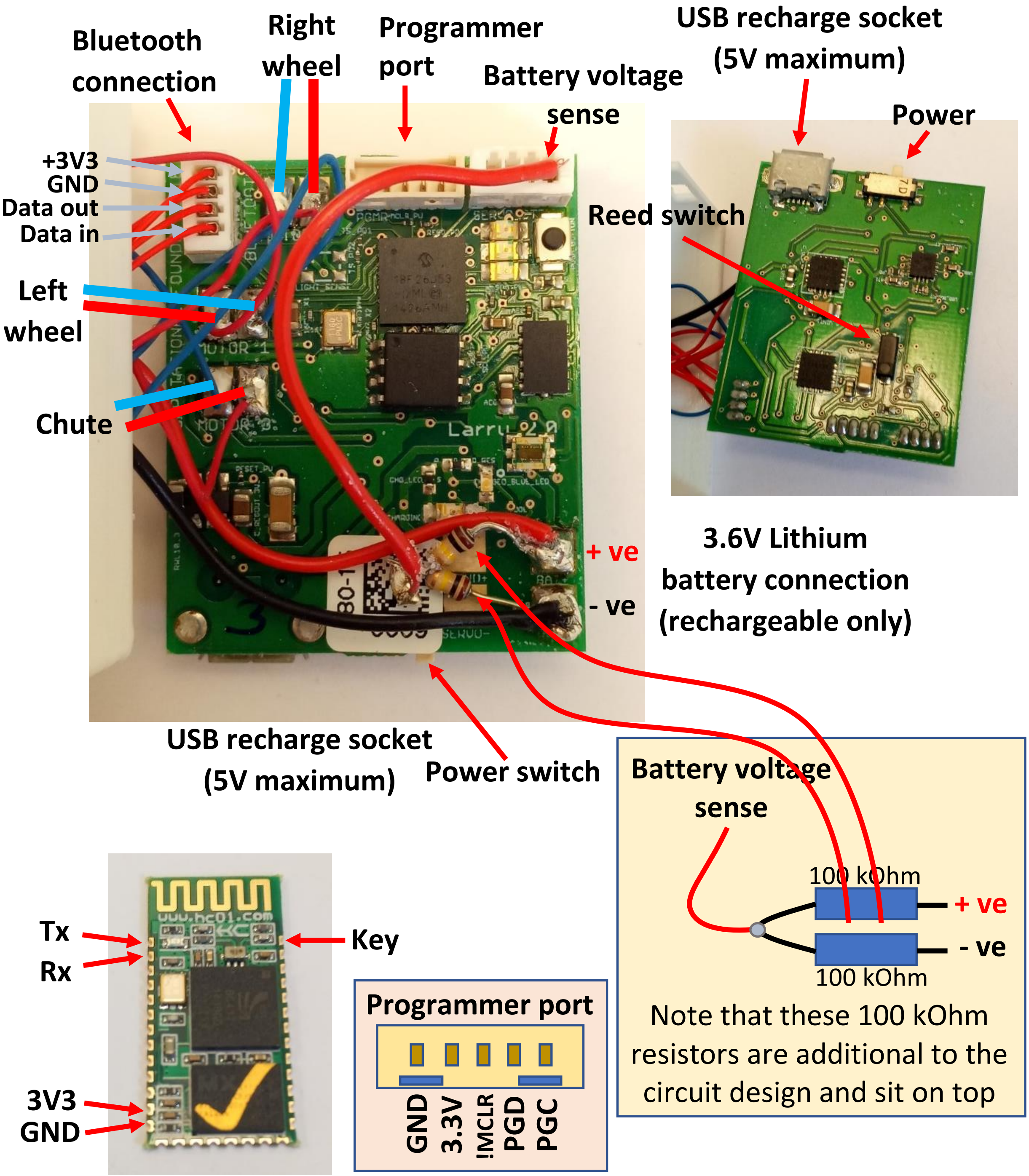
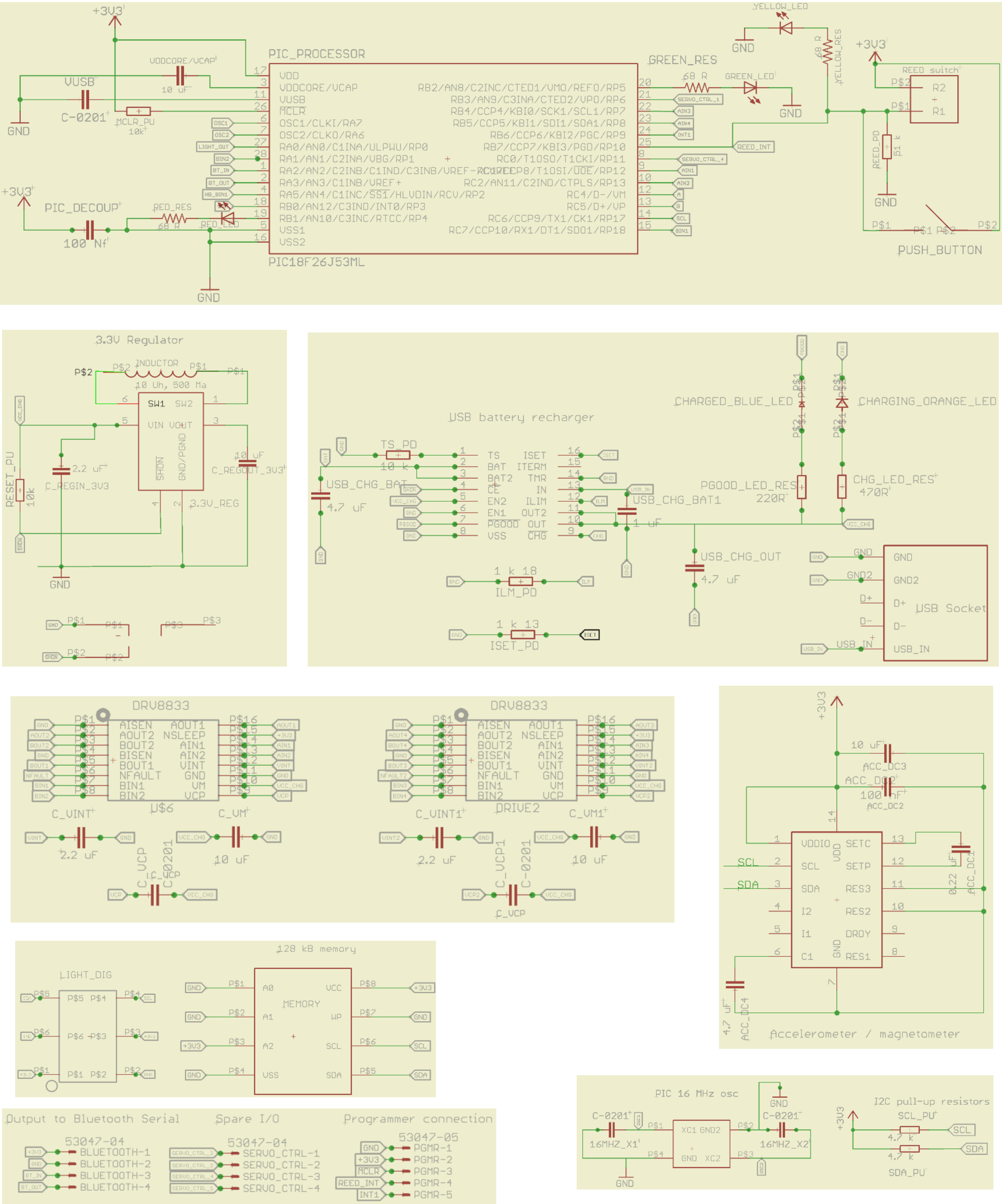
