

UNIVERSITY OF SOUTHAMPTON
FACULTY OF PHYSICAL AND APPLIED SCIENCES
Electronics and Computer Science

Two Dimensional Stereoscopic Mapping Robot

by

Henry S. Lovett

A project progress report submitted for the award of
MEng Electronic Engineering

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Examiner: Prof. Mark Zwolinski

23rd March, 2013

Turn off iNotes!

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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Abstract Needed!

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List of Symbols

I^2C	Inter-Integrated Circuit
TWI	Two Wire Interface
SCCB	Serial Camera Control Bus
SPI	Serial Peripheral Interface
kB	KiloBytes
ISR	Interrupt Service Routine
φ_0	Field of view of the camera
φ_1, φ_2	Angle from camera to the object
B	Separation distance of two cameras
D	Distance from camera to the object
i, j	Pixel index of an Image
x_0	Horizontal resolution of the image
x_1, x_2	Distance of object from the normal of the camera

Chapter 1

Introduction

Talk about what I set out to do, include some definitions etc.

What I ended up doing

The uses of my robot.

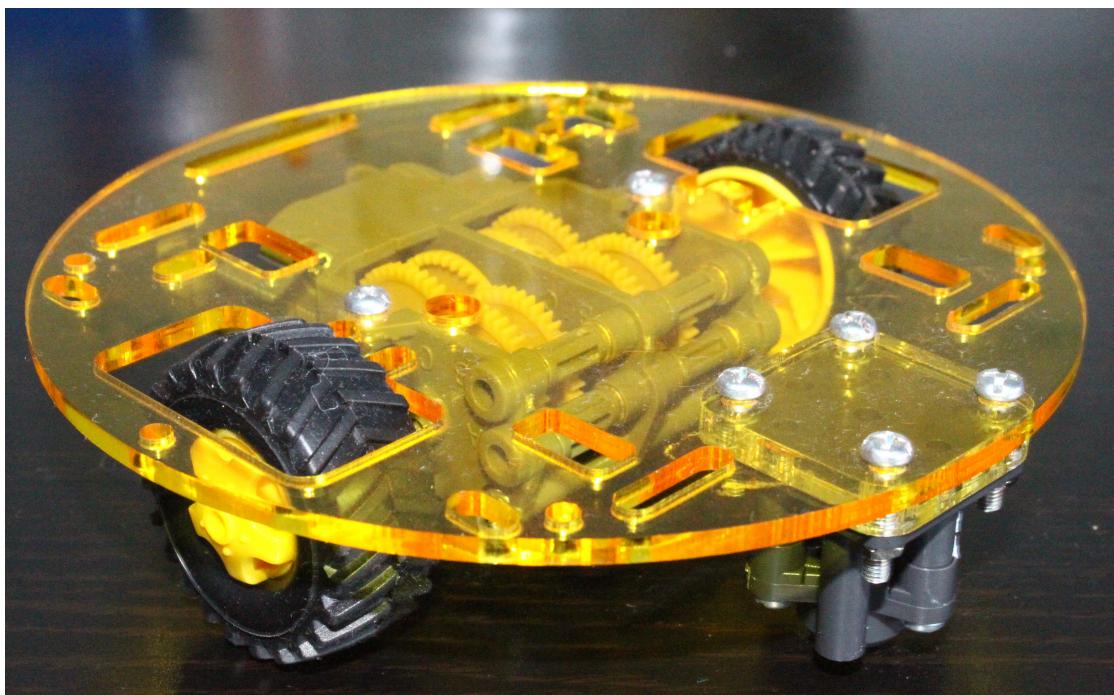


Figure 1.1: The base of the robot

Risk	Severity	Prevention
Parts not arriving on time	High	Order parts as early as possible
Project not fulfilling specification	High	Develop in stages to obtain functionality in parts. Ensure enough time is allocated to the project.
PCB Design is incorrect	Medium	Check the design carefully and get second opinion
Failure of personal computer causing data loss	Low	Keep back ups of all work on Devtrack Git repository and Dropbox.

