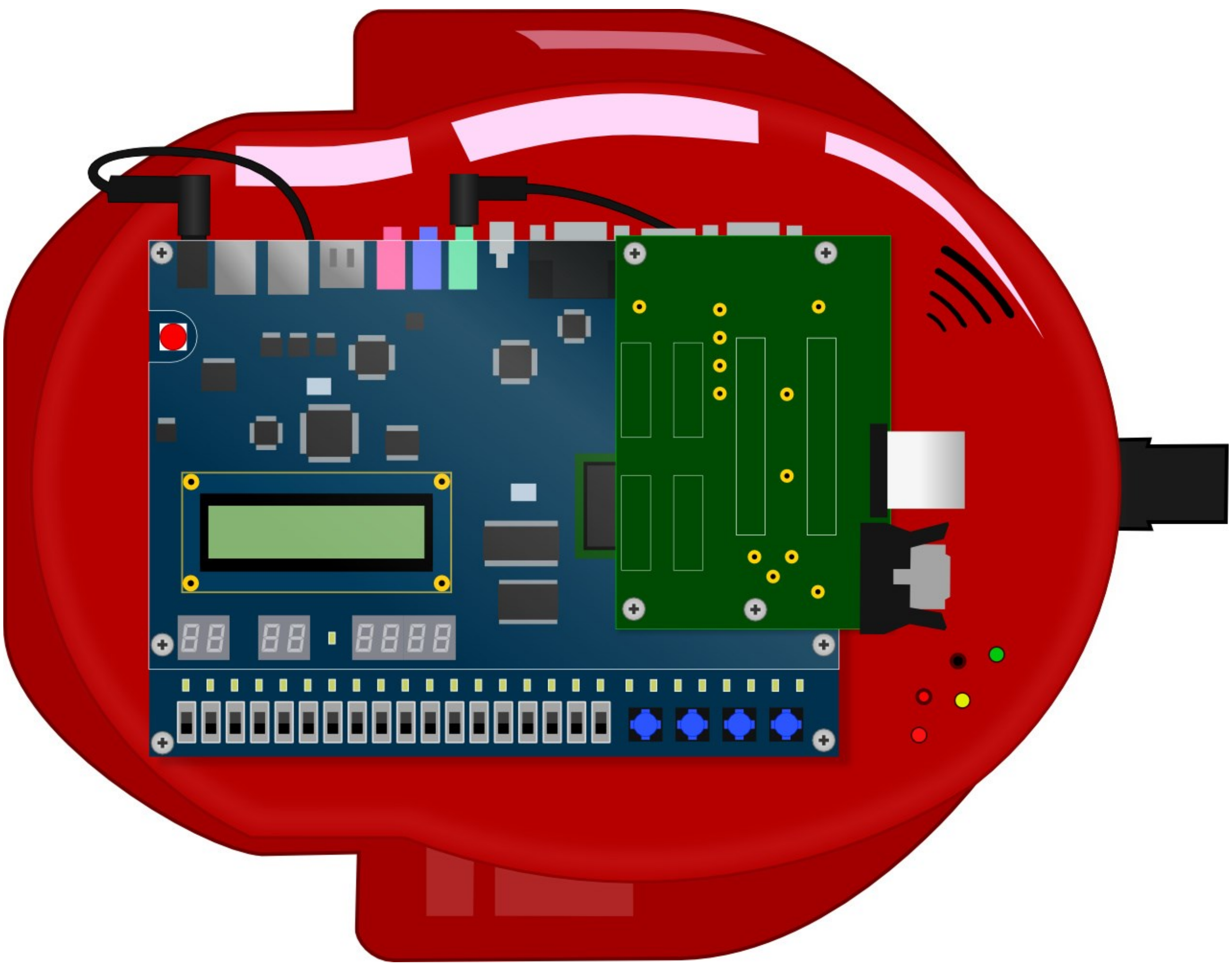
DE2Bot User's Manual
Georgia Institute of Technology ECE2031



Introduction

This document is intended for the end-user of the DE2Bot: students in ECE2031. It provides an overview of the hardware, a walkthrough of the built-in self-test program, and a programming guide for use with the version of SCOMP provided during the final design project.

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DE2Bot Hardware Overview

The DE2Bot is comprised of the commercially-available AmigoBot with its electronics removed and replaced with custom hardware and an Altera DE2 FPGA development board. This configuration allows complete control of the robot hardware using custom digital circuits created within the FPGA.

Locations of important features are shown below in Figure 1.