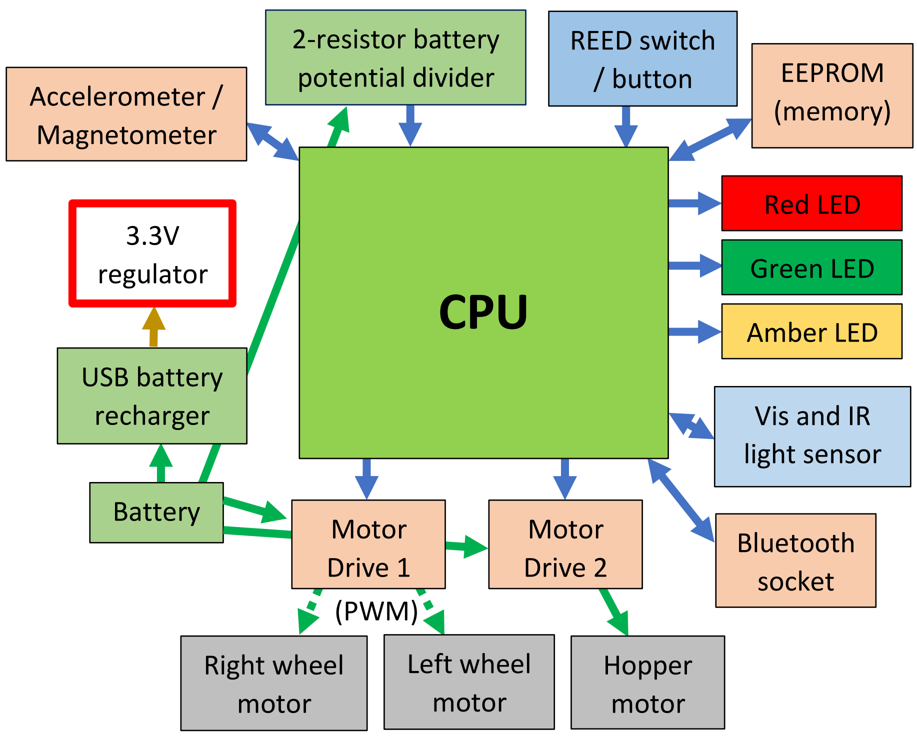