Table 1.1: A list of risks and the prevention steps taken to reduce their impact

1.1 Project Management

In order to reduce the risk within the project, all aspects of potential issues are looked at and are summarised in table 1.1. A Gantt chart of how time will be spent can be seen in figure A.1.

The project will be designed in stages - first, gaining operation of all the basic sections; movement, image capturing, image detection algorithms etc. These will then be brought together once tested to create the final product.

Chapter 2

Research

The research for this project was split into three sections:

1. Hardware
2. Software, broken down into:
 - (a) Firmware, and
 - (b) Algorithms

Hardware and firmware research will be discussed in this section. Vision algorithms are looked at in detail in chapter [4](#).

2.1 Hardware Research

2.1.1 Microcontrollers

The robot is to be designed with a budget of £80 (not including P.C.B.). The choice of microcontroller will be an important one, as a compromise between cost, power and usability must be made. There are two main brands of microcontrollers present in the consumer market: ARM and Atmel AVRs.

ARM is an architecture which is developed by ARM Holdings. ARM devices come in a many varieties: ARM9, ARM7, Strong ARM, ARM Cortex etc. Whilst ARM Holdings do not fabricate and sell the devices themselves, many companies, such as Texas Instruments, use the architecture and manufacture their own devices.

ARM cores are based on a RISC Harvard architecture and tend to be 32-bit with a high clock speed. ARM microcontrollers have onboard support for SPI, I^2C , PWM, ADCs and can have Flash, SRAM and EEPROM memory built-in. For this comparison, the Stellaris by Texas Instruments will be examined.

Atmel have a variety of products in the microcontroller market. They range from 8-bit, low clock speed devices for the hobbyist (ATMega and ATTiny series), to an improved 8-bit variant (XMega), and a 32-bit design (AT32UC3). XMegas and AVR32s tend to have higher clock speeds than the ATMegas. The AVR core also has a Harvard RISC architecture, and is mainly 8-bit. Atmel devices often have on board peripherals such as I^2C (called TWI on AVRs), SPI and ADCs, as well as a number of different memories: Flash, EEPROM and SRAM. An AT32UC3C0512C, ATXmega256A3BU and ATMega644P will be compared in this section.

Table 2.1 shows a brief summary of some common ARM and AVR microcontrollers. The Stellaris offers the most power with the largest DMIPS performance. However, due to the necessity of floating point operations, the AT32 clearly has a distinct advantage by having a built-in floating point unit. The XMega and ATMega do not offer enough power and are restricted by a small amount of SRAM and Flash. All devices looked at use 3.3V supply and have basic communication protocols (SPI, I^2C and USART). Overall, the AT32UC3C0512C is the best choice with a high throughput, a floating point unit and a vast amount of GPIO and communications. There is no EEPROM which may be desirable, but these can be added onto an SPI or I^2C bus. This device, although slightly more costly, is best suited to this application out of the selection researched.

2.2 Firmware

2.2.1 Camera

The camera used is the OV7670 camera by OmniVision. Steve Gunn provided source code for use on the Il Matto development board which uses an ATMega644P and also has an onboard SD Card reader. The original code streamed video from the camera to a colour TFT screen. The camera is supplied on a small breakout board with a FIFO buffer. The camera operation is discussed in section 3.1. Many implementations of firmware for this camera exist.

