University of Klagenfurt

Basic Lab: Robot Design

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Final Report

Group B

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1 Task Description (Bozhidar Bozhikov)

The goal behind this project is to design a circular robot (diam. = 30cm) with nominal speed 100mm/s. The robot must also fullfill the following requirements:

a) be able to clear gaps of 6cm,

b) be able to operate in darkness,

c) be able to run for a minimum of 15 minutes,

d) have line-tracking capability,

e) have RC capability,

f) be able to give acoustic feedback (75dB)

g) have maximum weight 800g,

h) fit in a budget of 300€

The design we decided to develop is inspired by real-world screw-propelled vehicles, which are moved with the help of a pair of rotating helix-shaped cylinders made of soft plastic or rubber. The cylinders have a spiral form like the thread of a screw which make contact with the ground. Motion is produced by the inverse of the screw conveyor: one cylinder's helix runs clockwise and the other - counterclockwise. Rotation is done with the activation of only one of the corresponding cylinders. This form of propulsion is used in real life to move through difficult terrain such as ice, mud, snow and water. As such, our robot would ideally operate on carpet (simulating mud and swamp) or on very smooth ground (simulating ice).

2 Specifications (Bozhidar Bozhikov, Vladyslav Uhrik)

2.1 Physical Calculations (Vladyslav Uhrik)

Step 1: Define Requirements Target speed = 0.1 m/s (100 mm/s) Helix pitch (measured or estimated) = 2 cm = 0.02 m Robot mass = 0.8 kg Wheel radius = 6 cm = 0.06 m Surface type = linoleum or carpet friction coefficient μ=0.4

Step 2: Calculate Required RPM We assume 1 full revolution of the helix moves the robot forward by 1 pitch length.

$$\text{Revolutions per second (RPS)} = \frac{\text{Linear speed}}{\text{Helix pitch}} = \frac{0.1}{0.02} = 5\,\text{rev/sec}$$

Helix pitch = the axial distance (i.e., forward movement along the wheel's centerline) that the thread travels in one full 360° rotation around the wheel.

$$\text{RPM} = 5 * 60 = 300 \text{ RPM}$$

Step 3: Calculate Normal Force per Wheel Assume equal weight distribution across two wheels:

$$\begin{aligned} F_N &= \frac{m \cdot g}{2} \\ &= \frac{0.8\,\text{kg} \times 9.81\,\text{m/s}^2}{2} \\ &= 3.924\,\text{N} \end{aligned}$$

Step 4: Calculate Friction Force (Required to Move)

$$\begin{aligned} F_{\text{friction}} &= \mu \cdot F_N \\ &= 0.4 \times 3.924\,\text{N} \\ &= 1.57\,\text{N} \end{aligned}$$

Step 5: Calculate Required Torque per Wheel

$$\begin{aligned} \tau &= F \cdot r \\ &= 1.57\,\text{N} \times 0.06\,\text{m} \\ &= 0.0942\,\text{Nm} \end{aligned}$$

Apply Safety Margin (1.5×)

$$\begin{aligned} \tau_{\text{safe}} &= 0.0942 \times 1.5 \\ &= 0.1413\,\text{N}\,\text{m} \end{aligned}$$

Step 6: Convert RPM to Angular Velocity

$$\begin{aligned} \omega &= \frac{2\pi \times \text{RPM}}{60} \\ &= \frac{2\pi \times 300}{60} \\ &= 31.42\,\text{rad}\,\text{s}^{-1} \end{aligned}$$

Step 7: Calculate Mechanical Power per Motor

$$\begin{aligned} P &= \tau \times \omega \\ &= 0.1413\,\text{N}\,\text{m} \times 31.42\,\text{rad}\,\text{s}^{-1} \\ &= 4.44\,\text{W per motor} \end{aligned}$$

Total Power for 2 Motors

$$\begin{aligned} P_{\text{motors}} &= 2 \times 4.44\,\text{W} \\ &= 8.88\,\text{W} \end{aligned}$$

2.2 Electrical Power Calculations (Vladyslav Uhrik)

Step 8: System Power Budget We calculate the power P of each component using the formula: $P = VI$

Table 1: Component Power Consumption

Component	**V** (V)	**I** (A)	**P** (W)	**Notes**
ATmega32 8P MCU	5.0	0.020	0.10	Powered from 5V rail
nRF24L01 P RF module	3.3	0.012	0.04	Powered from 3.3V rail
VL53L1X ToF sensor	2.8	0.019	0.05	Direct 2.8V rail or on-board LDO
TP4056 charger module	5.0	1.000	5.00	During charging (input)
MT3608 (regulator loss)	12.0	0.010	0.12	Estimated conversion overhead
IIM-42652	3.3	0.007	0.023	Motion tracking
CNY70 IR sensor	5.0	0.018	0.09	IR sensor (emitter + transistor)
Buzzer (passive)	5.0	0.030	0.15	Approx. 75 dB
2x Pololu Stepper Motors	2.8	3.400	9.52	Two motors: $1.7\,\text{A} \times 2$