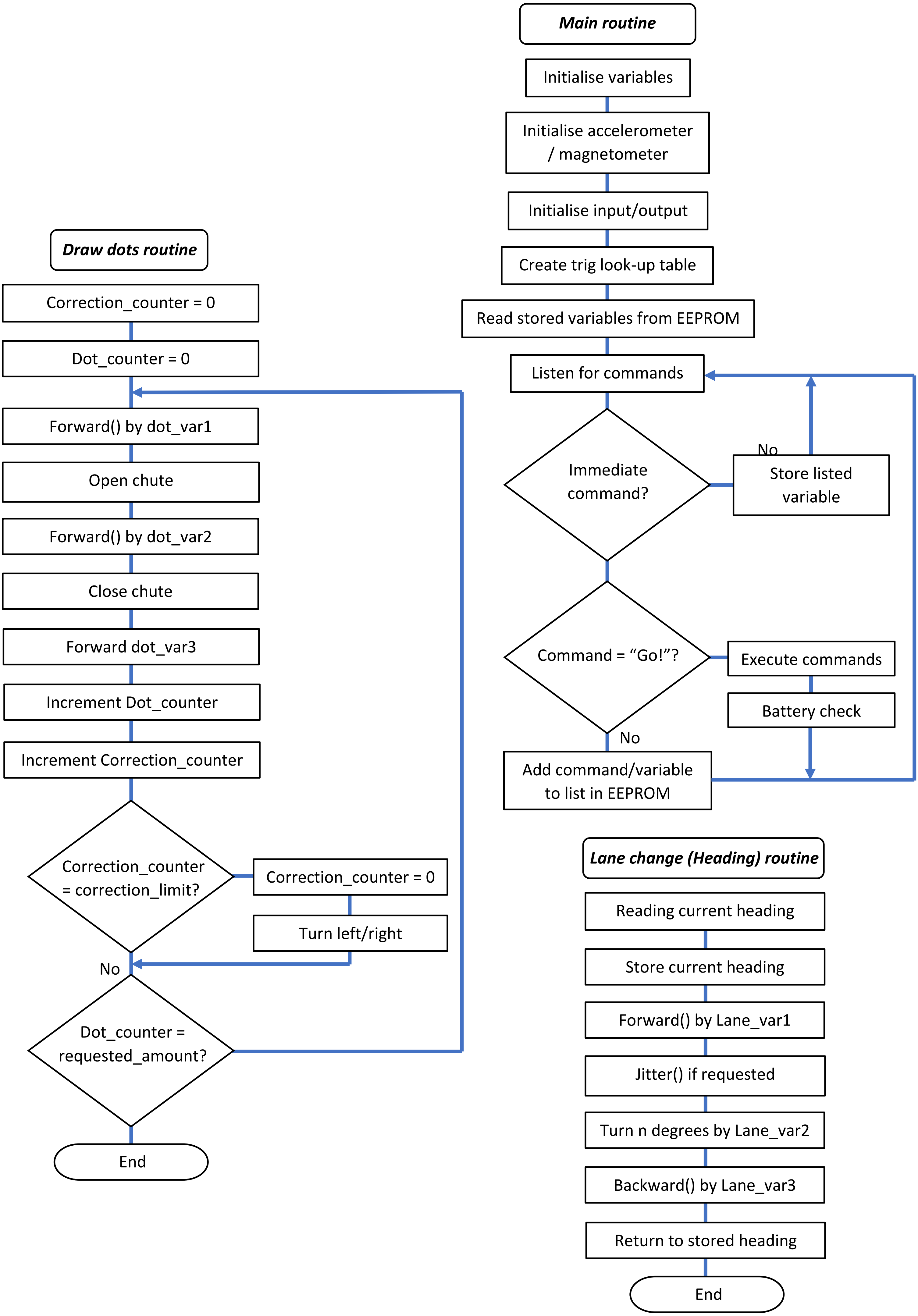
Bluetooth connection
Right wheel
Programmer port
Battery voltage sense
USB recharge socket (5V maximum)
Power
+3V3
GND
Data out
Data in
Reed switch
Left wheel
Chute
Larru 2.0
MOTOR 1
MOTOR 3
+ ve
- ve
3.6V Lithium battery connection (rechargeable only)
USB recharge socket (5V maximum)
Power switch
Battery voltage sense
100 kOhm
+ ve
- ve
100 kOhm
Note that these 100 kOhm resistors are additional to the circuit design and sit on top
Tx
Rx
Key
3V3
GND
www.hc01.com
Programmer port
GND
3.3V
!MCLR
PGD
PGC