	ARM Stelllaris	AT32UC3C0512C	XmegaA3BU	ATmega644P
Clock Speed (MHz)	80	33 or 66	32	12
DMIPS	100	91	-	20 MIPS
Package	100 LQFP or 108 BGA	64, 100, 144TQFP	64 QFP or QFN	40 DIP, 44 TQFP, 44 QFN
Cost of 1 unit(£)	10.30	15.39	6.65	6.86
Flash Size(kB)	256	512	256	64
SRAM Size (kB)	32	64	16	4
EEPROM Size(kB)	2	None internal	4	2
GPIO	64	45, 81 or 123	47	32
Operating Voltage (V)	3.3	5 or 3.3	1.6- 3.6 ¹	2.7-5.5
Communication Interfaces	SPI, I^2C , SSI, MAC, CAN, EPI, USB, US- ART, I2S	SPI, TWI, EBI, USB, Ethernet, CAN, USART, I2S	USART, TWI, USB, SPI	SPI, TWI, USART
Floating Point	None	Built in FPU	None	None
ADCs	16	16	16	8
Timers	4	3 16-bit	7 16-bit, 8 8-bit	2 8-bit, 1 16-bit

Table 2.1: Comparison Table of some common microcontrollers. Data of microcontrollers taken from [Atmel Corporation \(2012a\)](#), [Atmel Corporation \(2012b\)](#), [Atmel Corporation \(2012d\)](#) and [Texas Instruments \(2012\)](#). Costings from [Farnell \(2012\)](#)

2.2.2 Atmel Software Framework

Atmel offer a software framework which contains basic code and device drivers for many of their Xmega and AT32 devices ([Atmel Corporation \(2009\)](#)). There are also many AVR application notes which provide explanations and example code for protocols like TWI, SPI and timers. These application notes are aimed at older devices like the ATTiny and ATMega and are generally written for IAR Embedded Workbench compiler, as opposed to the AVRGCC compiler used within Atmel Studio.

Chapter 3

Hardware and Firmware Development

For initial development, the *Il Matto* board, designed by Steve Gunn, was used. The system has an ATMega644P clocked at 12MHz and has an on-board SD card socket. This provided the ability to prototype circuits which are then used to create a Printed Circuit Board

The following section is broken down into the following parts:

- [3.1 Camera Code](#)
- [3.2 SD Card](#)
- [3.3 Motor Development](#)
- [3.4 PCB Development](#)

3.1 Camera

The camera used is an OV7670 by OmniVision. It is mounted onto a break out board and connected to a AL422B FIFO Buffer. The breakout board has all passive components needed and a 24MHz clock mounted. The schematic for the device can be seen in appendix [B](#).

Original code for the camera operation was given by Steve Gunn, which was used to gain the operation required. This code streamed continuous video to a TFT

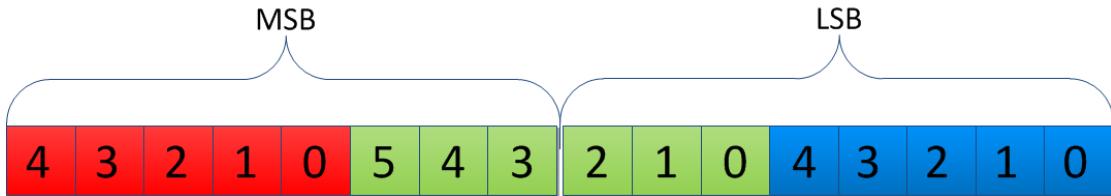


Figure 3.1: RGB565 pixel format

screen. The operation required was to take a single photo from the camera and store the data.

3.1.1 Single Camera Operation

The camera uses a SCCB Interface ([OmniVision, 2007](#)) created by OmniVision. This is almost identical to the I^2C Interface by Phillips and the two protocols are compatible. The original code used a bit-banged SCCB interface which was very slow and used up processing time. This was changed to make use of the built-in interrupt-driven I^2C interface (named TWI in Atmel AVR^s)¹. This communication bus is used to set up the control registers of the OV7670 to enable operation in the correct format. RGB565 is used in my application.

RGB565 is a 16 bit pixel representation where bits 0:4 represent the blue intensity, 5:10 is the green intensity and 11:15 represent the red intensity (see figure 3.1). This is a compact way of storing data but only allows 65536 colours. Greys can also appear to be slightly green due to the inconsistent colour ratio of the green field.

