LEAN Power Efficient Robotic Car Platform

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Contents

1 Introduction

Low-power robotic platforms are of particular interest due to an increasing demand for platforms of small form factor or long duration, which often constrain the power of robots. Miniature and long duration robotics can open up applications in environmental monitoring and robotic exploration. Figure 1 outlines examples of energy to move one meter in various vehicles as well as the energy required for one second of computation on popular embedded computers. The power consumption taken by various components highlights the intricate balance between actuation and computing power required to design effective robotic solutions that both move and compute efficiently.

The fundamental design constraint in the project is that the robot must move at 1 m/s at 1 Watt of power consumption. An example of a previous technology is the race car built by MIT for the Beaver Works Summer Institute robotics program [2], which travels at a maximum speed of 17 m/s, and likely consuming much more than 17 Watts. The goal of the project is to design a wheeled robotic platform which moves 1 m/s at 1 Watt with a control system and communication system to work with the motion capture laboratory in order to conduct experiments on low power motion planning algorithms and hardware.

2 Hardware

2.1 Kinematics

The first step in choosing (or creating) hardware for an application is to model the physics of the motion to understand the specifications required by components. With a mass estimate starting at about 80 grams, we can calculate the forces that a motor will experience on a wheeled robot. We can calculate the maximum tangential force that a wheel will experience on the ground by using the coefficient of static friction (mu_s about 0.51 for polyurethane on concrete and 1 for thermoplastic elastomers). The maximum static friction a wheel will experience before slipping is given by $F_f = \mu_s \cdot N$, where N is the normal force of the object.

$$F_f max = \mu_s \cdot N = 0.51 * 0.08(kg) \cdot 9.8(\frac{m}{s^2}) = 0.39(N)$$

$$\text{Where } \mu_s = 0.51 \text{ for PU}$$

Thus, because $F = ma$, the maximum acceleration driven by the static friction of a wheel rolling without slipping is given by $a = \frac{F}{m} \approx 5\frac{m}{s^2}$. Knowing the tangential force experienced at the edge of the wheel along the ground, we can calculate the torque on the wheel during acceleration to be given by $\tau = F \times r$. With a wheel radius of 0.5 inch (0.0127 meters),

$$\tau = 0.39(N) \cdot 0.0127(m) \approx 0.005(N \cdot m)$$

1 Watt is given by $1\ \frac{N \cdot m}{s} = 1 \frac{J}{s}$. Thus, the power output required to accelerate the load should theoretically be 0.005 Watts.

2.2 Motor Selection

With a wheel radius of 0.0127 meters, our target RPM is about 750RPM to move at $1\ \frac{m}{s}$ The actual physical energy required to move the robot may be low, but sourcing a light weight motor that consumes less than 1 watt at 750RPM while being of small form factor is quite challenging. The motor chosen for the first iteration of this project is the GA12-N20 6V motor. The power consumption data sheet can be seen in Figure 1. The data points of interest relate to the power consumption at 1000 RPM with a 6 Volt source.