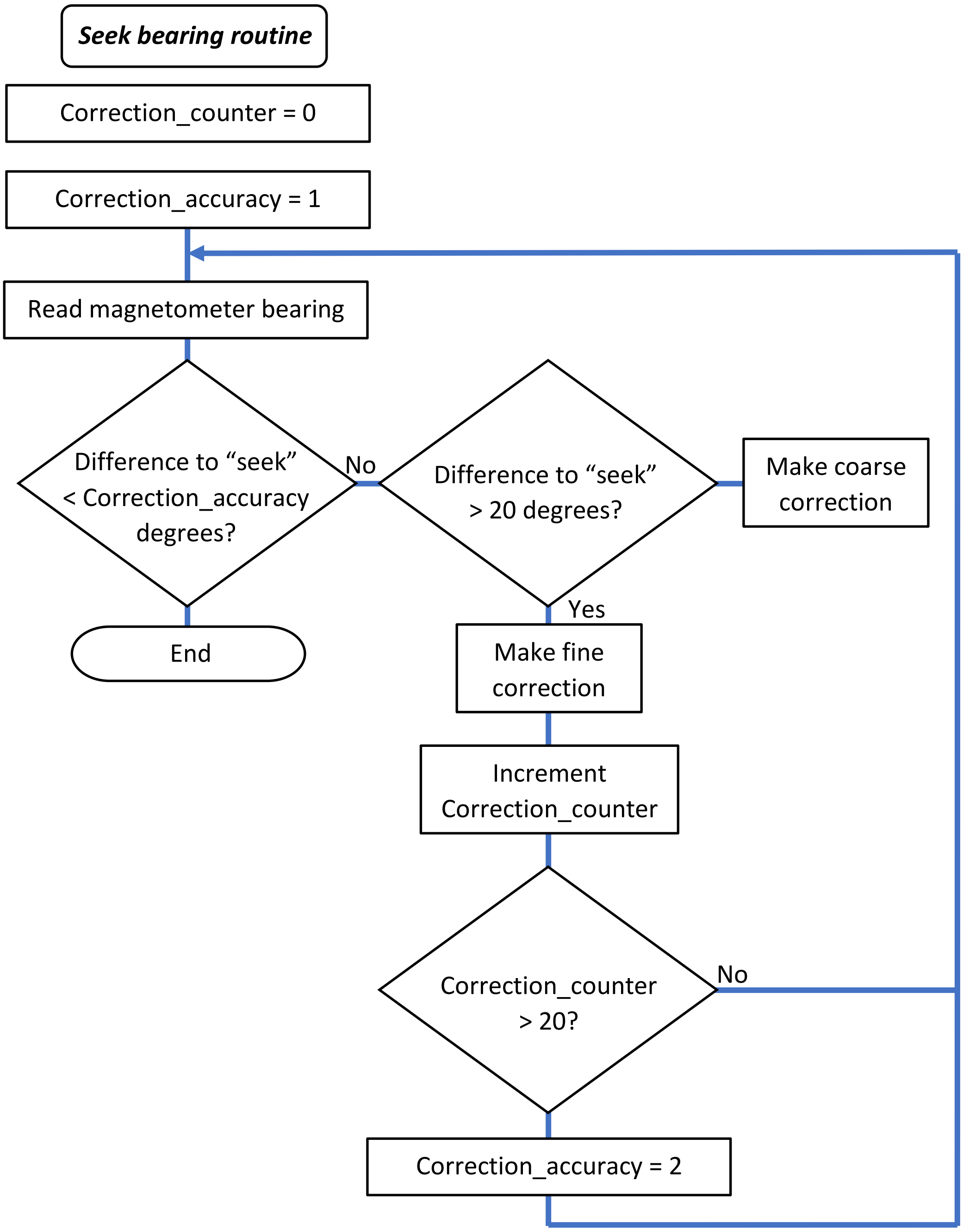


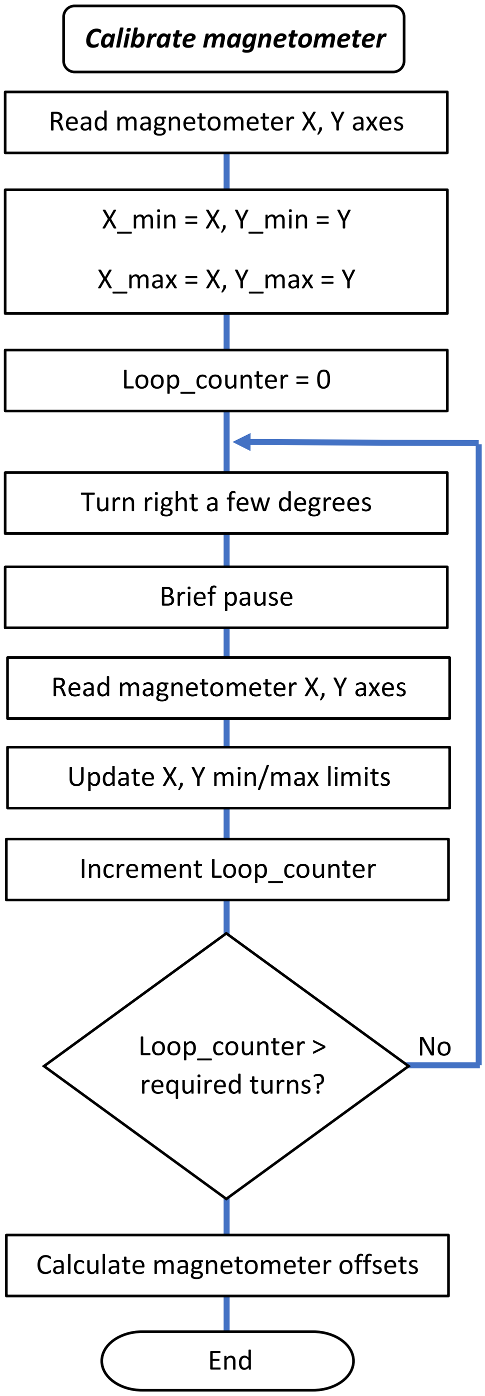
PIC_PROCESSOR
PIC18F26J53ML
VDD
VDDCORE/VCAP
VUSB
MCLR
OSC1/CLKI/RA7
OSC2/CLKO/RA6
RA0/AN0/C1INA/ULPWU/RP0
RA1/AN1/C2INA/VBG/RP1
RA2/AN2/C2INB/C1IND/C3INB/VREF-/CVREF
RA3/AN3/C1INB/VREF+
RA5/AN4/C1INC/SS1/HLVDIN/RCV/RP2
RB0/AN12/C3IND/INT0/RP3
RB1/AN10/C3INC/RTCC/RP4
VSS1
VSS2
RB2/AN8/C2INC/CTED1/VMO/REFO/RP5
RB3/AN9/C3INA/CTED2/VPO/RP6
RB4/CCP4/KBI0/SCK1/SCL1/RP7
RB5/CCP5/KBI1/SDI1/SDA1/RP8
RB6/CCP6/KBI2/PGC/RP9
RB7/CCP7/KBI3/PGD/RP10
RC0/T1OSO/T1CKI/RP11
RC1/CCP8/T1OSI/UOE/RP12
RC2/AN11/C2IND/CTPLS/RP13
RC4/D-/VM
RC5/D+/VP
RC6/CCP9/TX1/CK1/RP17
RC7/CCP10/RX1/DT1/SDO1/RP18
+3V3
VUSB
C-0201
VDDCORE/VCAP
10 uF
MCLR_PU
10k
PIC_DECOUP
100 Nf
RED_RES
68 R
RED_LED
GND
GREEN_RES
68 R
GREEN_LED
YELLOW_LED
68 R
YELLOW_RES
REED_INT
REED suitch
REED_PD
51 k
PUSH_BUTTON
3.3V Regulator
INDUCTOR
10 Uh, 500 Ma
SW1 SW2
VIN VOUT
SHDN
GND/PGND
2.2 uF
C_REGIN_3V3
10 uF
C_REGOUT_3V3
3.3V_REG
RESET_PU
10k