The camera must use a high speed clock in order to ensure the pixels obtained are from the same time. This makes it difficult for an AVR to be able to respond to the camera quick enough (ATMegas typically clocked at 8-12MHz). This highlights the necessity for a FIFO Buffer.

The OV7670 is set up so that the VSYNC pin goes low at the beginning of every full frame of data, and HREF is high when the data being output is valid. The pixel data is then clocked out on every rising edge of PCLK. To control the buffer, WEN (write enable) is NAND with the HREF signal. When both are high, the write enable to the buffer will be active and the data will be clocked in by PCLK. In order to acquire a full frame, the first VSYNC pin is set up to interrupt the

¹ I^2C , SCCB and TWI are all the same but are called differently due to Phillips owning the right to the name “ I^2C ”

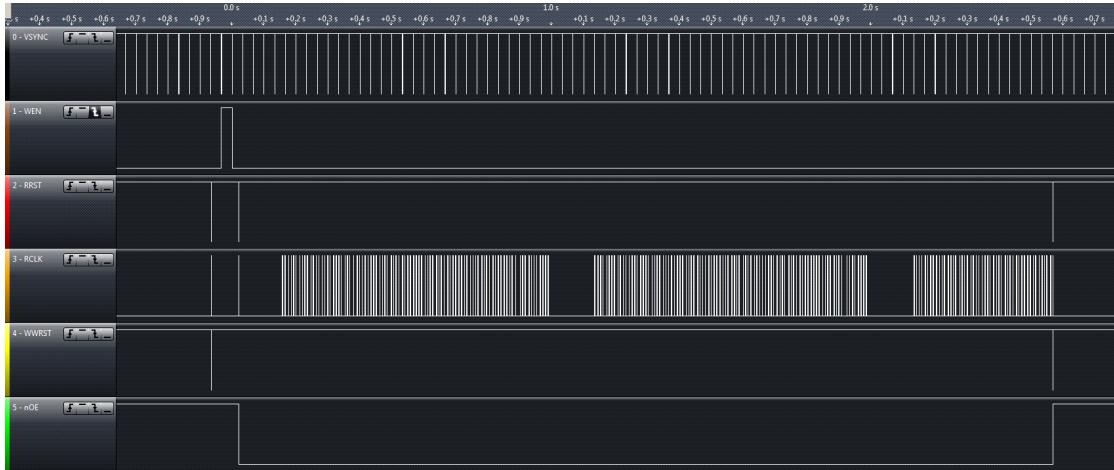


Figure 3.2: Signals generated to control the OV7670 capture and read

AVR to enable WEN. The camera will output an entire frame of pixel data and store it into the buffer. When the second VSYNC is received, the WEN signal is disabled, stopping any more data being stored. The FIFO buffer now contains an entire image.

To obtain the data from the buffer, the AVR sets output enable and pulses the read clock. Valid data is available on the input port while RCLK is high. All the data is then read in half a pixel at a time. The entire operation can be seen in figure 3.2.

Difficulties arose at this point with the storage of the data. The ATMega644P has 4kB of internal SRAM, but 153.6kB of memory is needed to store a single image at QVGA (320 by 240 pixels, 2 bytes per pixel) quality.

Firstly, data was sent straight to a desktop computer via a COM Port using USART. A simple desktop program was written in C# to receive and store all the data, and to make a Bitmap image from the data. This method was slow, taking around 30 seconds to transmit one uncompressed image.

The second option was to use extra memory connected to the microcontroller. An SD card is used as FAT file system so that data can be looked at by a user on a computer. Text log files are also written to aid debugging. This is discussed in section 3.2.

3.1.2 Dual Camera Operation

In order for stereovision to be successful, two cameras separated by a horizontal distance (B) will need to be driven at the same time to obtain photos within a small time frame of one another.