Total Power = 24.613 W

Step 9: Energy Required for 15 Minutes Convert 15 min to hours:

$$E = 24.613 * 0.25 = 6.15325Wh$$

Step 10: Calculate Battery Capacity at 12V

$$C = \frac{6.15325}{12} = 512.77\,\text{mA h}$$

Add 30% Safety Margin:

$$C_{\text{safe}} = 512.77 \times 1.3 = 666.6\,\text{mA h}$$

- Voltage: 12 V
- Minimum capacity: 670 mA h (rounded up) (we end up using a 1000 mA h battery)

3 Hardware and CAD (Nikita Smolianinov)

The Fusion model discussed in this section can be found in the .stp file. The robot's design follows real-world screw-propelled vehicles such as the ZIL-2906 and other Amphirols. The circular mount of the robot is made from 4mm thick plywood, with the propulsion cylinders attached with a custom 3D-printed mount, which are driven by 2 bipolar stepper motors, chosen for their power and precision. The stepper motors provide 3 degrees of movement.

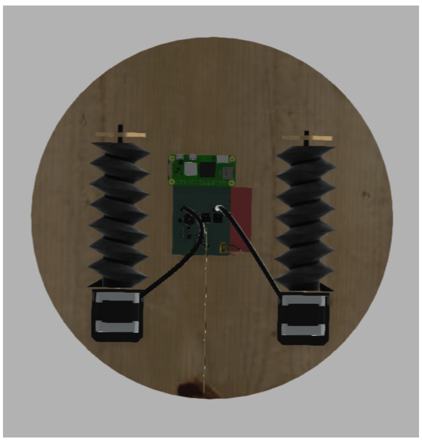

Figure 1: Bottom-down view of the CAD model.

4 PCB (Bozhidar Bozhikov)

The circuits and PCB layout discussed in this section can be found in the PCB folder. We chose a Raspberry Pi 4 Compute Module as our microcontroller for ease of integration and programming since it fit the budget, connected externally via a 40-pin array on

our custom PCB. Connected to the microcontroller are a 6-axis IMU, time-of-flight sensor, two motor drivers for out screw-propulsion helical cylinders, an RF transciever for control, two infra-red reflective optical sensors to ensure line-tracking even in darkness as stated in the requirements and a buzzer. Additionally, since the motors operate at 12V, the microcontroller at 5V, and most of the components at 3.3V, we also included a 5V step-down converter and a 3.3V fixed-output regulator. The exact components and their respective datasheets can be found in the BillOfMaterials folder.
The following circuits were designed by following the Application Examples in their respective datasheets and then connecting them to the microcontroller via GPIO pins. The raspberry's pinout is as follows:

- GPIO08: RF chip select
- GPIO09: RF MISO
- GPIO10: RF MOSI
- GPIO11: RF clock
- GPIO12: IR sensor 1
- GPIO13: IR sensor 2
- GPIO22, GPIO23: pulse input (STEP) and direction control (DIR) respectively for motor 1
- GPIO24, GPIO25: pulse input (STEP) and direction control (DIR) respectively for motor 2
- GPIO26: buzzer
- GPIO27: RF enable

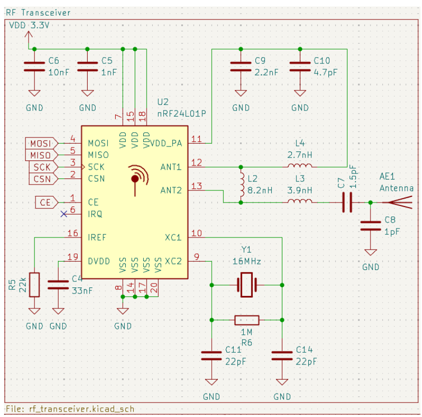

Figure 2: nRF24L01+ single-chip RF transciever, featuring a 16Mhz clock and an antenna.

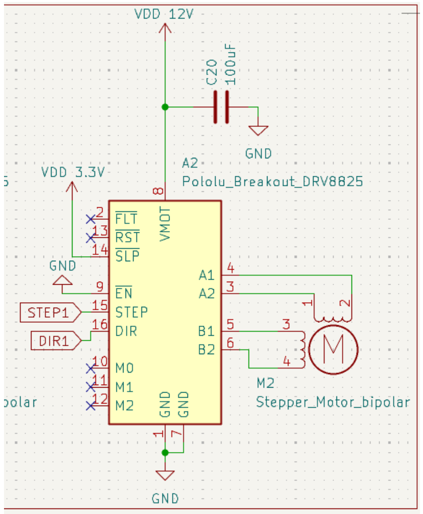

Figure 3: Motor driver sub-circuit.

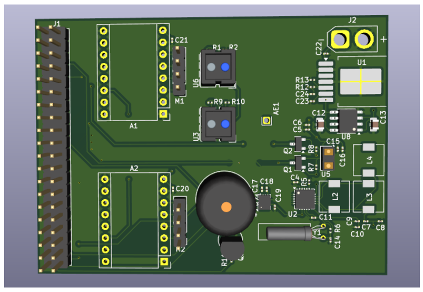

Figure 4: Top-down view of the custom pcb.

5 Discussion (Bozhidar Bozhikov)

The robot discussed in this report follows a real-world practical, albeit unorthodox, design utilizing the screw conveyor mechanism for propulsion on rough carpeted surfaces or smooth ground with 3 degrees of movement.