USB battery recharger
TS_PD
10 k
USB_CHG_BAT
4.7 uF
TS BAT BAT2 CE EN2 EN1 PGOOD VSS
ISET ITERM TMR IN ILIM OUT2 OUT CHG
USB_CHG_BAT1
1 uF
USB_CHG_OUT
4.7 uF
1 k 18
ILM_PD
1 k 13
ISET_PD
CHARGED_BLUE_LED
CHARGING_ORANGE_LED
PGOOD_LED_RES
220R
CHG_LED_RES
470R
USB Socket
GND GND2 D+ D- USB_IN
DRV8833
AISEN AOUT1
AOUT2 NSLEEP
BOUT2 AIN1
BISEN AIN2
BOUT1 VINT
NFAULT GND
BIN1 VM
BIN2 VCP
U$6
DRIVE2
C_VINT
2.2 uF
C_VM
10 uF
C_VCP
C-0201
C_VINT1
C_VM1
C_VCP1
Accelerometer / magnetometer
VDDIO SCL SDA I2 I1 C1
SETC SETP RES3 RES2 DRDY RES1
10 uF
ACC_DC3
ACC_DC
100 nF
ACC_DC2
0.22 uF
ACC_DC1
4.7 uF
ACC_DC4
128 kB memory
MEMORY
A0 A1 A2 VSS
VCC WP SCL SDA
LIGHT_DIG
Output to Bluetooth Serial
53047-04
BLUETOOTH-1
BLUETOOTH-2
BLUETOOTH-3
BLUETOOTH-4
Spare I/O
53047-04
SERVO_CTRL-1
SERVO_CTRL-2
SERVO_CTRL-3
SERVO_CTRL-4
Programmer connection
53047-05
PGMR-1
PGMR-2
PGMR-3
PGMR-4
PGMR-5
PIC 16 MHz osc
C-0201
16MHZ_X1
16MHZ_X2
XC1 GND2
GND XC2
I2C pull-up resistors
SCL_PU
SDA_PU
4.7 k
4.7 k

