Steer-by-Wire bicycle Documentation

Simonas Draukas

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Contents

Chapter 1

Electronics box at the rear of the bicycle

1.1 Connections

The rear electronics box contains two PCBs and a microcontroller. Originally, Teensy 3.6 was used, however, it is a discontinued model. Therefore, the controller was upgraded to a Teensy 4.1. One of the PCBs, from now on referred to as "Power board", is housing the two Maxon ESCON 50/5 motor drives and converts the battery's voltage of 37V to other required voltages. The other PCB interfaces with the microcontroller and is referred to as "MC board".

Table 1.1 lists the connections between Teensy and MC board. Table 1.2 lists the connections between MC and Power boards.

1.2 Teensy

1.2.1 Teensy 3.6

The bicycle originally featured a Teensy 3.6 installed at the very back of the electronics box. This Teensy contains the code necessary to control the handlebars and the fork. It runs a PD controller implemented by Georgios Dialynas, which runs at 1000 Hz and makes the handlebar angle follow the fork angle, and vice-versa. The code can be found on GitHub/gdialynas/Steer-by-wire-bicycle.

1.2.2 Teensy 4.1

Teensy 3.6 has been discontinued and is out of stock (as of April 2022). Therefore, in order to ensure the longevity of the bicycle, it was decided to move to Teensy 4.1, as it is going to be significantly easier to obtain spare microcontrollers in the event of Teensy getting damaged.

The pinout of the Teensy changed slightly between the versions 3.6 and 4.1. The most impactful change was the location of the Analog pins. For this exact application, this meant that pins 33 and 34 are no longer Analog and the wires need to be redirected to other pins. Pins 40 and 41 were chosen as replacements, respectively.

Starting from here, the documentation assumes that Teensy 4.1 is used.

Table 1.1: Teensy and MC board connections

Variable name in the code	Device	Teensy 4.1 Pin	MC Board Pin	Teensy pin requirements
Serial1.begin();	Bluetooth TX	0	-	Hardware Serial RX
Serial1.begin();	Bluetooth RX	1	-	Hardware Serial TX
Encoder wheel_counter(2,3);	Rear wheel gear encoder	2, 3	PA0, PA1	Digital with Interrupt
pwm_pin_hand	PWM signal to handlebar motor	8	PA8	PWM
pwm_pin_fork	PWM signal to the fork motor	9	PA9	PWM
cs_imu	Chip Select for the IMU	10	PB0	Digital
SPI.begin();	MOSI for hardware SPI0	11	PA7	MOSI
SPI.begin();	MISO for hardware SPI0	12	PA6	MISO
SPI.begin();	SCK for hardware SPI0	13	PA5	SCK
a_force	Force transducer	20	-	Analog
a_torque	Torque sensor	21	PC2	Analog
Encoder pedal_counter(23, 22);	Pedal gear encoder	22, 23	PC6, PC7	Digital with Interrupt
cs_hand	Chip Select for handlebar encoder	24	PA4	Digital
cs_fork	Chip Select for fork encoder	25	PA3	Digital
SPI1.begin();	MOSI for hardware SPI1	26	-	MOSI1
SPI1.begin();	SCK for hardware SPI1	27	-	SCK1
hand_switch	Handlebar switch	28	-	Digital
enable_hand	Enable handlebar motor	29	PB12	Digital
enable_fork	Enable fork motor	30	PB13	Digital
enable_encoder	Enable handlebar and fork encoders	31	PA10	Digital
hand_led	Handlebar LED	32	-	Digital
enable_radio	Enable nRF24L01 radio	37	-	Digital
cs_radio	Chip Select for nRF24L01 radio	38	-	Digital
SPI1.begin(); SPI1.setMISO(39);	MISO for hardware SPI1	39	-	MISO1
a_fork	Read torque of the fork motor	40	PC1	Analog
a_hand	Read torque of the handlebar motor	41	PC0	Analog
-	3.3V supply to the MC board	3.3V (between 12 and 24)	3.3V VDD (EXT1)	-
-	Ground pin	GND (above 23)	GND (EXT1)	-
-	Ground pin	GND (above 0)	GND (EXT2)	-
-	Micro-USB Power Supply to Teensy	Micro-USB GND	GND_VSS (EXT2)	-
-	Micro-USB Power Supply to Teensy	Micro-USB +5V	VIN (EXT2)	-

