Chirobot

Footprint Optimization of a Holonomic Drive Base for a Supine Rehabilitation Platform

Rany Fouad | Creative Machines Lab, Columbia University | Advisor: Prof. Hod Lipson

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1 Project Overview

Chirobot is a low-profile, three-wheeled holonomic robot designed to drive underneath a patient lying in a supine position and deliver controlled positional movement as part of a physical therapy protocol. The platform must satisfy three simultaneous constraints: a chassis height low enough to slide under a patient, full omnidirectional mobility (translation in any horizontal direction combined with simultaneous rotation), and a structural capacity for full-body patient loads. A camera-based localization system is planned for a future phase.

This report covers the mechanical design and prototyping work carried out during spring 2026. The central contribution is the evolution of the drive base across two major iterations — from an initial radial layout to an optimized tangential layout — which reduces the chassis diameter by 29 % while preserving the complete drivetrain. The electrical architecture is described as a design projection; wiring is partially assembled but not yet fully commissioned.

2 Mechanical Architecture

2.1 Holonomic Drive Strategy

The robot uses three Mecanum wheels arranged at 120° around the chassis (Fig. 1). Mecanum wheels carry passive rollers mounted at 45° to the wheel axis; by independently controlling the speed and direction of each wheel, the platform can generate arbitrary combinations of longitudinal, lateral, and rotational velocity without reorienting. This is the standard holonomic drive constraint: the three wheel velocities span the full chassis velocity space (v_x, v_y, ω_z).

A common misconception in three-wheeled Mecanum layouts is that the wheel axes must point radially toward the chassis center. In fact, the only kinematic constraint is that the three wheel-plane orientations produce a full-rank 3×3 inverse-kinematic matrix H. Each row of H depends on the position and orientation of the corresponding wheel in the chassis frame; as long as the three rows remain linearly independent, the platform retains full holonomic mobility regardless of wheel orientation. This observation is the geometric key that enables the footprint reduction described in Section 3.

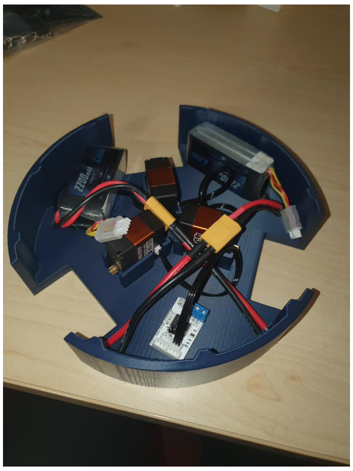


Figure 1: Drivetrain assemblies in the first-iteration chassis. Two 2200 mAh LiPo packs and power electronics fill the central bay.

2.2 Drivetrain: Servo, Transmission, and Wheel

Each of the three drive assemblies consists of the following serial chain of components:

1. **Hiwonder HTD-45H bus servo.** Rated at 45 kg·cm torque at 11.1 V. Body dimensions are 51.1 × 39.8 × 20.1 mm. The servo communicates over a half-duplex serial bus (LewanSoul protocol), allowing all three units to be daisy-chained on a single data line. The output spline is 25-tooth with a 6 mm shaft bore. *Note:* the first prototype was assembled with a 5 mm-to-4 mm coupler due to an early mismeasurement of the spline; the correct part is 6 mm-to-4 mm.
2. **Shaft coupling adapter (6 mm → 4 mm).** A 26 mm brass coupler connects the 6 mm servo output to a 4 mm stainless shaft. Two M3 set screws clamp each end independently, preventing backlash under load reversal.
3. **Shaft (4 mm diameter).** A hardened stainless rod transmits torque from the coupler to the wheel hub. Its length is set so that the wheel sits flush with the outer edge of the chassis, with 2 mm of axial clearance to avoid contact with the chassis wall.
4. **Pillow-block bearing.** A KP08 pillow block (8 mm bore, sleeved to 4 mm) mounted on the chassis floor provides a second radial support point for the shaft, beyond the servo's own output bearing. Without it, the full bending moment generated by wheel-to-ground reaction forces would be reacted entirely through the servo's internal gearbox bearing, which is not rated for sustained radial loading at patient-body-weight

magnitudes.