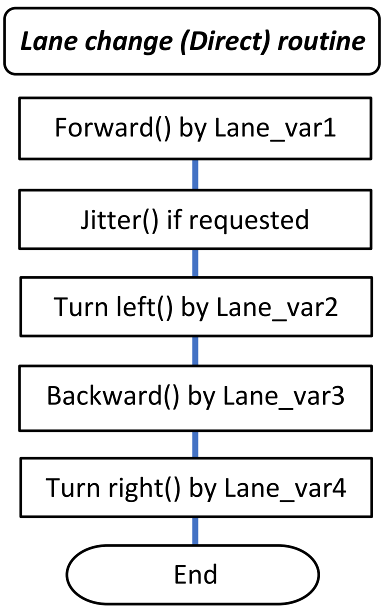


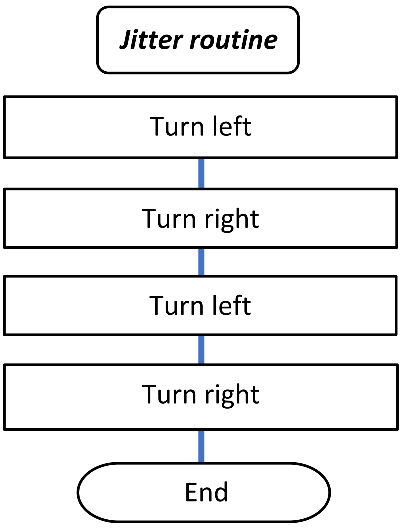
2-resistor battery potential divider
REED switch / button
EEPROM (memory)
Accelerometer / Magnetometer
Red LED
3.3V regulator
Green LED
CPU
Amber LED
USB battery recharger
Vis and IR light sensor
Battery
Motor Drive 1
Motor Drive 2
Bluetooth socket
(PWM)
Right wheel motor
Left wheel motor
Hopper motor

