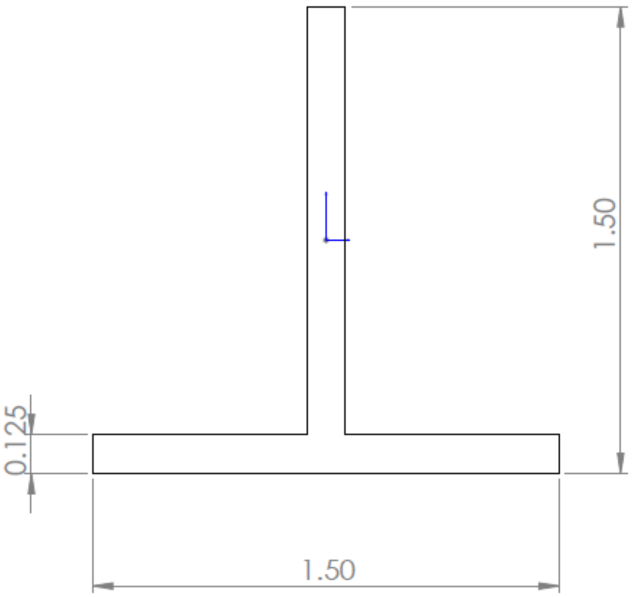
IMPROVED ELEVATED ROBOTIC SYSTEM AND METHOD

Since the advent of robotic systems and devices, the primary application focus has been with enhancing productivity and safety in industrial and agricultural markets such as manufacturing assembly lines (e.g. vehicles, integrated circuits and circuit boards, food preparation), warehouse package/container retrieval and disbursement, and crop harvesting to name a few. Robotic assistance devices have also been deployed in military applications employing various form factors (e.g. tanks, unmanned aerial vehicles) and various levels of artificial intelligence. The popularity of robotic assistance devices in personal and domestic markets comparably have been primarily confined to toys including flying devices (e.g. drones) and cleaning devices (e.g. carpet or pool cleaners). Consequently, these devices typically occupy space in the open air or on the ground. While floor-based mobile robots (e.g. telepresence robots) may have great potential for automating processes and assisting people (i.e. the disabled and infirmed or home/industrial security), their need to navigate around objects (people, furniture, stairs, pets..) makes them expensive while still not alleviating the potential for a sense of obtrusiveness on the part of the users.   Elevated robotics systems exist with varying mechanical designs and control mechanisms to traversal along an elevated track. Accordingly, it would be advantageous to provide an elevated robotic system which provides smooth and efficient traversal along an elevated track.

Elevated Robotic Module Chassis Mechanical Design

In an exemplary embodiment, an elevated robotic module traverses along a T-extrusion track as shown in the following figure.



In an exemplary embodiment, the rigidity of the mounting solution of the base carriage to the track improves stability and efficient traversal along the track.

Previous iterations of the carriage utilized a combination of grip wheels (rubber tread) or non-compliant 3D-Printed tread wheels (High-Temp PLA or PETG) that were either vertically oriented making significant contact with the top surface of the upside-down T-extrusion or horizontally oriented making contact with the thin side-face of the extrusion. Out of these iterations, the designs that seemed to operate best were the vertically oriented wheels, providing consistent contact even during motion.

To secure the carriage to the track, some of the vertical-wheel iterations would have lips on the treads which would hang over the edge and lock the carriage laterally. In the horizontally oriented wheels, the carriage was already laterally locked by nature of the wheel contact to the track, and lips were added on both ends of the treads to lock the carriage in the vertical orientation. Neither of these solutions proved particularly elegant; the friction component from the lip would increase if the lip faces were pressured onto the surface. This meant that tight and fully-secure contact with lip-wheel designs was inherently not feasible; there would always exist a bit of slop between the lip faces and the extrusion faces, resulting in a carriage that could be shifted around while the track remained static.