5. **Hex wheel adapter (6 mm hex, 4 mm bore).** A 26 mm coupler converts the 4 mm round shaft to the 6 mm hexagonal hub required by the Mecanum wheel. It protrudes 2 mm beyond the chassis wall, staying within the axial clearance margin.
6. **Mecanum wheel (60 mm diameter, 30.6 mm wide).** Nine rubber rollers at 45° provide the holonomic contact patch. The wheel is rated at 10 kg load bearing, giving a theoretical platform maximum of 30 kg across three wheels; the actual safe patient load will be determined by structural testing of the chassis.

The total radial chain length from the servo output face to the inner edge of the wheel is approximately 63 mm (26 mm adapter + shaft section + 15 mm pillow-block half-width + 2 mm hex adapter overhang + 2 mm clearance margin). The wheel itself contributes an additional 30 mm of radius beyond the chassis rim.

3 Chassis Design Iteration

3.1 Iteration 0 — Organic Prototype

The first physical prototype (Fig. 2) was printed from a freeform organic geometry intended to explore the spatial relationships between servos, batteries, and wheels without committing to a clean parametric model. The geometry was not suitable for re-parametrization, but it validated the drivetrain stack and revealed the key dimensional constraints fed into subsequent iterations: the 63 mm radial chain length, the 2 mm axial clearance requirement, and the vertical height budget imposed by the 60 mm wheel diameter.

Figure 2: Iteration 0: organic FDM prototype, used to validate the servo–bearing–wheel stack geometry.

3.2 Iteration 1 — Radial Layout, ∅ 226 mm

The first clean chassis (Fig. 3) placed each servo with its long axis (51.1 mm) oriented *radially*, pointing toward the chassis center. In this configuration, the 51.1 mm servo length and the 63 mm transmission chain are collinear and both consume radial space. The minimum chassis radius is therefore:

$$R_{\min} = 51.1 + 63 = 114.1 \text{ mm} \quad\Longrightarrow\quad \varnothing_{\min} \approx 228 \text{ mm}.$$

The built chassis measures ∅ 226 mm, consistent with this estimate. A ∅ 72 mm central free zone remains for electronics once the servos are placed.

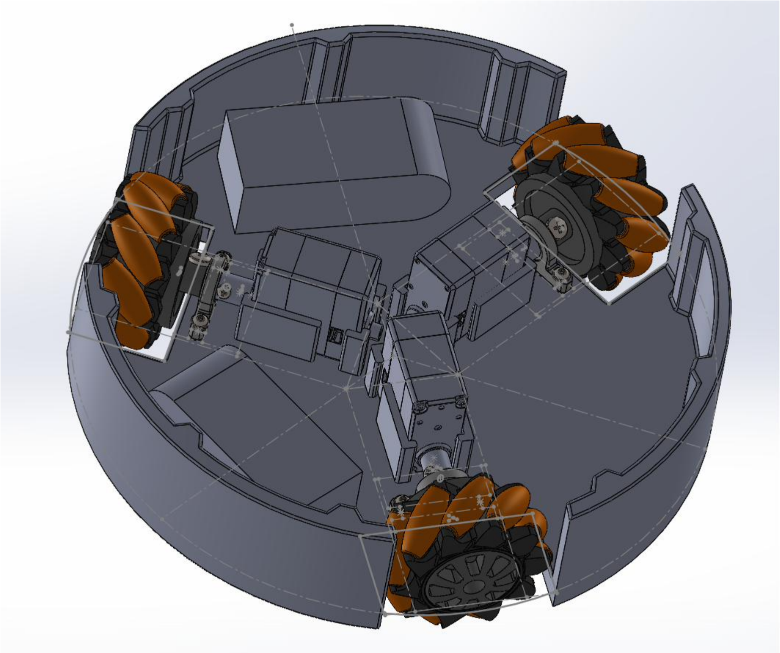


Figure 3: Iteration 1, SolidWorks model with side walls. Servos are oriented radially; the full servo length lies along the radius and drives the ∅ 226 mm chassis diameter.