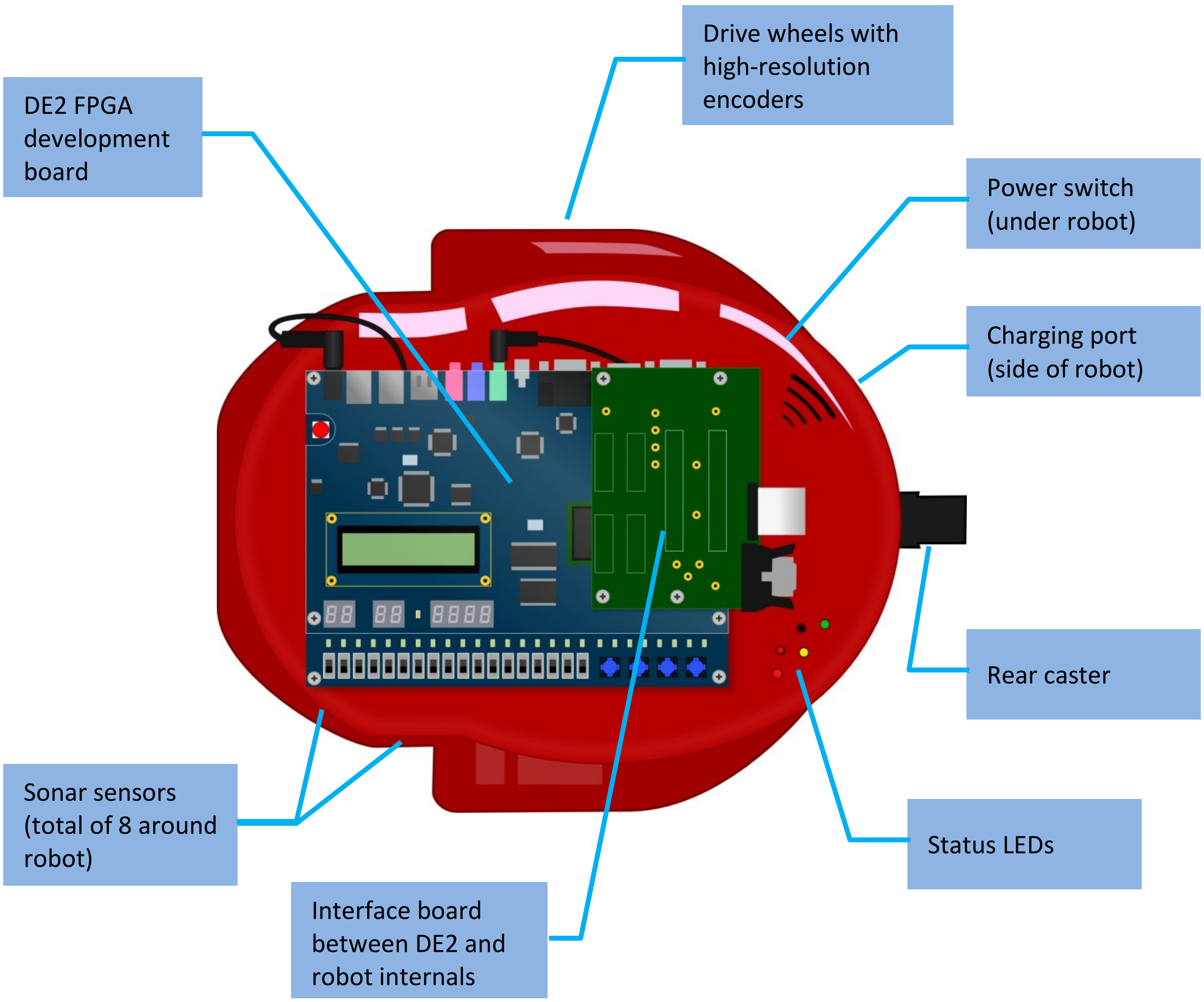

Figure 1. Locations of important DE2Bot features.

Feature Descriptions

Wheels and Encoders

The DE2Bot has two drive wheels, one on each side, allowing it to use differential steering to move around smooth or dense-carpeted surfaces. A rear caster wheel helps to support the robot without interfering with movement. The drive wheels are powered by DC motors through a reduction gearbox.

Each motor is equipped with a high-resolution (39000 ticks per wheel revolution) quadrature encoder which can be used to keep track of wheel rotation and calculate angular position, velocity, and acceleration. The addition of specialized hardware can enable dead reckoning estimation of robot position.

The control circuitry for the motors includes a watchdog timer that disables the motors if no 'alive' signal is received for approximately one second. In the default Quartus project for ECE2031, an additional safety mechanism disables the motors until SW17 has been toggled (both up and down) after power-up or reset. This is to ensure that the robot does not move immediately after being programmed, and guarantees that the robot will stop when PB0 is pressed.

Sonar Distance Sensors

The DE2Bot is equipped with eight sonar transducers that can be used to measure distances to objects. The sensors are arranged around the robot as shown in Figure 2 and numbered clockwise starting with Sonar 0, which is facing left (from the robots forward orientation; downwards in the figure).