A major problem occurred with using the I^2C interface to set up both cameras. The camera has a set I^2C address of 21_{16} , which cannot be changed. Multiple I^2C devices with exactly the same address cannot be used on the same bus. Two solutions to this are possible: driving one from I^2C and one from SCCB, or using an I^2C multiplexer. By using two different buses, there can be no bus contention. However, SCCB is slow and processor-hungry as it deals with the protocol bit by bit in software. This takes up memory and is not reusable for other operations.

An I^2C multiplexer sits on the bus and has multiple output buses. The master can then address the multiplexer and select whether to pass the bus to bus 0, bus 1 or not allow the data to be transferred. This saves processor time, but means a write operation has to be done to select the camera bus before being able to write to the camera. This slows down the operation, but not as much as using SCCB. The main disadvantage to the I^2C MUX is the extra hardware needed; firstly the MUX itself, but also 7 extra resistors to pull up the two extra buses and the three interrupt lines must be added.

Overall, the disadvantages posed by using a MUX are small, so a multiplexer will be used as opposed to the SCCB interface. A suitable multiplexer is the Phillips PCA9542A ([Phillips, 2009](#)).

The buffers have an output enable pin so the data bus can be shared by both cameras to the AVR. The ATMega644P offers three interrupt pins, two of which are used by the two VSYNC pins for the cameras.

Two ISRs are used to control the VSYNC signals, and when taking a photo, both frames are taken at a time period close together to capture the same scenario. The data for both images are read back individually by the AVR.

Operation to read an image is identical to using one camera. However, an ID number is passed through the functions to make a decision on the pins to use to read the buffer and to enable the output. Care was taken to avoid bus contention, but no checking procedure is explicitly in place. Both images are then read back from the buffers and stored to memory.

	Bitmap	JPEG	PNG	GIF
Extension	*.bmp	*.jpg /*.jpeg	*.png	*.gif
Compression	No	Lossless and Lossy	Lossless ZIP	Lossy
File Size of 320 by 240 pixel Im- age (kB)	225	20	23	24
Bits per Pixel	8, 16, 24 or 32	24	24, 32 or 48	24, but only 256 Colours

Table 3.1: A table comparing different image formats available ([Fulton \(2010\)](#))

3.2 SD Card

To use the SD card, the FATFS library ([Electronic Lives Manufacturing, 2012](#)) was used. The library supplies all the functions for writing a FAT File System in the files *ff.c*, *ff.h*, *ffconf.h*, *diskio.c*, *diskio.h* and *integer.h*. The *diskio.h* functions control what device is being used - SD/MMC Card, USB drive etc. The *ff.h* header contains all the functions to write to in a FAT File system.

An SD card was chosen due to it's small size, low cost and a large data storage. The cards work using an SPI bus which can be used for other devices within the system so the card only uses one extra enable pin in hardware to function.

3.2.1 Storing Images

Many image formats are common, such as Joint Photographic Expert Group (JPEG), Portable Network Graphics (PNG), Bitmap (BMP) and Graphics Interchange Format (GIF). Table 3.1 shows a summary of some common image formats.

It is clear that the best choice for images would be either PNG or JPEG. However, these require more computational time to compress the image into the correct format. To avoid compression, and thereby save processing time, bitmap was chosen at the expense of using more memory. The data in a bitmap image is also stored in RGB format so can be read back easily when processing the image. Appendix F shows the make up of a Bitmap File that was used.



Figure 3.3: An Example Image taken using the OV7670 and stored as a Bitmap on the SD Card

By writing the image in this format, they are then able to be opened on any operating system. This aids debugging and allows the prototyping of image algorithms in a more powerful environment. Figure 3.3 shows a photo taken by the OV7670 and stored on a SD card.