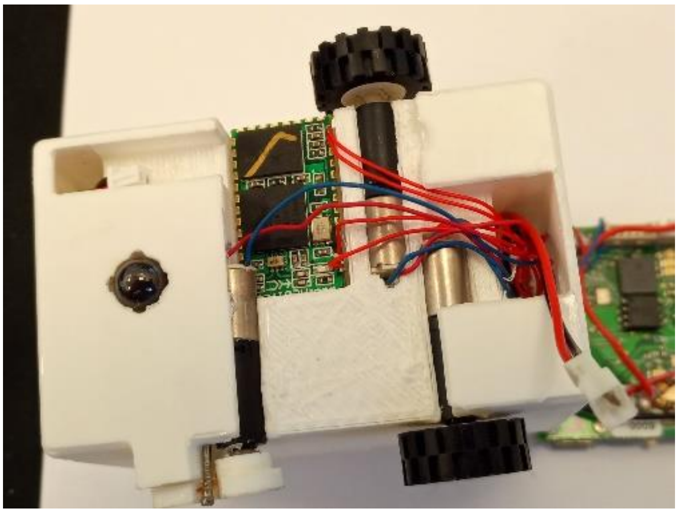

Main routine
Initialise variables
Initialise accelerometer / magnetometer
Initialise input/output
Create trig look-up table
Read stored variables from EEPROM
Listen for commands
Immediate command?
No
Store listed variable
Command = “Go!”?
Execute commands
Battery check
No
Add command/variable to list in EEPROM
Draw dots routine
Correction_counter = 0
Dot_counter = 0
Forward() by dot_var1
Open chute
Forward() by dot_var2
Close chute
Forward dot_var3
Increment Dot_counter
Increment Correction_counter
Correction_counter = correction_limit?
Correction_counter = 0
Turn left/right
No
Dot_counter = requested_amount?
End
Lane change (Heading) routine
Reading current heading
Store current heading
Forward() by Lane_var1
Jitter() if requested
Turn n degrees by Lane_var2
Backward() by Lane_var3
Return to stored heading
End

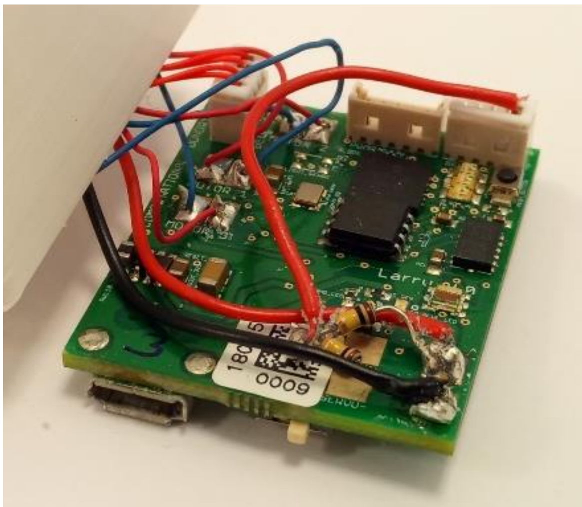

Seek bearing routine
Correction_counter = 0
Correction_accuracy = 1
Read magnetometer bearing
Difference to “seek” < Correction_accuracy degrees?
End
No
Difference to “seek” > 20 degrees?
Make coarse correction
Yes
Make fine correction
Increment Correction_counter
Correction_counter > 20?
No
Correction_accuracy = 2


Calibrate magnetometer
Read magnetometer X, Y axes
X_min = X, Y_min = Y
X_max = X, Y_max = Y
Loop_counter = 0
Turn right a few degrees
Brief pause
Read magnetometer X, Y axes
Update X, Y min/max limits
Increment Loop_counter
Loop_counter > required turns?
No
Calculate magnetometer offsets
End


Lane change (Direct) routine
Forward() by Lane_var1
Jitter() if requested
Turn left() by Lane_var2
Backward() by Lane_var3
Turn right() by Lane_var4
End


Jitter routine
Turn left
Turn right
Turn left
Turn right
End





The Sustainabot circuit board, 29 x 36 x 10 mm, consists of two layers, with parts mounted on both top and bottom sides. These consist of a number of primary components, including a Microchip 8-bit microcontroller (PIC18F26J53) with multiple in-built timing modules, and highly flexible and programmable I/O ports. In addition to the CPU, there is an EEPROM (24AA1025 / 128kB) for storing command data, MEMS accelerometer/magnetometer (LSM303DLHC) for determining compass heading, H-bridge DC motor drivers (DRV8833), digital visible light and infrared, dual light sensor (APDS9300), 3.3V/200 mA buck-boost regulator, and a lithium recharge controller chip (BQ24074RGTR). The CPU is clocked by an external 16 MHz crystal (PLL disabled), drives 3 coloured LEDs for status indication, transfers sensor data to/from MEMS sensors and EEPROM for storage via the I2C protocol, and enables various combinations of motor drive via the two dual-port H-bridge controllers (only 3 of the 4 ports connected in-circuit).

The battery monitor, while not necessary for the operation of the system, was added as an extra feature for the user. It simply consists of two 100 kOhm resistors, connected in-series across the battery terminals, with the centre tap feeding to one of the analogue input ports on the CPU. This is a simple potential divider (/2) enabling the overall battery potential to be measured with an ADC on the CPU, by utilising a reference of 3.3V from the board's regulator. The firmware is configured to give the user a warning via the Bluetooth port when the voltage is at, or below, 3.3V, and that a recharge is required to maintain sufficient drive current to the wheel motors.

The Bluetooth module is an HC-05 board, used for transmission/reception of data. This was configured for serial communications at 38400 BAUD; any higher and the bit-error rate would have been too great due to mismatch from the CPU's 16 MHz timing crystal. This board, or any similarly 3.3V powered Bluetooth serial communications board can be used in conjunction with the controller circuit.