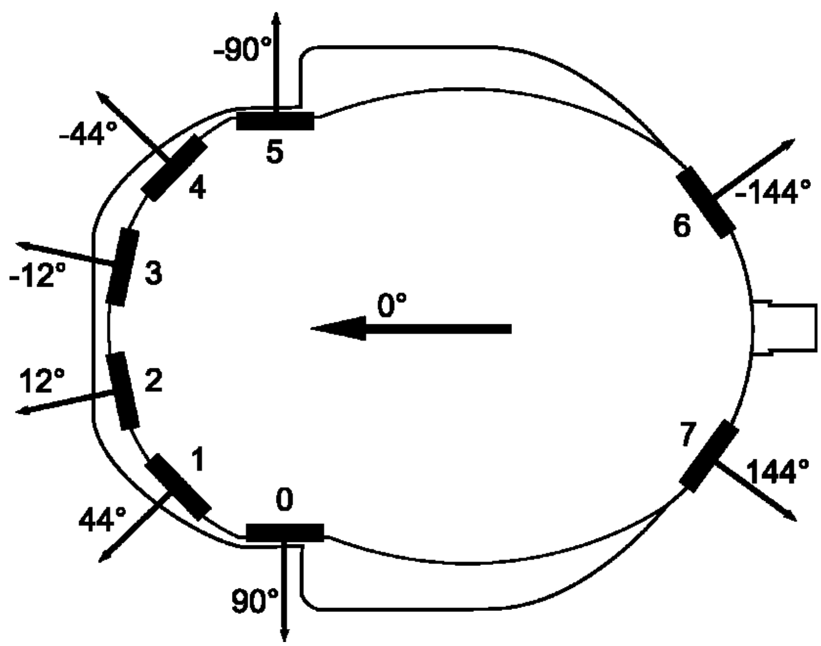

Figure 2. Sonar sensor numbering, positions, and directions.

The sonar sensors can measure distances from 15cm up to 5m or more depending on the reflectivity of the object. The resolution of the measurement is dependent on the sampling speed of the interfacing hardware; the default resolution of the DE2Bot hardware is 1mm. Note that this does *not* imply 1mm accuracy, though within ±5mm can be expected.

Each sonar sensor can be enabled independently. The sonar firing rate is 20Hz divided between all enabled sonars: if only one sonar is enabled, it is refreshed at 20Hz; if all eight sonars are enabled, the overall refresh rate is 2.5Hz (20Hz/8).

Battery and Charge Port

The DE2Bot contains a 5.5Ah rechargeable LiPo battery, enabling several hours of ‘idle’ use or approximately an hour of continuous use between charges. A charge port on the side of the robot provides easy attachment of an external charger.

Note that when the robot’s main power switch is ON, the charging port is disconnected from the battery. **In order to charge, the power switch must be in the OFF position.**

Care should be taken to never discharge the battery below 13V. Doing so will reduce the life of the battery and may cause permanent damage.

DE2 Development Board

The Altera DE2 board provides access to a Cyclone II FPGA as well as various I/O, such as:

- 18 slide switches
- four push buttons
- 27 LEDs
- a 16x2-character LCD
- eight 7-segment displays
- audio in and out with ADC/DAC
- VGA video output
- an RS-232 serial port
- SD card slot.

The DE2 on the DE2Bot connects to the robot’s internal circuitry through its GPIO ports, allowing direct digital control of all robot functions.

Note that the DE2’s power button (red button at top left of board) should not be used. Leave the DE2 ON and use the robot’s main power switch to turn the DE2Bot on and off.

Wireless Serial Connection

An internally-mounted XBee wireless communication module enables remote communication, either robot-to-robot or robot-to-PC. The module is connected to the DE2’s RS-232 port and, by default, transparently emulates a direct connection to a central PC.

For the serial communication to be useful, some “back-end” software must be running on the PC, which will vary from semester to semester. Check with lab administrators for current functionality.

The UART is internally rate-limited to ensure consistent results when many robots are communicating at the same time. Each robot may only send six bytes at a time, up to five times per second (every 200ms). Additionally, the [up to] six bytes must be sent in succession (within a few hundred SCOMP instructions) so that they can be packaged in to a single wireless packet.

The communication latency from the DE2Bot to the PC and back is undefined, but is typically 50-100ms.

Self-test Operation

On power-up, a self-test program is automatically loaded from non-volatile memory. This program enables the user to quickly test for proper operation of the DE2Bot hardware.

Note: the self-test program uses PB0 as RESET. Press PB0 to restart the program at any time.

Power-up Tests

As soon as the DE2Bot is turned on (or when the self-test is restarted with PB0):

- The DE2Bot beeps for 0.2s
- The battery voltage is displayed (in hexadecimal) on the HEX5 and HEX4 seven-segment displays
  - Voltage is in tenths of volts. ‘A7’, 16.7V, is fully charged and ‘82’, 13.0V, is dead.
- The battery level is displayed as a bar graph on red LEDs 0-14
  - A fully-charged battery will light all LEDs 0-14. A dead battery will light only LED 0.
- Green LEDs 0, 1, and 2 light, mirroring the inactive state of pushbuttons 1, 2, and 3 respectively
  - Pressing a PB will turn off the respective green LED.
- The LCD displays a menu prompting the user to choose “Self Test” or “Troubleshoot”

Power-up Errors

If the battery is too low to safely operate the DE2Bot, the user is warned with beeps, flashes, and a written warning on the LCD. In this case, turn off the DE2Bot immediately and plug it in to a charger.

If nothing happens when the DE2Bot is turned on, there is likely a problem with the battery or power circuitry. Turn the DE2Bot switch to the OFF position and notify an administrator.

Automated Self-test

At the LCD prompt after power-up, pressing PB1 will begin a mostly-automated self-test routine.