3.2.2 User Interface

The ATMega 664P pinout for the dual camera operation can be seen in table 3.2. Due to a lack of available GPIO pins, an ATMega168 was added on the I^2C bus to act as a port extender. The ATMega168 accepts a read or write command. A write places the written data on Port D and a read returns any button pressed that occurred on Port C. When a button is pressed, this is stored in the ATMega168 until a read has been done. This is so the master (644P) does not miss any button presses while busy doing lengthy operations such as writing an image. The code is based on Application Note AVVR311 ([Atmel Corporation, 2007](#)), written for IAR Compiler. This code was altered to compile with GCC under Atmel Studio. AVRs contain a hardware based I^2C protocol that is interrupt based in software. The interrupt service routine of the TWI vector is a state machine which loads the data to send, stores received data, responds to acknowledges and address calls and deals with bus errors that can occur.

	Port A	Port B	Port C	Port D
0	Data 0	SD Write Protect	I^2C - SCL	No Connection
1	Data 1	SD Card Detect	I^2C - SDA	No Connection
2	Data 2	USB Data Plus	Read Clock 1	VSync 0
3	Data 3	USB Data Minus	Read Reset 1	VSync 1
4	Data 4	SPI Chip Select	Write Enable 1	Read Clock 0
5	Data 5	SPI MOSI	Write Reset 1	Read Reset 0
6	Data 6	SPI MISO	Output Enable 0	Write Enable 0
7	Data 7	SPI Clock	Output Enable 1	Write Reset 0

Table 3.2: Pin Connections of the ATMega644P for Dual Camera Operation.

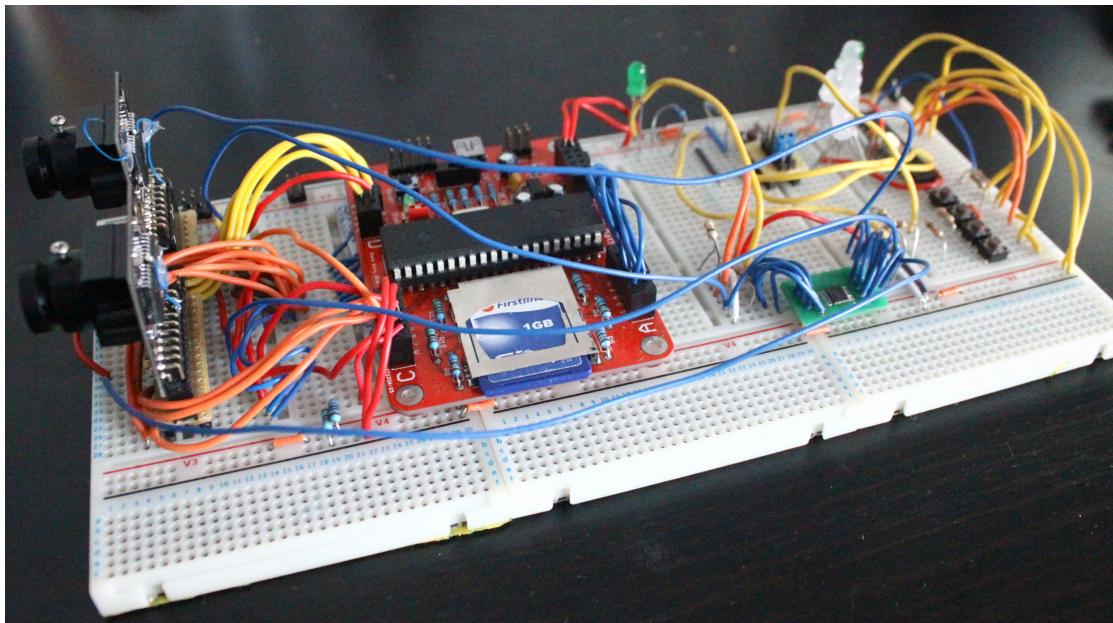


Figure 3.4: Prototype of Dual Camera operation.

The entire prototype for the dual camera operation can be seen in figure 3.4. This circuit was developed to test the cameras and is used to develop the PCB in section 3.4.