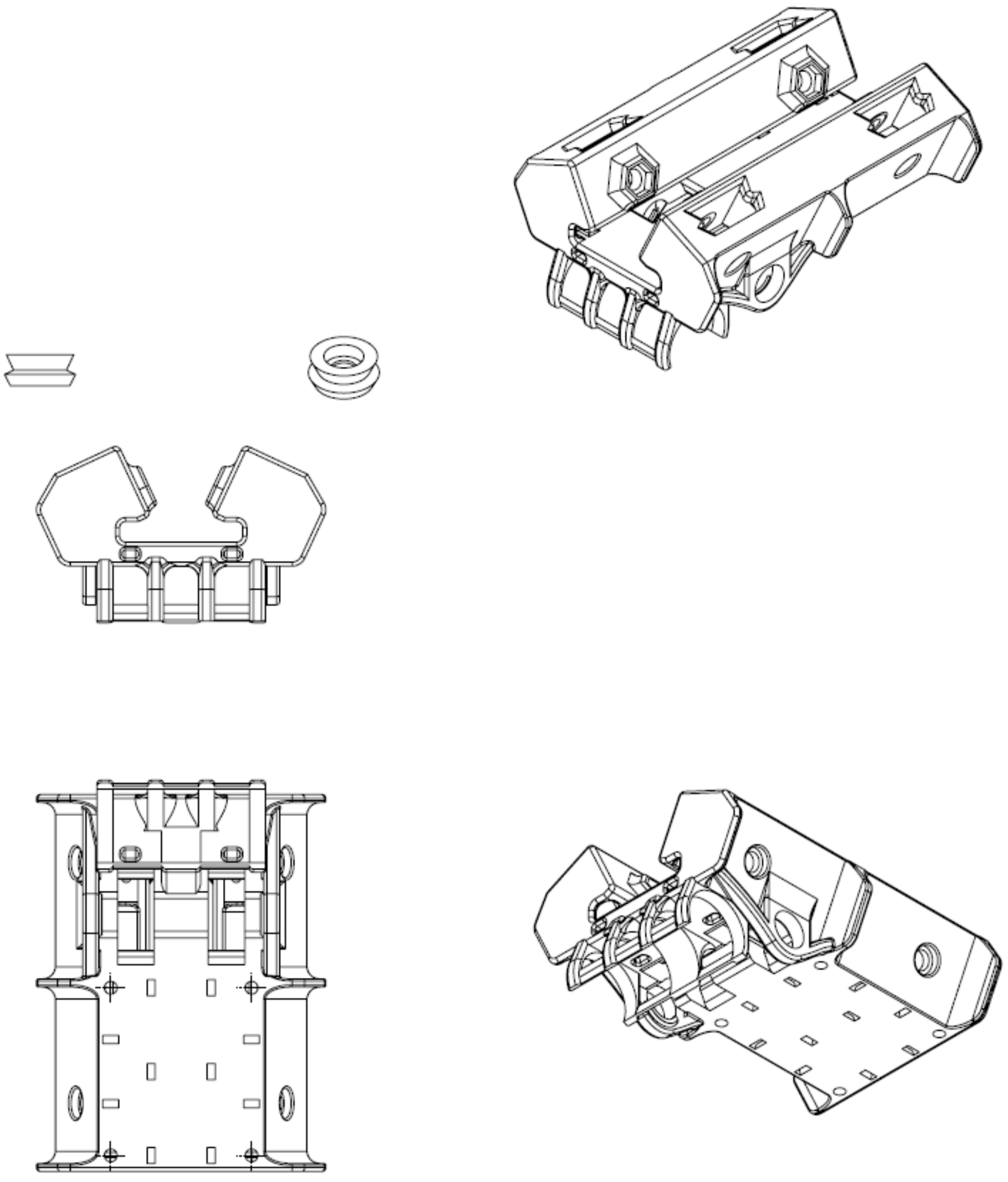
In an exemplary embodiment, the friction issue is bypassed completely and instead, significant contact with the top corner edges of the track is created with angled groove wheels.

Instead of having either a vertical or horizontal surface rubbing on the track as the carriage traverses, by angling the wheels and creating grooved wheels, two wheels are effectively created, one with rolling motion on the top surface, and another also with rolling motion on the side surface, with neither producing excessive kinetic friction. The groove wheel design allows both tread surfaces to “peel away” from contact with the track faces, creating a thinner contact patch than lipped designs would allow. The grip wheels that drove the carriage from the underside were also situated as close as possible to the 3D-Printed groove wheels. This would mitigate any bowing and deflection of the groove wheels while also better securing the contact from both wheels. One option for robust v-groove wheel mounting was 45 degree metal v-groove bearings.