The LCD will provide prompts that allow the user to execute the automated self-test without this document, but detailed information is provided here for first-time users or in the case of errors.

1) Battery Check

The battery voltage is tested and displayed in decimal on the LCD screen. Battery voltage should be 13-17V for proper robot operation.

2) Sonar Test

Each of the eight sonar sensors is tested, starting with Sonar0 (left-facing sonar) and proceeding clockwise. Each sonar is polled until either a valid reading is obtained, or 5 seconds elapse.

If the test pauses on a particular sonar, move an object (such as your hand) in front of that sonar so that a reading can be obtained. The current sonar is indicated on the red LEDs, or you can listen for the characteristic ‘clicking’ sound.

Once all sonar sensors are tested and working, the message “All sonars are working” is displayed on the LCD, and the program automatically proceeds to the next test.

Sonar Errors

If a sonar does not return a valid reading within 5 seconds, it is assumed to be defective. At the end of the sonar test, the green LEDs display which sonar(s) are not working. Note the number(s), and return the DE2Bot to an administrator.

3) Encoder Test

Warning: The test immediately following this test will cause the robot to move under its own power. Ensure that the DE2Bot is either on the floor in a clear area, or its wheels are raised off of the supporting surface. Continuing this test with the robot on a table can cause it to fall when the following test begins.

Once the sonar test is complete, the LCD will display “Rotate left wheel 30+ degrees”. At this prompt, manually rotate the left wheel in either direction until the LCD changes to “Rotate right wheel 30+ degrees”, then repeat the rotation with the right wheel.

During this test, the current encoder position value is displayed on HEX3-0.

Encoder Errors

If no wheel motion is detected within 10 seconds, the test fails and an error is displayed on the LCD. Inform an administrator.

4) Motor Test

Immediately after the encoder test completes, the motor test begins. If the safety switch (SW17) has not been toggled since reset, the LCD will prompt “Toggle SW17”, at which point you should raise and lower SW17. Once the safety is disabled, the left wheel will begin turning forwards and the LCD will display “Left wheel turning? 2-N/1-Y”. If the wheel is turning, press PB1. If not, press PB2. The test will then repeat with the right wheel.

Motor Errors

If either wheel does not turn when expected:

If LEDG8 (between HEX4 and HEX3) is flashing, the battery is too low to operate the motors. Turn the DE2Bot off and plug it in to a charger.

If LEDG8 is not flashing, there is likely a problem with the motors or supporting electronics. Notify an administrator.

Self-test Finish

Once the motor test is complete, the LCD will display “Self Test Finish   PB1 – Main Menu”. If any errors occurred during the self-test, a red LED will be lit as follows:

- LED0-7 indicate sonar 0-7 errors
- LED8 and LED9 indicate left and right encoder errors
- LED9 and LED10 indicate left and right motor errors

Press PB1 to return to the main menu.

Manual Tests

From the main menu, pressing PB2 will enter manual-test (troubleshooting) mode, where specific hardware can be tested more thoroughly.

Entering Tests

Once in troubleshooting mode, raising a switch and pressing PB1 will enter the corresponding test - see Table 1 below. If multiple switches are up, the lowest-indexed test is selected. While in a test, pressing PB2 and PB3 together will return to the troubleshooting test selection mode. Use PB0 to return to the main menu.

TABLE 1
MANUAL TEST SELECTION

Switch Raised	Hardware Tested
SW0	Battery
SW1	Speaker
SW2	Switches and Pushbuttons
SW3	Sonars
SW4	LEDs, 7-segment displays, LCD
SW5	Wheel encoders
SW6	Motors

Battery Test (SW0)

The battery voltage is continuously read and displayed on the LCD (in decimal) and 7-segment display (in hex).

Speaker (SW1)

The robot emits a stream of beeps with 0.15s on and 0.5s off. The LEDs light when the beep should be on.

Switches and Pushbuttons (SW2)

Switches 0-16 are reflected on red LEDs 0-16. The pushbuttons are reflected on the green LEDs 0-2.

Sonars (SW3)

Switches 0-7 will individually enable sonars 0-7. The value returned by the sonar is displayed on the 7-segment display in hexadecimal. If more than one sonar is enabled, only the lowest-indexed one's value is displayed.

LEDs, 7-segment displays, LCD (SW4)

All LEDs flash at 1Hz. The 7-segment displays alternate between 0x1111 and 0xEEEE (exercising all segments). The LCD alternates between blank and black.

Wheel Encoders (SW5)

SW0 up/down selects between the left and right wheels. The selected wheel's current position value is displayed on HEX3-0 and the immediate velocity on HEX7-4.

Motors (SW6)

Hold PB1 to power the right motor and PB2 to power the left motor. Raise SW0 to reverse the right motor, and SW1 to reverse the left motor.

Programming Guide

At the beginning of the final project in ECE2031, students are provided with a Quartus project containing the SCOMP processor and many IO devices which interface with the DE2 and DE2Bot hardware. Each of these devices is assigned an IO address in the SCOMP system as detailed in Table 2.