Table 1.2: MC and Power board connections

Cable label	MC board header	Power board header
1	J3	-
Red wire from Bluetooth module	J4 +5V	-
Brown wire from Bluetooth module	J4 GND	-
2	J5	-
3	J6	J6
7	J7	J7
6.	J8	-
8	J9	-
Analog output, handlebar motor	J10	J10
Analog output, fork motor	J11	J11
Torque sensor value	J12	J12
Grey wire - A	J13 bottom pin	-
Yellow wire - Y	J14 bottom pin	-
Black wire - X	J15 bottom pin	-
Torque sensor measure enable	J16	J16
10	-	J1
9.	-	J2
14	-	J3
13	-	J4
Output torque sensor	-	J5 VAL
Protoboard red cable	-	J5 +18V
Protoboard black cable	-	J5 GND
11	-	Glued 4-pin under the inductor
12	-	Remaining glued 4-pin

The updated code for the Teensy is stored at GitHub/sdrauksas/TUDelft-SbW-Bicycle.

1.3 Microcontroller Board

This is a custom made PCB that was designed by Oliver Lee, Georgios Dialynas, and Andrew Berry. This PCB is used in both the Steer-by-Wire bicycle and the fixed-base Bicycle Simulator. It is designed as an expansion board for the STM32-H405, that features an MPU-9250 IMU, two Ethernet ports, an SD card reader and was designed to be used together with the Power supply board discussed later.

However, now a Teensy is used instead of the STM32-H405, therefore, most of the Teensy's pins are connected to this board to the `EXT1` and `EXT2` headers, where the STM32-H405 would sit.

The PCB schematic can be found in either GitHub/oliverlee/gyropcb or its fork GitHub/gdialynas/gyropcb under the name `mc_pcb`.

1.3.1 Board's Pinout

This board features two 26-pin headers `EXT1` and `EXT2` in the middle of the board. These headers were made for the OLIMEX STM32-H405[1] microcontroller. There are also seven 2-pin headers (from `J10` to `J16`), three 4-pin headers (`J3, J4, J5`), two 6-pin headers (`J8, J9`), and two 8-pin headers (`J6, J7`) along the sides of the board. For the Steer-by-Wire application, four more wires are soldered to the pads on the PCB in the location, where a `U4` IC chip should be soldered.

The `EXT1` and `EXT2` header pins are numbered according to OLIMEX User Guide, page 9[2]).

Headers are connected according to Tables 1.1 and 1.2.

1.4 Power Board

This is a custom made PCB that was designed by Oliver Lee, Georgios Dialynas, and Andrew Berry. This PCB is used in both the Steer-by-Wire bicycle and the fixed-base Bicycle Simulator. It is a power supply board that interfaces with two Maxon ESCON 50/5[3] servo controller modules.

The PCB schematic can be found in either GitHub/oliverlee/gyropcb or its fork GitHub/gdialynas/gyropcb under the name `power_pcb`.

1.4.1 Board's Pinout

In the middle of the board, there are two 18-pin headers `EXT1` and `EXT3`, and two 11-pin headers `EXT2` and `EXT4`. These headers are used to seat the ESCON modules. There are also four 2-pin headers (`J10`, `J11`, `J12`, `J16`), one 5-pin header (`J5`), two

[1] https://www.olimex.com/Products/ARM/ST/STM32-H405/

[2] https://www.olimex.com/Products/ARM/ST/STM32-H405/resources/STM32-H405_UM.pdf

[3] https://www.maxongroup.com/maxon/view/product/control/4-Q-Servokontroller/438725

6-pin headers (J2, J4), and four 8-pin headers (J1, J3, J6, J7) along the sides of the board. There are also two 4-pin headers glued on the bottom side of the board.

Headers EXT1 and EXT2 are used to seat the handlebar motor's ESCON module.

Headers EXT3 and EXT4 are used to seat the fork motor's ESCON module.

Other headers are connected according to Table 1.2.