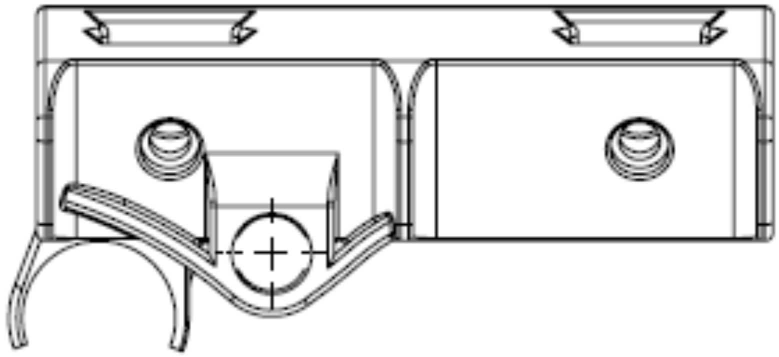
However, a 45 degree angle may be too shallow of an angle, and providing a steeper angle might allow for larger loads on the base carriage without excessive torsional stress on the mounted shoulder bolts and the rest of the carriage body. In an exemplary embodiment, a 65 degree angle from horizontal may be used, so as to provide improved mounting support in the vertical orientation and still allow for a thin contact patch on the side wheel contacts.

In an exemplary embodiment a compression of 0.03 inches provided to the grip wheels on the underside provides a secure contact between all wheels and the track. Care must be taken to ensure the carriage isn’t too tight on the track which would prohibit the motor from overcoming friction such that it can begin to turn the wheels.

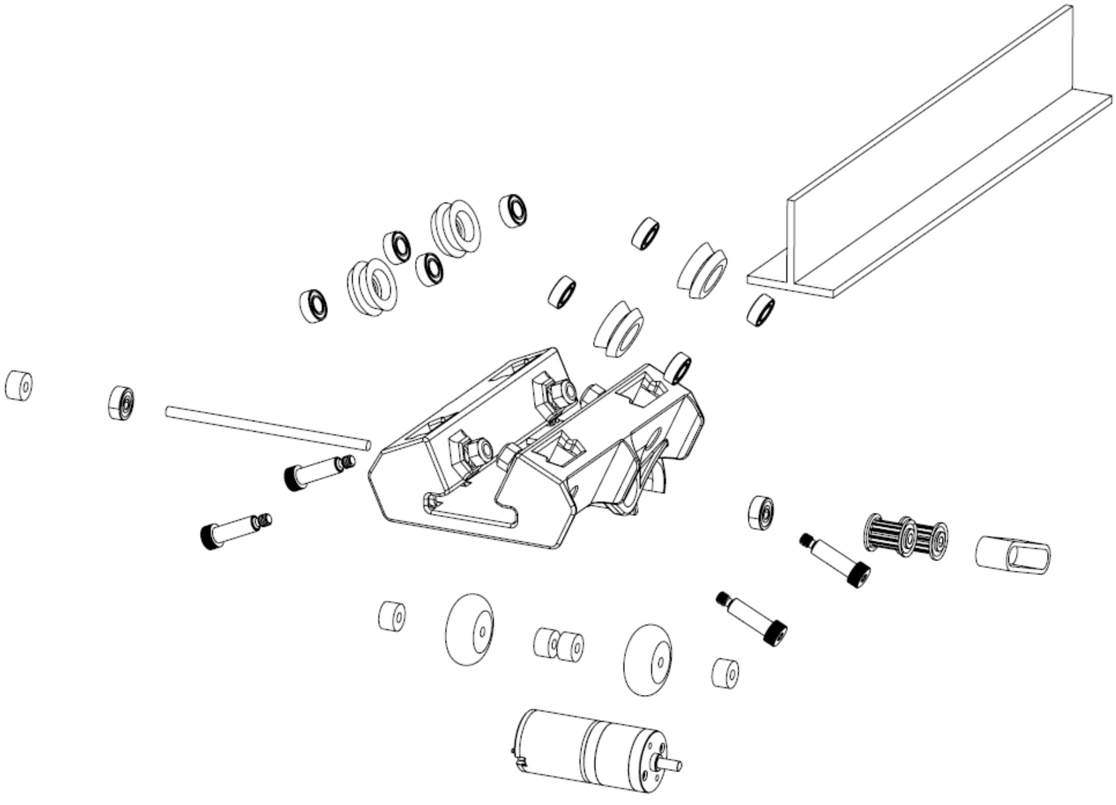
Small “wings” or tabs may be added to the side face of the carriage to increase the effective thickness of the base, alleviating some of the torsional stress from the load of an additional module. Increased effective thickness works for the same reason that tape measures use curved profiles to allow them to remain extended at longer distances.