Changes to SCOMP

SCOMP and its Quartus project have been modified from lab 8 in the following ways:

- SCOMP clocked at 12.5MHz.
- All SCOMP instructions in Table 7.1 of the lab manual implemented.
- Subroutine stack depth increased to 6.
- SHIFT instruction changed from “logical” to “arithmetic” to better support mathematical operations.
- Central IO_DECODER device replaces AND/NAND decoders for each peripheral.
- IO_CYCLE and IO_WRITE operation slightly modified to avoid possible contentions.

SCOMP Interrupt System

An interrupt system is being developed for SCOMP. Details will be added here when it is complete.

IO Device Quick Reference

TABLE 2
SCOMP QUARTUS PROJECT I/O DEVICE DESCRIPTIONS

Name	IO Address	IN/OUT	Description
SWITCHES	0x00	IN	Read DE2 switches SW15-S0.
LEDS	0x01	OUT	Write to DE2 LEDs LEDR15-LEDR0.
TIMER	0x02	IN/OUT	Read 10Hz timer count. Write anything to reset to 0.
XIO*	0x03	IN	Read PB3-PB1, SW16, SAFETY signal, and some GPIO.
SSEG1	0x04	OUT	Write to left 4-digit seven-segment display.
SSEG2	0x05	OUT	Write to right 4-digit seven-segment display.
LCD	0x06	OUT	Write to LCD (16-bit hexadecimal).
XLEDS	0x07	OUT	Write to DE2 LEDs LEDG7-LEDG0 and LEDR17/LEDR16
BEEP	0x0A	OUT	Write 1-7 for beep frequency (360Hz*N). Write 0 to turn off beep.
LPOS*	0x80	IN	Read the current position of the left wheel encoder; 1.05mm/tick.
LVEL*	0x82	IN	Read the current velocity of the left wheel; 1.05mm/s.
LVELCMD*	0x83	OUT	Write the desired velocity of the left wheel; 1.05mm/s.
RPOS*	0x88	IN	Read the current position of the right wheel encoder; 1.05mm/tick.
RVEL*	0x8A	IN	Read the current velocity of the right wheel; 1.05mm/s.
RVELCMD*	0x8B	OUT	Write the desired velocity of the right wheel; 1.05mm/s.
I2C_CMD*	0x90	OUT	Write configuration information to the I2C controller.
I2C_DATA*	0x91	IN/OUT	Read or write data from/to the I2C controller.
I2C_RDY*	0x92	IN/OUT	Begin I2C transaction or check transaction status.
UART_DAT	0x98	IN/OUT	Read or write one byte (low-byte of AC) from/to the UART.
UART_RDY	0x99	IN	Read the status of the UART controller.
DIST0 - DIST7*	0xA8 - 0xAF	IN	Read the measured distance from Sonar0 - Sonar7.
SONAREN*	0xB2	OUT	Write bits 0-7 to enable Sonar0 - Sonar7.
XPOS*	0xC0	IN	Read dead-reckoning X position estimation; 1.05mm/count.
YPOS*	0xC1	IN	Read dead-reckoning Y position estimation; 1.05mm/count.
THETA*	0xC2	IN	Read dead-reckoning angle estimation; 702 counts/circle.
RESETODO	0xC3	OUT	Reset dead-reckoning odometer: X,Y,θ = 0,0,0.

* additional details in following sections

Detailed Description of Select Devices

Wheel Position, Velocity, and Velocity Commands

The values read from LPOS and RPOS provide the wheel encoder counts since reset. The encoders provide 304 ticks/revolution, which corresponds to linear movement of approximately 1.05mm/count for LPOS and RPOS.

LVEL and RVEL provide approximations of wheel velocity by sampling the position every 0.1s and providing the difference x10; the units are thus approximately 1.05mm/s.

LVELCMD and RVELCMD accept values in the same units as LVEL and RVEL, and attempt to control the wheel velocities to match that value. Be aware that very low speeds (usually <50mm/s) may not be able to overcome the static friction of the motors, gearboxes, axles, and wheels, and so may not result in any movement. However, once moving, the lower bits of LVELCMD and RVELCMD do provide additional resolution to the speed.

The values sent to LVELCMD and RVELCMD should not exceed ±511. If a value outside that range is provided, the motor controller will interpret it as 0 (stopped).

The acceleration (including deceleration) of each wheel is fixed at 512units/s; thus, if the robot is moving at velocity v (in robot units) and is commanded to stop (by sending 0 to LVELCMD and RVELCMD), the expected overshoot can be estimated by $v^2/1024$ (the result of which is, again, in robot units of 1.05mm).

Sonar Sensors

Each sonar can be independently enabled through the SONAREN register. Bits 0-7 of this register correspond to sonars 0-7; e.g. writing 0b00000001 will enable only Sonar0 and writing 0b11111111 will enable all sonars.

Each enabled sonar makes its measurements available at the corresponding DIST register DIST0-DIST7. This value is in mm and has a resolution of 1mm, but its accuracy (both linearity and offset) are undefined and typically varies ±5mm.

If no ping is returned (usually because either nothing is in front of the sonar, or the object is angled such that the ping bounces in another direction), the value is set to the maximum positive value of 0x7FFF.

