Mini-Mapper: Motor prototype board design notes

Ian Ross

July 23, 2020

These notes describe the motor prototype board for the Mini-Mapper robot. This is intended as a platform to test motor driver and motor encoder setup, and to develop motor early control algorithms (particularly constant-speed PID control and soft start).

Requirements

- Power single Dagu DG01D gearmotor (4.5 V, 250 mA max.);
- PWM speed control, bidirectional, coast/brake functionality;
- Rotation measurement using optical encoder;
- Interface to STM32F767ZI Nucleo-144 board;
- Clean mechanical design for interface between motor and motor encoder disk.

Mechanical design

- Final PCB to be mounted on top chassis plate of robot: do this also for prototype motor board, to get placement right.
- Principal constraints are:
  - Access to mounting holes on top chassis plate (there is interference with the motor under some holes);
  - Clearance under PCB:both for the possibility of mounting components on the bottom of the PCB and for space for routing wires and to avoid shorts to chassis plate from THT components;
  - Alignment of photoencoder with motor encoder disk: photointerrupter slot and optical axis need to align with the holes in the motor encoder disk, there needs to be no interference between the photointerrupter and the motor body, and there needs to be little enough interference between the photointerrupter and the top chassis plate to make modifying the chassis plate easy.

- Motor encoder disk needs to be manufacturable by hand, which means a simple disk with holes, rather than slots. This leads to a strong alignment requirement in the vertical direction between the motor encoder disk and the photointerrupter optical axis.

Component choices

Motor driver: Toshiba TB67H450FNG Chosen to match supply voltage requirements for motors, to have a standard PWM-capable control interface, internal current regulation and an easy-to-use package.

Current sense opamp: TI TLV9051 This is a low-side current sensing application, which imposes some requirements on the input range of the opamp. The TLV9051 is specifically intended for this application.

Photointerrupter: Vishay TCST1202 Phototransistor type photointerrupter, because we're not going to get a perfect transistion between full occlusion and full non-occlusion of the photointerrupter's optical aperture, so it will be useful to be able to set thresholds for occluded/non-occluded switching. The primary constraints here are mechanical, since most devices like this have similar electrical characteristics. The selected device has a 0.5 mm wide optical aperture, which matches up with some simulations I've done, and it can be mounted without interference with the motor body using reasonably sized standard hardware (i.e. 5 mm standoffs between the PCB and the top chassis plate).

Motor encoder comparator: TI LMV331 The requirements here are simple, so a jellybean comparator is a good choice. Not an LM339 though! Something more modern. I chose a TI LMV331, which is a single supply device available in an SOT-23 package.

4.5 V regulator: TI TLV702 Need a linear regulator to produce 4.5 V from a 5 V input: TI's TLV702 is cheap, simple, can provide 300 mA and comes in a 4.5 V version.

Power connectors ***Measure barrel plug from 5 V wall wart to select barrel jack. Also check power supply connector polarity!***

Motor connectors 2-hole 0.1" header vertical socket (motor leads have individual 0.1" pins).

Nucleo board connectors 6-hole 0.1" header vertical socket or header (two digital motor control inputs, one analogue motor coil current sense output, one digital encoder pulse output, 3.3 V supply, ground).

Decide on connector gender based on connector leads I have.

Schematic capture

Motor driver

- Power decoupling: following schematic in application note.
- Current sense resistor: motors run from a 4.5 V supply, and want to keep the maximum sense voltage to some small fraction of this. For a maximum current of 250 mA, a sense resistor of 400 mΩ gives a maximum sense voltage of 100 mV.
- Current regulation: the maximum allowed motor coil current is set following the datasheet's instructions for setting the V_{ref} input.
- Current sensing: this is a simple non-inverting amplifier setup converting the 0–100 mV sense voltage to a suitable range for input to the microcontroller's ADC (0–3 V). Following a suggestion in a TI app note[1] about layout for motor drivers, the current sensing connections are highlighted to be routed as a differential pair (trying the net tie trick suggested in the app note to make the routing less confusing).

Motor encoder

- The LED side of this is simple: take V_f and I_f from the datasheet and find a suitable resistor based on the power rail (3.3 V, taken from the Nucleo board).
- On the phototransistor side, a current sensing resistor is needed. The light current from the phototransistor is quoted as being at least 1 mA, and typically 2 mA, but remember that we'll only be getting about half of that because of the size of the holes in the motor encoder disk. A 5.7 kΩ resistor will give a sense voltage of 2.85 V for a phototransistor current of 0.5 mA. Higher phototransistor currents will just lead to the phototransistor saturating, so the sense voltage will also be close to the positive rail.
- The threshold to use for the comparator used to turn the analogue output from the phototransistor into pulses for counting holes in the encoder disk is set at $V_{\text{cc}}/2$. This is conservative enough to be higher than any likely "dark current", which includes the true dark current from the phototransistor plus any additional current due to ambient light falling on the phototransistor.

[1] `http://www.ti.com/lit/an/slva959a/slva959a.pdf`

- A bare comparator will produce spurious output transistions in the presence of noise (see simulations), so some hysteresis is included. The resistor values selected give a hysteresis of about 0.1 V.

Nucleo board interface

Connections:

- 3.3 V power and ground;
- Two GPIO outputs for motor control (PWM-capable);
- One ADC input for motor coil current sense;
- One GPIO input for photoencoder pulses (interrupt-capable).

Use 0.1" headers on motor board, and connect to Nucleo board using jumper cables, since the connections we'll want are pretty spread out.

Use	**PCB**	**Nucleo**	**Conn**	**Pin**
Power	`3V3`	`+3V3`	CN8	7
Ground	`GND`	`GND`	CN8	11
Motor control	`IN1`	`PD14 (TIM4_CH3)`	CN7	16
Motor control	`IN2`	`PD15 (TIM4_CH4)`	CN7	18
Motor current sense	`Vsense`	`PA3 (ADC123_IN3)`	CN9	1
Encoder pulses	`PULSE`	`PG3`	CN8	16

Label connections with use and Nucleo pin names on silkscreen.

Power

Supplies:

- Need 4.5 V (250 mA max.) for motor, and 3.3 V for logic.
- For prototype board, use 3.3 V supply from Nucleo board, and use external 5 V wall wart supply plus linear regulator for 4.5 V supply.

3.3 V

For the 3.3 V supply, the current draw is approximately:

Component	**Worst case current draw (mA)**
Motor driver (control inputs)	0.11
TLV9051 opamp	0.45
LMV331 comparator	0.1
TCST1202 photointerrupter	25 + 2
Total	**28**

This 28 mA total is well within the 500 mA limit for the 3.3 V supply from the Nucleo board, so we can run the 3.3 V devices on the motor prototype board directly from the 3.3 V supply from the Nucleo board.

4.5 V

The current draw for the 4.5 V supply can be up to 250 mA from the motor, plus perhaps 5 mA for the motor driver. This is too much for the 5 V supply from the Nucleo board to supply reliably, so we need to use a separate power source for the 4.5 V supply.

We will use a 5 V wall wart power supply with a TI TLV702 LDO regulator (which comes in a 4.5 V version and can supply 300 mA).

Layout

Mechanical board outline: photoencoder placement, mounting holes. Measure carefully directly from chassis plate: just motor axis, mounting holes and photointerrupter location.

Assembly

Mounting hardware 5 mm spacers between PCB and top chassis plate, M2.5 bolts and nuts to secure PCB.

Power supply connections