1.5 Protoboard

There is a protoboard containing two IC chips, 2 capacitors and a couple of resistors. The two ICs are INA125P[4] amplifiers. The analog torque sensor and force transducer go through these amplifiers. Each chip has 16 pins.

These are the connections:

- Pins 1 and 2 of both chips are connected to +5V (orange wire).
- Pins 3, 5 and 12 of both chips are connected to GND (black wire).
- Pins 4 and 14 of both chips are connected to a blue wire each.
- Pins 6 of both chips are connected to a white wire each.
- Pins 7 of both chips are connected to a green wire each.
- Pins 8 and 9 of both chips are connected through resistors (47 Ohms for the torque sensor amplifier and 62 Ohms for he force transducer amplifier).
- Pins 10 and 11 of both chips are connected together with a wire (yellow labelled Output torque sensor for one chip, and purple labelled Output force transducer for another)
- Two black and a grey wires are connected to GND as well.
- Capacitors are placed between +5V and GND wires.

[4]https://www.ti.com/lit/ds/symlink/ina125.pdf

Chapter 2

Motors

2.1 Front assembly

Front assembly consists of two Maxon EC45 Flat brushless DC motors. The motors have hall sensors and encoders. Power is unknown.

The motors are equipped with Maxon GP42C planetary gearheads.

The 8-pin connector has this pin-out (according to [1] and [2]):

- Pin 1 – Hall sensor 1
- Pin 2 – Hall sensor 2
- Pin 3 – `+5V`
- Pin 4 – Motor winding 3
- Pin 5 – Hall sensor 3
- Pin 6 – `GND`
- Pin 7 – Motor winding 1
- Pin 8 – Motor winding 2

2.2 Rear wheel

The rear wheel is driven by a brushless "Magic Pie"[3] hub motor manufactured by "Golden Motor". It is a 36V model, but not sure what power output.

The hub motor is controlled using a twist throttle and has cruise-control. Cruise control is (de-)activated using the red button above the green button with a horn logo. Pulling the brakes deactivates the cruise-control as well. The cruise-control does not account for wind or slopes, all it does is keep the same current in the motor.

The hub motor also features regenerative braking.

The motor can be easily disabled by unplugging 4 cables at the front of the bicycle. Cables are labelled A-D. Cable A carries cruise-control's commands, cable

[1] https://www.maxongroup.com/medias/sys_master/root/8882563055646/EN-21-297.pdf
[2] https://www.maxongroup.com/medias/sys_master/root/8882567512094/EN-21-310.pdf
[3] https://www.goldenmotor.com/magicpie/magicpie.html

B - front brake lever's, cable C - throttle's, and cable D - rear brake lever's. Cables A and C can only be plugged in to their respective plugs, while B and D can be plugged in to either.

Chapter 3

Things to improve or repair

3.1 Microcontroller Board

- Adjust the board to accommodate the Teensy instead of STM32-H405. This would get rid of a big part of wires, make the electronics box cleaner and more presentable, reduce the amount of space needed, and possibly reduce interference between long wires.
- Four wires are soldered to the PCB instead of using a header. Adjusting the PCB for this would make the PCB look more presentable.

3.2 Power Board

- Some cables running to/from this board might need extending and replacing the connectors.
- The cables carrying power to the fork motor are the ones requiring the most care.

3.3 Protoboard

- Some of the wires going to the protoboard are soldered straight to it without any connectors in-between. This means that taking the electronics box apart is a hassle since de-soldering is needed. Installing connectors would improve this.
- A custom PCB might make disassembly even easier.
- The sensors were not tested out nor calibrated during the MPC project as they were not needed. Before making use of the sensors – calibrate the sensors.

3.4 Bicycle

- Adjust front brakes to not rub, if the bicycle is to be used outside on the road.[1]
- Weather-proof the steering motors.
- Fix the kick-stand. Currently it is not stable.

[1] The brakes and the electric motor should be disabled while riding on the treadmill.

- Slick tires are not very suitable for riding outside on the road.
- Fix the wheel speed sensor.
- Adjust the rear chain derailleur.
- Implement a better data-logging functionality that can work in parallel to the PD controller.