Base + 3DP Wheel



Base Side View



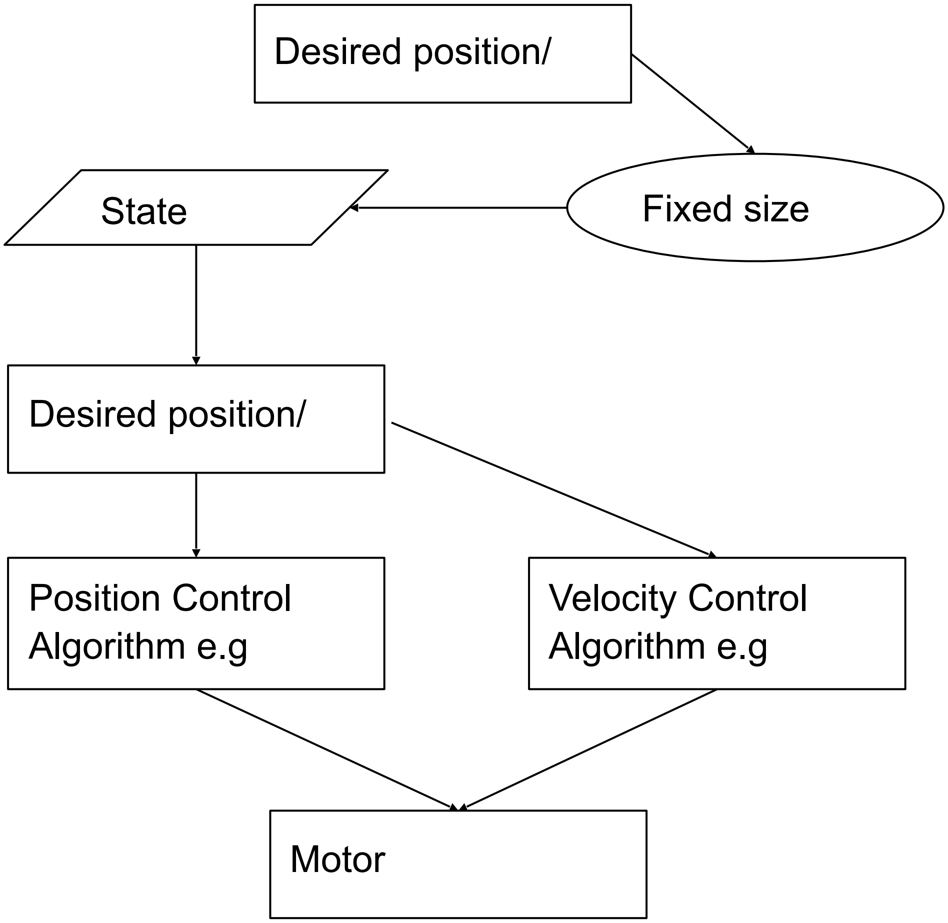
Main Carriage Assembly Exploded View

In an exemplary embodiment, shoulder bolts may be used to retain a 3d printed wheel+bearing combo rather than regular bolts due to its smooth surface, allowing for better fit of the bearing inside races compared to bolts with thread all along its body.