Sonars update in a round-robin fashion at 20Hz, skipping any that are not enabled. If all sonars are enabled, a particular measurement will update at 2.5Hz (20Hz/8). If only one sonar is enabled, it will update at the full 20Hz.

I^{2}C Controller and Battery Voltage

The DE2Bot contains an I^{2}C bus, which is currently used to communicate with the A/D converter that measures the battery voltage. SCOMP interfaces with the I^{2}C bus through a controller with three I/O registers:

- **I2C_CMD**: write-only; contains configuration information for the controller.
  - bits 15-12: number of bytes to write (0, 1, or 2)
  - bits 11-9: number of bytes to read (0, 1, or 2)
  - bits 8-1: 7-bit I^{2}C address of device to communicate with; <u>excludes</u> RnW bit
  - bit 0: ignored; the RnW bit is set on the fly according to the current operation
- **I2C_DATA**: read/write; data to send, and data received.
  - If transmitting or receiving one byte, bits 7-0 are used
  - If transmitting or receiving two bytes, bits 15-9 are the first byte, then bits 7-0
- **I2C_RDY**: read/write; status indicator
  - Writing to I2C_RDY begins an I2C transaction; set up I2C_CMD and I2C_DATA first.
  - Reading I2C_RDY will return zero if the controller is idle, or non-zero if a communication is in progress. Do not modify I2C_CMD or I2C_DATA while I2C_RDY reads as non-zero.

Odometry

The Quartus DE2Bot project contains a device that performs dead-reckoning odometry: continuously integrating the movement of the wheels to maintain an estimate of the robot's position and heading. This estimation can be read from IO registers XPOS, YPOS, and THETA.

At power-up or reset, the position of the robot defaults to X,Y,θ=0,0,0. The coordinate system is shown in Figure 3: the reset orientation is defined as facing the positive X direction, with positive Y to the left, and theta following the normal right-handed convention (with Z upwards). Writing to IO location RESETODO will reset the odometry to this position.

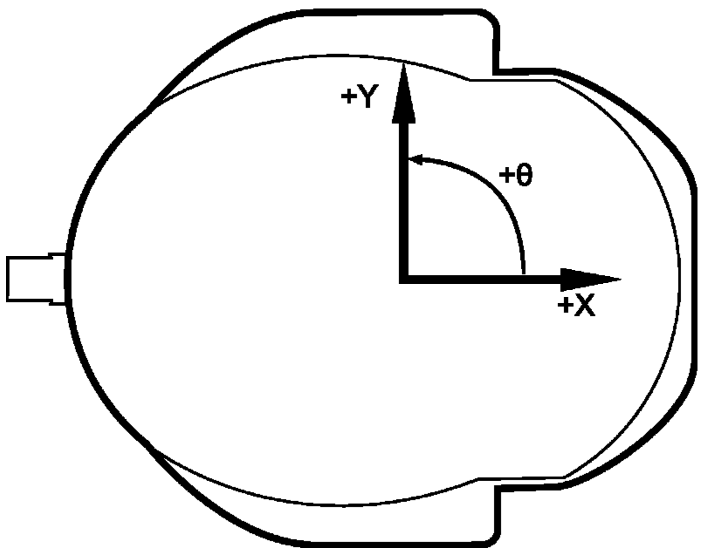

Figure 3. Coordinate system used for DE2Bot odometry.

The units for the X and Y positions are 1.05mm/count – the same as the resolution of LPOS and RPOS.

For theta, one full rotation of the robot is divided in to 702 units (a product of the robot geometry), giving an approximate resolution of 0.51°/count. The theta value will always be [0,701]; rotating counterclockwise past 701 will rollover to 0, and rotating clockwise past 0 will rollover to 701.

Dead-reckoning is highly susceptible to accumulated error from wheel slippage, wheel-size and wheel-base errors, mathematical rounding, and other sources. The odometry values will likely contain significant error after as little as a few meters of travel or one rotation of the robot, and much of the error will *not* be systematic.

XIO

The value read from XIO contains the following signals:

- XIO[15..5] : GPIO pins on the DE2 header
- XIO[4] : SAFETY signal, which indicates whether or not SW17 has been toggled
- XIO[3] : SW16
- XIO[2..0] : Pushbuttons PB3– PB1 (PB0 is global reset and cannot be read)

Note that the pushbuttons are active-low: a pressed pushbutton will appear as a '0' in XIO.

Good Practices for Robot Programming

This section details some recommended practices for safe and effective use and control of the DE2Bot.

At Program Start

As soon as the program starts or is reset, the following should be done in order:

1. Immediately stop the robot by writing 0 to LVELCMD and RVELCMD
2. Check the battery voltage, and prevent execution if it is below 13V
3. Wait for the safety switch (SW17) to be toggled
4. Wait for some form of user input (e.g. pressing a PB)

An example of this initialization procedure can be found in Appendix A.