3.3 Iteration 2 — Tangential Layout, ∅ 160 mm

Design rationale

In the radial layout, the servo's 51.1 mm long dimension lies along the radius and is the dominant contributor to chassis size. Rotating each servo by 90° so that its long axis becomes *tangential* exchanges this with the short dimension (39.8 mm): the radial budget now contains only the servo width and the transmission chain. The updated minimum radius is:

$$R_{\text{min}} = 39.8 + 63 = 102.8\,\text{mm} \quad \Longrightarrow \quad \varnothing_{\text{min}} \approx 133\,\text{mm}.$$

As established in Section 2.1, this reorientation does not compromise holonomic mobility: the wheel-plane orientation changes from tangential (Iteration 1) to approximately radial (Iteration 2), but the inverse-kinematic matrix H remains full-rank.

Parametric placement study

Two free parameters control the position of each servo within the 120°-symmetric pattern (Fig. 4):

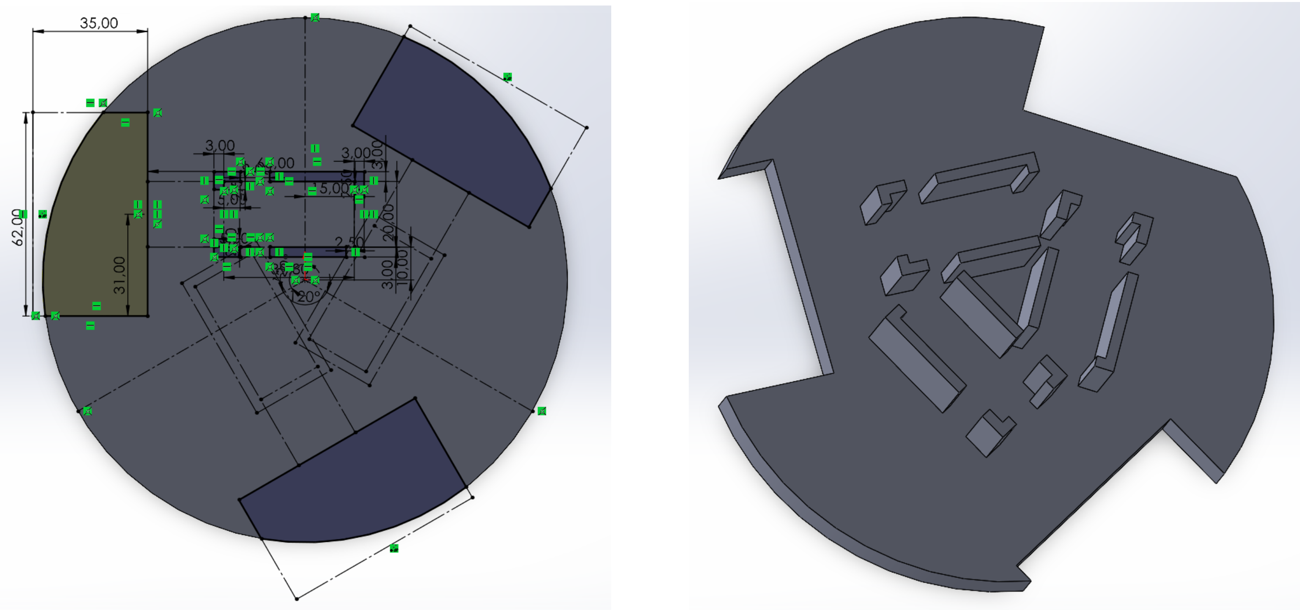
- d_{in}: distance from the servo's inner radial face to the chassis center.
- d_{off}: tangential offset of the servo body from the nominal radial axis of each drive unit.

A numerical sweep over (d_{in}, d_{off}) was run with a no-collision constraint between the three servo footprints, verified using the Separating Axis Theorem. For each valid configuration, two quantities were computed: the chassis radius (furthest servo corner from center) and the diameter of the largest circle fitting the central free zone. These trade off against each other: shrinking the chassis necessarily reduces the central free zone.

The chosen parameters $d_{\text{in}} = 15\,\text{mm}$ and $d_{\text{off}} = 23\,\text{mm}$ (including a 3 mm offset for the servo mounting rivets) give:

- Chassis diameter: ∅ 160 mm **(–29% vs. Iteration 1)**.
- Inscribed central free zone: ∅ 30 mm.