Some of the CPU's ports were reconfigured to make use of one of the internal timers, to output sub-microsecond-width pulses at frequencies of 100s of kHz. This, together with the ability to define different pulse-widths for different I/O ports that rapidly switch the H-bridge circuits on/off i.e. vary the 'duty cycle', enabled us to finely control the mean current delivered to each of the two motors, a technique commonly referred to as pulse width modulation (PWM). The H-bridge controllers in the circuit are configured to operate in two different modes. For the chute, this is in a full-on/off mode, while the drive wheels operate under PWM. The advantage of using PWM is that it also allows for compensation of different motor characteristics due to subtle size variations between the motors, in addition to independent drive at different speeds/directions for slow curved turning.

The drive motors we used on this device are 700:1 planetary-drive geared motors, lightweight, and with enough torque to manoeuvre a small robot around a flat surface.

The on-board magnetometer can be used to give the robot a sense of directionality, although, sensing magnetic fields can be prone to confusion due to ferrous material such as metal table legs, under-table support structures, all capable of causing a shift locally in the Earth’s magnetic field. This aside, the robot can be instructed to turn in a circle of more than 360 degrees, collecting magnetic data on the two axes parallel to the ground. From this, it is able to determine any hard- or soft-iron offsets and correct for them.

Upon switch-on:

Variables are initialised
Wheel outputs to control H-bridges are set off/low
Duty cycle for the forward and backward motion PWMs are set to EEPROM stored values
Magnetometer is initialised
Green LED is switched on
An array is filled with a trigonometric look-up table
Listens for user-defined commands until "Go" command received
Execute list of commands
Check battery voltage (if 2-resistor battery mod fitted)
Return to "Listens for user-defined commands"

Commands are sent from a phone or PC via Bluetooth/serial link as a series of 5 characters, each beginning with $, followed by the command character, and then 3 numerical digits i.e. $F030

List of available commands (### values are not used, xxx values are used):

Immediate commands (not added to the command list)

J###	Display this list of commands
L###	List commands currently stored in EEPROM
C###	Clear all stored commands
G###	Execute all stored commands
0xxx (zero)	Perform a compass calibration for xxx turn units (calculate magnetometer offsets)
Z###	Request current heading
I###	Battery voltage request
K###	Continuously seek random headings (until magnet switch)
t###	List Wheel calibration and Drop/Stop values
qxxx	Left wheel Forward set to xxx (duty cycle – 100 to 255)
wxxx	Left wheel Backward set to xxx (duty cycle – 100 to 255)
rxxx	Right wheel Forward set to xxx (duty cycle – 100 to 255)
exxx	Right wheel Backward set to xxx (duty cycle – 100 to 255)
Vxxx	Turning duration per unit (for Left/Right) to xxx
uxxx	Turning duration per unit (for Heading) to xxx

Stored/sequence commands

Fxxx	Forward by xxx units
Bxxx	Backward by xxx units
Oxxx	Left turn by xxx units
Pxxx	Right turn by xxx units
Hxxx	Turn to heading xxx degrees (0 – 255, not 0 – 359)
axxx	Left wheel Forward set xxx (temporary; allow differential wheel speeds)
sxxx	Left wheel Backward set xxx (temporary; allow differential wheel speeds)
dxxx	Right wheel Forward set xxx (temporary; allow differential wheel speeds)
fxxx	Right wheel Backward set xxx (temporary; allow differential wheel speeds)
gxxx	Reset forward/backward correction to stored values (make forward straight again)
D###	Start drop (uses chute open time defined by $Txxx)
S###	Stop drop (uses chute close time defined by $Sxxx)
Txxx	Chute open set to xxx (motor engaged for xxx time units)
Uxxx	Chute close set to xxx (motor engaged for xxx time units – likely longer than $Txxx)

Qxxx	Perform Lane change (non-heading version) xxx = 1 for jitter
Rxxx	Perform Lane change (Heading version) xxx = 1 for jitter
4xxx	Lane change var 1 set to xxx how much to initially move forward
5xxx	Lane change var 2 set to xxx how much to turn left
6xxx	Lane change var 3 set to xxx how much to move forward
7xxx	Lane change var 4 set to xxx how much to finally turn right
@xxx	Draw dots with xxx = number of dots to draw
1xxx	Draw dot var 1 set to xxx how much to initially move forward
2xxx	Draw dot var 2 set to xxx how much to move forward, chute open
3xxx	Draw dot var 3 set to xxx how much to initially move forward, chute closed
8xxx	Draw dot left/right correction (100+/-) after $9xxx dots, perform a left/right turn
9xxx	Draw dots, turn correction dot counter, before performing a turn correction
Ixxx	Jitter strength set to xxx How much it turns left/right
Exxx	Jitter
pxxx	Pause (xxx * 50) milliseconds