Testing Values

Two points must be kept in mind when making decisions based on values obtained from LPOS/RPOS, odometry, sonars, or any other real-world measurement:

- Never test for exact values, as there is no guarantee that a particular value will occur. Instead, always test for a range.
    - Example1: polling LPOS while the robot is moving might return 0xFE at one sample and 0x100 at the next sample, so testing for 0xFF will never pass.
        - Testing for ≥0xFF would correctly trigger even if 0xFF itself never occurs.
    - Example2: many values are impossible to obtain from peripherals because of limited range or resolution. For example, LVEL and RVEL only have a resolution of 10 units.
- Be aware of edge conditions, which can erroneously cause tests to pass or fail.
    - Example 1: if the robot is facing its reset direction then ideally theta would be 0, but any small turn clockwise will change theta to 701, in which case a test for theta>100 (intended to check if the robot has turned a certain amount) will immediately pass.

Appendix A:

Example starting point for ASM code.

```
; SimpleRobotProgram.asm
; Created by Kevin Johnson
; (no copyright applied; edit freely, no attribution necessary)
; This program does basic initialization of the DE2Bot
; and provides an example of some peripherals.

; Section labels are for clarity only.


ORG        &H000       ;Begin program at x000
;***************************************************************
;* Initialization
;***************************************************************
Init:
      ; Always a good idea to make sure the robot
      ; stops in the event of a reset.
      LOAD   Zero
      OUT    LVELCMD     ; Stop motors
      OUT    RVELCMD
      OUT    SONAREN     ; Disable sonar (optional)

      CALL   SetupI2C    ; Configure the I2C to read the battery voltage
      CALL   BattCheck   ; Get battery voltage (and end if too low).
      OUT    LCD         ; Display batt voltage on LCD

WaitForSafety:         ; Wait for safety switch to be toggled
      IN     XIO         ; XIO contains SAFETY signal
      AND    Mask4       ; SAFETY signal is bit 4
      JPOS   WaitForUser ; If ready, jump to wait for PB3
      IN     TIMER       ; We'll use the timer value to
      AND    Mask1       ;  blink LED17 as a reminder to toggle SW17
      SHIFT  8           ; Shift over to LED17
      OUT    XLEDS       ; LED17 blinks at 2.5Hz (10Hz/4)
      JUMP   WaitForSafety

WaitForUser:           ; Wait for user to press PB3
      IN     TIMER       ; We'll blink the LEDs above PB3
      AND    Mask1
      SHIFT  5           ; Both LEDG6 and LEDG7
      STORE  Temp        ; (overkill, but looks nice)
      SHIFT  1
      OR     Temp
      OUT    XLEDS
      IN     XIO         ; XIO contains KEYs
      AND    Mask2       ; KEY3 mask (KEY0 is reset and can't be read)
      JPOS   WaitForUser ; not ready (KEYs are active-low, hence JPOS)
      LOAD   Zero
      OUT    XLEDS       ; clear LEDs

;***************************************************************
;* Main code
;***************************************************************
Main: ; "Real" program starts here.
      OUT    RESETODO    ; reset odometry in case wheels moved after programming
      JUMP   Main        ; this example does nothing.

Die:
; Sometimes it's useful to permanently to stop execution.
; This will also catch the execution if it accidentally
```

```
; falls through from above.
      LOAD   Zero         ; stop everything
      OUT    LVELCMD
      OUT    RVELCMD
      OUT    SONAREN
      IN     TIMER
      OUT    SSEG2        ; an indication that we are dead
      JUMP   Die          ; do this forever


;***************************************************************
;* Subroutines
;***************************************************************

; Subroutine to wait (block) for 1 second
Wait1:
      OUT    TIMER
Wloop:
      IN     TIMER
      OUT    XLEDS       ; user-feedback that a pause is occuring
      ADDI   -10         ; 1 second in 10Hz
      JNEG   Wloop
      RETURN

; This subroutine will get the battery voltage,
; and stop program execution if it is too low.
; SetupI2C must be executed prior to this.
BattCheck:
      CALL   GetBattLvl
      JZERO  BattCheck   ; A/D hasn't had time to initialize
      SUB    MinBatt
      JNEG   DeadBatt
      ADD    MinBatt     ; get original value back
      RETURN
; If the battery is too low, we want to make
; sure that the user realizes it...
DeadBatt:
      LOAD   Four
      OUT    BEEP        ; start beep sound
      CALL   GetBattLvl  ; get the battery level
      OUT    SSEG1       ; display it everywhere
      OUT    SSEG2
      OUT    LCD
      LOAD   Zero
      ADDI   -1          ; 0xFFFF
      OUT    LEDS        ; all LEDs on
      OUT    XLEDS