	Voltage		No load		At Max. Efficiency			Stall	
Part Number	Range	Rated	Speed	Current	Speed	Current	Torque	Torque	Current
GA12-N20-3V30	1.5-5VDC	3VDC	30RPM	10mA	25RPM	20mA	0.26Kg/cm	2.00Kg/cm	1.00A
GA12-N20-3V50	1.5-5VDC	3VDC	50RPM	10mA	40RPM	20mA	0.20Kg/cm	1.60Kg/cm	1.00A
GA12-N20-3V100	1.5-5VDC	3VDC	100RPM	10mA	80RPM	20mA	0.11Kg/cm	1.00Kg/cm	0.17A
GA12-N20-3V200	1.5-5VDC	3VDC	200RPM	30mA	160RPM	70mA	0.09Kg/cm	0.70Kg/cm	0.18A
GA12-N20-3V500	1.5-5VDC	3VDC	500RPM	10mA	400RPM	30mA	0.05Kg/cm	0.40Kg/cm	0.10A
GA12-N20-3V1000	1.5-5VDC	3VDC	1000RPM	30mA	700RPM	80mA	0.02Kg/cm	0.30Kg/cm	0.30A
GA12-N20-6V30	3-9VDC	6VDC	30RPM	20mA	25RPM	40mA	1.50Kg/cm	10.0Kg/cm	1.00A
GA12-N20-6V50	3-9VDC	6VDC	50RPM	20mA	40RPM	50mA	1.50Kg/cm	10.0Kg/cm	1.00A
GA12-N20-6V100	3-9VDC	6VDC	100RPM	10mA	80RPM	30mA	0.40Kg/cm	3.20Kg/cm	1.00A
GA12-N20-6V200	3-9VDC	6VDC	200RPM	30mA	160RPM	60mA	0.30Kg/cm	1.80Kg/cm	0.23A
GA12-N20-6V300	3-9VDC	6VDC	300RPM	30mA	240RPM	40mA	0.20Kg/cm	1.60Kg/cm	0.20A
GA12-N20-6V500	3-9VDC	6VDC	500RPM	160mA	400RPM	230mA	0.17Kg/cm	1.40Kg/cm	0.20A
GA12-N20-6V1000	3-9VDC	6VDC	1000RPM	10mA	800RPM	30mA	0.06Kg/cm	0.40Kg/cm	0.16A
GA12-N20-12V100	6-12VDC	12VDC	100RPM	40mA	80RPM	70mA	2.00Kg/cm	16.0Kg/cm	1.00A
GA12-N20-12V200	6-12VDC	12VDC	200RPM	20mA	160RPM	40mA	1.00Kg/cm	7.00Kg/cm	1.00A
GA12-N20-12V300	6-12VDC	12VDC	300RPM	50mA	240RPM	90mA	0.60Kg/cm	4.00kg/cm	0.30A
GA12-N20-12V600	6-12VDC	12VDC	600RPM	30mA	500RPM	70mA	0.40Kg/cm	3.20Kg/cm	0.20A
GA12-N20-12V1000	6-12VDC	12VDC	1000RPM	190mA	800RPM	280mA	0.30Kg/cm	2.40Kg/cm	0.60A

Figure 1: GA12-N20 Data Sheet

This motor was a good choice for the first iteration with its weight of about 25 grams and length of less than 2.5cm. In addition, its no load power consumption at 1000RPM is 0.06 Watts (0.12 Watts total for two motors) which is well below our threshold of 1 Watt. The torque for maximum efficiency at 1000RPM is given to be 0.06 $Kg \cdot cm$. Our torque for maximum acceleration is equal to about 0.05 $Kg \cdot cm$, where 1 $N \cdot m \approx 0.1 Kg \cdot cm$, thus it will be 0.025 $Kg \cdot cm$ for each motor which should be even less power consumption. Overestimating our output torque to be 0.05 $Kg \cdot cm$, our power consumption during maximum acceleration for both motors together will be given by $2 \cdot I \cdot V$, where V is voltage and I is current in Amps.

$$2P = 2 \cdot I \cdot V = 2 \cdot 0.03(A) \cdot 6(v) = 0.36(W)$$

2.3 Electronics

The computer being used for experimentation is the Raspberry Pi Zero W. An L9110S motor controller is used in order to allow for forward and backward functionality of the DC motor. The motor controller also allows for a voltage of 6 Volts to be passed to the motors, as the Raspberry Pi Zero output from PWM channels is limited to 3.3 Volts. An MPU6050 is used to collect acceleration data for testing purposes. Two independent Li-Po batteries power the robot; one battery powers the computer through a 5V boost converter and a second battery powers the motor through a 6 volt boost converter. These circuits include two INA219 current sensors. Figure 2 displays a schematic of the circuit.

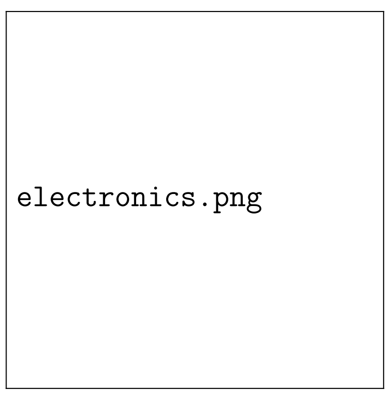

Figure 2: Electronics Schematic

2.4 Structure

Figure 3 shows a front and rear view of the assembled robot. The structure of the robot is a 3d-printed, multi-level frame that weighs less than 10 grams. The components are assorted such that the center of mass of the robot is low and close to the center of the vehicle for better handling. The motors are mounted to the frame via screws, and a hole isolates the moving axle from the frame such that there is no friction between the frame and the axle. This is to completely isolate the motor's components from any part of the robot in order to maximize power output. A camera is mounted in front to enable visual inertial odometry (VIO) testing. The IMU is mounted in between the battery and motors in a slit within the frame such that the chip is as close to the center of mass as possible. The design considers the addition of a rubber or silicone gasket in the mounting area such that noise in IMU data due to vibration is reduced. The computer and boost converter are mounted on a second level to keep the electronics packaged closely and reduce the footprint of the vehicle.