Although the 30 mm central circle is narrow, the three inter-servo sectors between adjacent servo bodies provide additional usable area for flat electronics and cabling. If the wheels are allowed to protrude past the chassis rim by half their diameter — a geometrically valid configuration for Mecanum wheels — the chassis can be further reduced to ∅ 134 mm (–41 %).



(a) Top-view sketch with dimensions. Servo positions: $d_{\text{in}} = 15\,\text{mm}$, $d_{\text{off}} = 23\,\text{mm}$.

(b) SolidWorks 3D render with servo mounting pockets and wheel-well cutouts.

Figure 4: Iteration 2: tangential layout, ∅ 160 mm chassis.

4 Electrical Architecture (Projected)

The electrical system has been partially assembled. What follows is the intended final architecture; full wiring and commissioning are planned for the next phase.

4.1 Power Distribution

Two 3S LiPo batteries (11.1 V nominal, 2200 mAh each, XT60 connectors) will be connected in parallel via an XT60 Y-splitter. Parallel connection keeps the bus voltage at 11.1 V while doubling capacity to 4400 mAh. The combined output passes through a KCD1 rocker switch (10 A rated) acting as the system kill switch.

Power is then split into two independent rails:

- **Servo rail (11.1 V):** Connected directly to the screw terminals of the LewanSoul BusLinker TTL/USB board, which injects the battery voltage into the three-wire servo bus. This rail powers all three HTD-45H servos through their daisy-chain cable. Peak demand can reach approximately 9 A if all three servos stall simultaneously.

- **Logic rail (5 V):** An LM2596 adjustable buck converter steps 11.1 V down to a regulated 5.0 V for the Raspberry Pi Zero 2W. Output voltage is set by trimming the onboard potentiometer against a multimeter reference before installation. The Pi draws 150–200 mA under load, well within the LM2596's 3 A rating.

Isolating the logic rail from the servo rail is essential for stability. Servo commutation produces large current transients that cause voltage drops on a shared supply, which can trigger Pi brownouts and uncontrolled reboots. The two-rail architecture eliminates this coupling, at the cost of a slightly more complex wiring harness.

4.2 Control Architecture

The Raspberry Pi Zero 2W serves as the sole onboard computer. It connects to the BusLinker board via USB (using a micro-USB OTG adapter), which presents as a virtual serial port. All three HTD-45H servos share the same serial bus and are addressed by individual IDs. The Pi sends position or speed commands over this bus using the LewanSoul half-duplex protocol.

The planned control loop is:

1. Receive a target chassis velocity (v_x, v_y, ω_z) from a higher-level planner or operator input.
2. Apply the 3-wheel Mecanum inverse-kinematic transform to map chassis velocity into individual wheel angular velocities.
3. Send speed commands to each servo over the serial bus.
4. Read back position and load feedback to monitor for stall or overload conditions.

Localization is deferred to a later phase: cameras mounted on the chassis walls will provide visual positioning for closed-loop path following.

5 Summary and Remaining Work

Table 1: Chassis diameter across design iterations.

Iteration	**Servo orientation**	**Chassis ∅**
0 — Organic prototype	Radial	∼230 mm
1 — Clean radial	Radial	226 mm
2 — Tangential	Tangential	160 mm (–29 %)
2b — Wheels half-exposed	Tangential	134 mm (–41 %)

The tangential layout achieves a 29 % reduction in chassis diameter with no changes to the drivetrain. The same servos, couplers, shafts, bearings, and wheels carry over unchanged from Iteration 1; only the chassis geometry was modified.

The current chassis height (∼65 mm including ground clearance) is set by the 60 mm wheel diameter, not by the servo height (20.1 mm on its thin face). Any further reduction in robot height would require either a different drive wheel or a transmission that redirects the servo output axis — both deferred to a future design phase.

Remaining work:

- Replace the 5 mm-to-4 mm shaft couplers with the correct 6 mm-to-4 mm parts on all three drive assemblies.
- Complete the wiring harness, calibrate the buck converter output to 5.0 V, and commission the two-rail power architecture.
- Assign servo IDs via the BusLinker board, implement the 3-wheel Mecanum inverse-kinematic drive loop on the Pi, and validate basic omnidirectional motion on a flat surface.
- Conduct structural load testing to characterize chassis deflection under patient-representative loads.