      CALL   Wait1       ; 1 second
      Load   Zero
      OUT    BEEP        ; stop beeping
      LOAD   Zero
      OUT    LEDS        ; LEDs off
      OUT    XLEDS
      CALL   Wait1       ; 1 second
      JUMP   DeadBatt    ; repeat forever

; Subroutine to read the A/D (battery voltage)
; Assumes that SetupI2C has been run
GetBattLvl:
```

```
      LOAD   I2CRCmd     ; 0x0190 (write 0B, read 1B, addr 0x90)
      OUT    I2C_CMD     ; to I2C_CMD
      OUT    I2C_RDY     ; start the communication
      CALL   BlockI2C    ; wait for it to finish
      IN     I2C_DATA    ; get the returned data
      RETURN

; Subroutine to configure the I2C for reading batt voltage
; Only needs to be done once after each reset.
SetupI2C:
      CALL   BlockI2C    ; wait for idle
      LOAD   I2CWCmd     ; 0x1190 (write 1B, read 1B, addr 0x90)
      OUT    I2C_CMD     ; to I2C_CMD register
      LOAD   Zero        ; 0x0000 (A/D port 0, no increment)
      OUT    I2C_DATA    ; to I2C_DATA register
      OUT    I2C_RDY     ; start the communication
      CALL   BlockI2C    ; wait for it to finish
      RETURN

; Subroutine to block until I2C device is idle
BlockI2C:
      IN     I2C_RDY;   ; Read busy signal
      JPOS   BlockI2C    ; If not 0, try again
      RETURN             ; Else return


;***************************************************************
;* Variables
;***************************************************************
Temp:     DW 0 ; "Temp" is not a great name, but can be useful

;***************************************************************
;* Constants
;* (though there is nothing stopping you from writing to these)
;***************************************************************
NegOne:   DW -1
Zero:     DW 0
One:      DW 1
Two:      DW 2
Three:    DW 3
Four:     DW 4
Five:     DW 5
Six:      DW 6
Seven:    DW 7
Eight:    DW 8
Nine:     DW 9
Ten:      DW 10

; Some bit masks.
; Masks of multiple bits can be constructed by ORing these
; 1-bit masks together.
Mask0:    DW &B00000001
Mask1:    DW &B00000010
Mask2:    DW &B00000100
Mask3:    DW &B00001000
Mask4:    DW &B00010000
Mask5:    DW &B00100000
Mask6:    DW &B01000000
Mask7:    DW &B10000000
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```
LowByte:  DW &HFF      ; binary 00000000 1111111
LowNibl:  DW &HF       ; 0000 0000 0000 1111

; some useful movement values
OneMeter: DW 952       ; ~1m in 1.05mm units
HalfMeter: DW 476      ; ~0.5m in 1.05mm units
TwoFeet:  DW 640       ; ~2ft in 1.05mm units
Deg90:    DW 176       ; ~90 degrees in odometry units
Deg180:   DW 351       ; 180
Deg270:   DW 527       ; 270
Deg360:   DW 702       ; can never actually happen; for math only
FSlow:    DW 100       ; 100 is about the lowest velocity value that will move
RSlow:    DW -100
FMid:     DW 350       ; 350 is a medium speed
RMid:     DW -350
FFast:    DW 500       ; 500 is almost max speed (511 is max)
RFast:    DW -500

MinBatt:  DW 130       ; 13.0V - minimum safe battery voltage
I2CWCmd:  DW &H1190    ; write one i2c byte, read one byte, addr 0x90
I2CRCmd:  DW &H0190    ; write nothing, read one byte, addr 0x90

;***************************************************************
;* IO address space map
;***************************************************************
SWITCHES: EQU &H00  ; slide switches
LEDS:     EQU &H01  ; red LEDs
TIMER:    EQU &H02  ; timer, usually running at 10 Hz
XIO:      EQU &H03  ; pushbuttons and some misc. inputs
SSEG1:    EQU &H04  ; seven-segment display (4-digits only)
SSEG2:    EQU &H05  ; seven-segment display (4-digits only)
LCD:      EQU &H06  ; primitive 4-digit LCD display
XLEDS:    EQU &H07  ; Green LEDs (and Red LED16+17)
BEEP:     EQU &H0A  ; Control the beep
LPOS:     EQU &H80  ; left wheel encoder position (read only)
LVEL:     EQU &H82  ; current left wheel velocity (read only)
LVELCMD:  EQU &H83  ; left wheel velocity command (write only)
RPOS:     EQU &H88  ; same values for right wheel...
RVEL:     EQU &H8A  ; ...
RVELCMD:  EQU &H8B  ; ...
I2C_CMD:  EQU &H90  ; I2C module's CMD register,
I2C_DATA: EQU &H91  ; ... DATA register,
I2C_RDY:  EQU &H92  ; ... and BUSY register
UART_DAT: EQU &H98  ; UART data
UART_RDY: EQU &H98  ; UART status
SONAR:    EQU &HA0  ; base address for more than 16 registers....
DIST0:    EQU &HA8  ; the eight sonar distance readings
DIST1:    EQU &HA9  ; ...
DIST2:    EQU &HAA  ; ...
DIST3:    EQU &HAB  ; ...
DIST4:    EQU &HAC  ; ...
DIST5:    EQU &HAD  ; ...
DIST6:    EQU &HAE  ; ...
DIST7:    EQU &HAF  ; ...
SONAREN:  EQU &HB2  ; register to control which sonars are enabled
XPOS:     EQU &HC0  ; Current X-position (read only)
YPOS:     EQU &HC1  ; Y-position
THETA:    EQU &HC2  ; Current rotational position of robot (0-701)
RESETODO: EQU &HC3  ; write anything here to reset odometry to 0
```