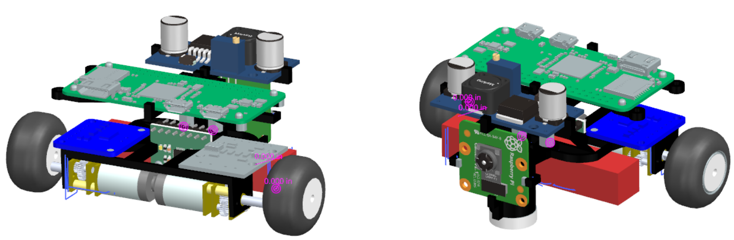

Figure 3: Car assembly

Figure 4 displays multiple views of the frame itself. The two levels are connected by standoffs. The battery is mounted on a cradle, which has physical stops that restrict how far in the battery can be inserted into the frame.

2.5 Wheel Design

Beyond reducing friction in all possible areas in the mechanisms that control the axle movement, a major factor in power efficiency is choosing the correct tire geometry to maximize power to the ground being converted into motion. Thin tires are ideal for this application, as the smaller surface area contacting

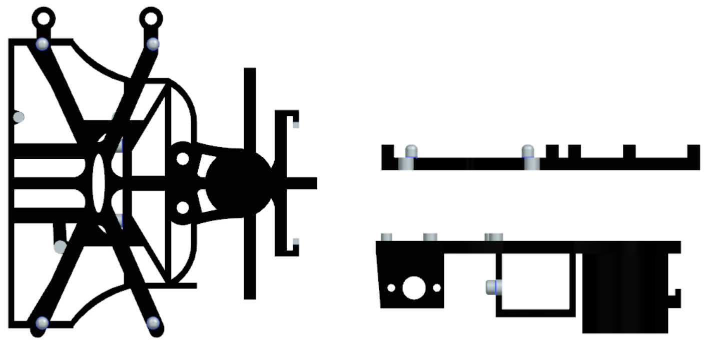

Figure 4: 3d-Printed Frame

the ground will produce less friction during turning. Perhaps more importantly, for very light weight applications, the small surface area of thin tires provides higher pressure per unit surface area which results in less wheel slip. 3d-printing a custom wheel from TPE allows for greater control over tire geometry in addition to almost double the coefficient of static friction of polyurethane, allowing for faster acceleration with less slip. 3D printing also allows for control over properties of the surface of the tire, such as roughness which provides even greater control of traction on the vehicle. With the light weight components and nearly instant torque from the DC motors, more traction is crucial to reach peak efficiency. Initial experimentation (discussed in chapter 4) suggests that accelerating to desired speeds as fast as possible is more power efficient than slower ramping, so maximizing traction to accommodate the instant torque of electric motors is necessary.

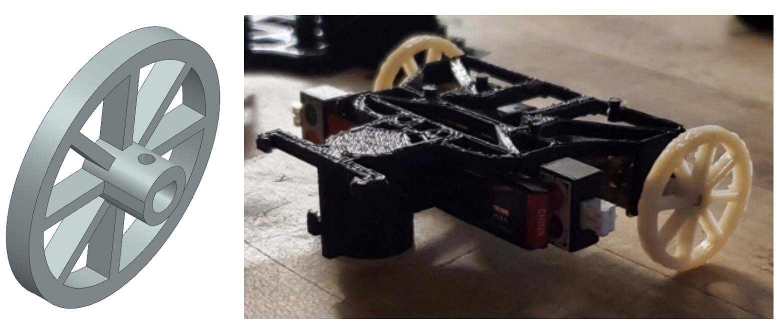

Figure 5: 3D Model of tire (left), Tires attached to robot (right)

3 Software

3.1 Installing dependencies

3.2 Motor Control

3.3 Data collection

3.4 Control

3.5 Message Passing

4 Power Consumption Data