Elevated Robotic Module System Control

An exemplary control mechanism is comprised of a SISO (single input single output) system--input is the voltage applied to the motor and the output is the linear position of the module on the track. This highly controlled and model-able environment allows the elevated robotics module to act as a very potent platform for a wide application of different technologies. However, the versatility of the elevated robotics module platform necessitates proper systems design in order to allow it to be easily applied from one application to another.

An exemplary system control and pipeline of the elevated robotics control system is shown as follows.


Desired position/
State
Fixed size
Desired position/
Position Control Algorithm e.g
Velocity Control Algorithm e.g
Motor

As aforementioned, keeping the low-level control of the elevated robotics module consistent is extremely important because it allows full utilization of the ERAD platform's versatility across multiple platforms. A summary of the pipeline follows:

The state vector that fully defines the elevated robotics module is its position (in meters) and velocity (in m/s). In an exemplary embodiment the drive signal would then be the desired position/velocity, meaning that the low-level elevated robotics module control would have to handle getting the module to those desired setpoints with only the drive signal as input. In this way, no matter the application that the elevated robotics module is deployed in, the high-level code only ever has to tell the module the desired position/velocity setpoint, and the position/velocity control algorithms will take care of reaching the setpoints.

However, considering the complexity of the more advanced applications an improved buffer system to handle the latency between the sent setpoints and the module actually reaching those setpoints is desired, for example, as a hand-gesture-obeying robot. In the example, the length of a hand swipe would determine how long the module would go in the direction of the hand swipe. For example, long swipe to the right would indicate a 30 cm movement in the right direction, and a short swipe would indicate a 10 cm movement. A computer vision system could read multiple hand swipes before the elevated robotics module could actually reach the desired positions based on the last setpoints. Instead of overriding the past commands, a sequential order of the hand swipes is retained.

Using a simple list or dynamic buffer is not memory efficient when resized or when their elements are rearranged/manipulated. Instead a Fixed-Size FIFO (first in first out) ring buffer is used. The explicit advantages of this approach are many:
First-in First-out behavior gives a temporal priority to the newer commands. In the case that all of the slots in the buffer are used, old commands are popped out of the buffer before newer commands
The fixed size of the ring buffer allows better management processing constraints (namely memory), which is especially important when running an object detection pipeline for hand tracking and gesture recognition on the same platform. The size of the FIFO ring buffer can be reduced as a compromise on how many back-logged commands we can run sequentially, for the sake of the object detection pipeline. This allows the ability to compromise on ignoring entire commands instead of the individual resolution of each command, which is very important, because missing new hand gestures or receiving sporadic hand detections due to insufficient system capabilities limits the performance of the system. In this case resizing the ring buffer is not needed, making it very memory efficient.
The existence of a ring buffer allows multiple processes to cleanly control the elevated robotics module without interference between them. For instance, the hand gesture recognition pipeline can add a drive signal to the ring buffer, and then some other process (like a direct drive command) can also add to the ring buffer, and they will get executed sequentially, retaining the drive signal sent by both processes.

It should be noted that the StateTracker Node in the diagram is a purely heuristic layer that allows setting a priority to some processes in terms of executing a drive signal. In a deployment scenario, it is likely that the StateTracker layer gets shifted up to a higher abstraction level before the drive signal gets added to the FIFO ring buffer, but it is convenient to have an abstracted layer for final heuristic logic in between the ring buffer and the actual execution of the drive signals. This layer is also responsible for determining when the position of the elevated robotics module has plateaued/converged on the setpoint, which is when this layer triggers the next drive signal in the ring buffer. This is unique from other control law implementations in that the system doesn’t try to reach the setpoint indefinitely. Rather, a tolerance for the position delta is defined from the setpoint and whenever inside that tolerance, the position is assumed to have plateaued. In an exemplary embodiment the elevated robotics module position is marked as plateaued within tolerance for more than 5 iterations of the main While loop, then the next drive signal in the ring buffer is executed.

The Position/Velocity Control algorithms are the common Feedforward + PID Feedback approach to controlling a motor’s angular position and angular velocity. The control algorithm effectively drives the elevated robotics module towards the desired drive signal position at the designated velocity setpoint. The velocity setpoint is reached by effectively adding a default negative term (proportional to the difference between the desired velocity and the current velocity) to the common FF+PID control law for position control.