no longer possible. The grasping mechanism was modified to allow more reliable capturing of trays, especially with poor alignment. A servo actuated rotating hook was found to work well, which serves the dual purposes of sliding the tray into place, and then securing it in position. Figure 6 shows the successful capture of a tray.

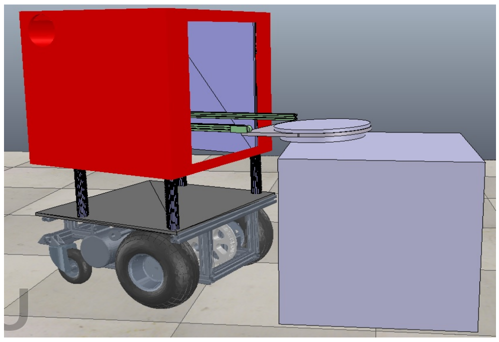

Figure 6: Hook mechanism

It is worth noting that, as recommended by the creators of CoppeliaSim, not all visual aspects were dynamically simulated, and were instead approximated by primitive shapes in a hidden dynamic model. Figure 7 shows this model, in which only components that interface with the tray are not approximated.

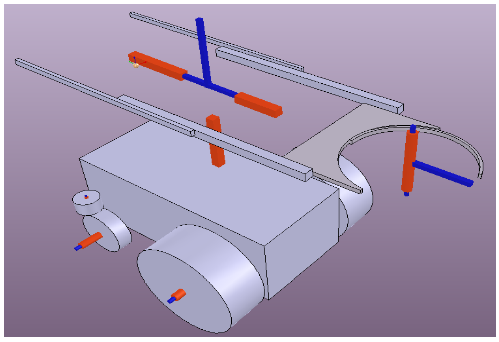

Figure 7: Dynamic model

6 Evaluation-FEA report

// we don't want it to work too well, if someone is sat on a tray it should break! not stay rigid and topple onto the person. Add point of failure, like a crumple zone/breakaway but it needs to be aware of what is underneath it like children.

6.1 Mobile base loadbearing

The 6063 aluminium frame of the mobile base is required to support the 80kg weight of the upper cabinet, and transmit this load to the wheels. Accordingly an FEA study was run, using an evenly distributed 784.5N force applied to the upper surfaces of the frame. Four fixed geometry load points were used in place of the wheels. Figure 8 shows the resulting deformation, exaggerated by a factor of 5000.

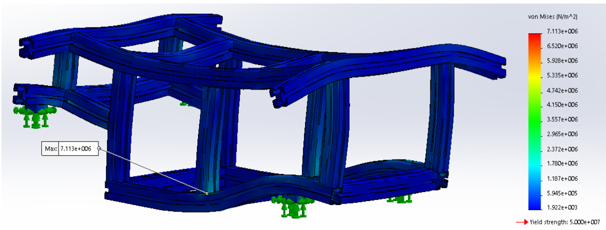

Figure 8: Loadbearing frame

The material yield strength of $5x10^7 N/m^2$ is comfortably greater than the labelled point of maximum stress $7.113x10^6 N/m^2$, giving a minimum safety factor of 7.03. This indicates that the frame does not require reinforcement, and that it may even be possible to use aluminium extrusions with a smaller cross sectional area.

However, these results should be interpreted with caution, as assumptions have been made. In reality the forces produced by the upper cabinet will not always be evenly distributed, especially under acceleration or when a tray collection arm is extended. A more grievous assumption is that the framework is a solid body, in reality it is likely that the brackets used to connect sections of extrusion are much weaker than the extrusion itself.

7 Discussion/Conclusion

8 Appendix

// github and teams link

References

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[7] Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., Wheeler, R. and Ng, A.Y., 2009, May. ROS: an open-source Robot Operating System. In ICRA workshop on open source software (Vol. 3, No. 3.2, p. 5).

[8] https://www.raspberrypi.org/products/raspberry-pi-4-model-b/specifications/

9 Appendix

9.1 Costings

The summed cost of the components listed in tables 1 - 3 is £1,837.63, but numerous minor components such as bolts, wires and connectors have not been accounted for. It is also expected that some listed components will require adapting or reworking. For these reasons, a 50% allowance has been added, bringing the total estimated cost of a functional prototype to £2,756.45.

Table 1: Mobile base cost breakdown

Mobile base components	Quantity	Unit Cost	Cost	Source
RS pro 30x30mm extrusion 1m	6	£21.34	£128.04	Vendor link
Pneumatic wheel	2	£9.11	£18.22	Vendor link
Castor wheel	2	£16.65	£33.30	Vendor link
DC motor	2	£46.99	£93.98	Vendor link
Encoders	2	£18.37	£36.74	Vendor link
Battery	1	£140.22	£140.22	Vendor link
DC motor controller	2	19.99	£39.98	Vendor link
PLA filament 1kg	2	£18.50	£37.00	Vendor link
2mm Aluminium sheet 2 m^2	2	£71.28	£142.56	Vendor link
Custom steel plate estimate	1	£150.00	£150.00	
MG995 servo	1	£7.79	£7.79	Vendor link
Mild steel rod 2m 20mm	1	£29.86	£29.86	Vendor link
Base total			£527.48	

Table 2: Main body cost breakdown

Main body components	Quantity	Unit Cost	Cost	Source
RS pro 30x30 extrusion/metre	10	£21.34	£213.4	Vendor link
2mm Aluminium sheet 2 m^2	3	£71.28	£213.84	Vendor link
Stepper drivers 10pcs	2	£7.56	£15.12	Vendor link
Air filter	1	£20	£20	
Fans	2	£10	£20	
Extrusion 20x20 per m	4	£7.54	£30.16	Vendor link
UVC lamp	1	£24.99	£24.99	Vendor link
MGN12 linear rail 400mm with block	8	£14.75	£118	Vendor link
Stepper motors	16	£10.47	£167.52	Vendor link
belts 5m	1	£4.18	£4.18	Vendor link
Belt tensioner	2	£8.66	£17.32	Vendor link
Carriage plates	8	£8.26	£66.08	Vendor link
Small steppers	4	£8.08	£32.32	Vendor link
Acrylic	1	£10	£10	Vendor link
Linear actuators	4	£49.25	£197	Vendor link
PLA filament kg	2	£18.50	£37.00	Vendor link
Main body total			£1,186.93	

Table 3: Sensing and control cost breakdown

Sensing and control components	Quantity	Unit Cost	Cost	Source
RGBD camera	1	£54	£54.00	Vendor link
Ultrasound sensor	8	£2	£16.00	Vendor link
Raspberry Pi 4	1	£53.22	£53.22	Vendor link
2D lidar	1	£95.80	£95.80	Vendor link
Sensing and control total			£123.22	