3.3 Motor Driver Development

Testing of the Motor system - conclusion is likely to be that it is not a good method, need noise reduction

3.3.1 Hardware

Tachometers are devices used to measure rotational speed of a shaft. Tachometers are most commonly found in bicycles where a small magnet is attached to the wheel and a sensor is attached to the frame. The sensor can then calculate the time period between rotations and therefore can calculate the speed ((?))

Cite Needed

Here, an optosensor, TCRT1010, is used to measure rotations of the wheel and used to be able to move a distance decided by the microcontroller. The TCRT1010 package contains an IR LED and a phototransistor ([Vishay Semiconductors, 2012](#)). The schematic of a simple transistor amplifier used can be seen in figure 3.5 and was taken from ?.

Cite Needed

The wheel's rubber absorbed the IR, so a high voltage was always seen at the collector of the phototransistor. White tipex marks were applied to the wheels at regular intervals, which reflected IR and thereby giving a cheap way to detect wheel rotation. Figure 3.6 shows the voltage at the collector (read by the ADC on the AVR) against the angle of the wheel. Five white tabs were marked on the wheel, and five dips in the voltage can be seen in figure 3.6.

Maybe do some simulations of this circuit? This could dictate a maximum speed

3.3.2 Firmware Development

As the voltage swing from the phototransistor does not reach 0V, the AVR cannot detect this as a logical 0. The internal ADC can be used to continually read the analogue voltage from the phototransistor and detect low points from this data. This method requires the processor to continually compare values and process the data. However, more control would be had over the noise in the data.

An alternative is to use an analogue comparator built in on most AVR's. This can be set up to run an interrupt service routine when the voltage crosses a threshold.

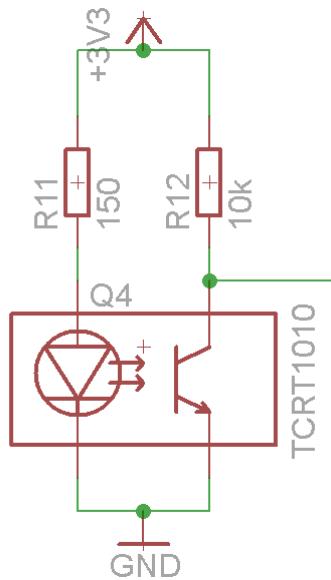


Figure 3.5: Circuit diagram of Optosensor

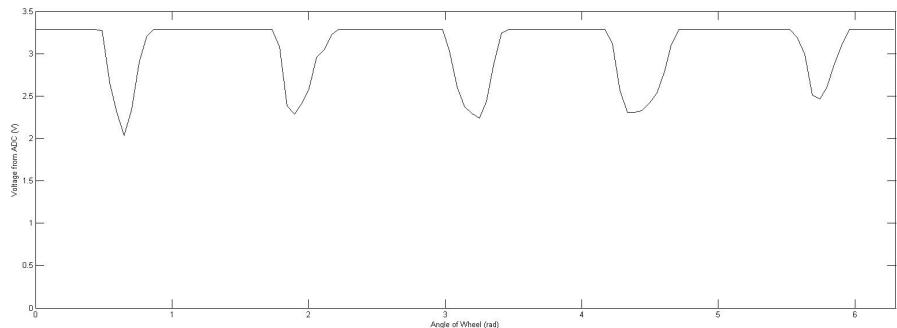


Figure 3.6: Graph of Wheel Angle against the Voltage read by the AVR

The threshold voltage can be determined by a potentiometer. The code is primarily two methods, the set up and the ISR.

Set up is different for if a rotation or movement is wanted. Moving in a straight line takes a parameter of how far to move as a signed integer and calculates the total number of interrupts that need to occur can be calculated using (3.1). This value is put in a global variable. The PWM and input pins to set the correct direction are then set up before enabling the motor.

$$\text{Interrupts} = D \times \frac{IPR}{C_w} \quad (3.1)$$

To rotate, one of three methods can be used: Spot rotation on the centre of the robot, or pivot on either left or right wheel. For ease, the Spot rotation is the

only one implemented. To calculate the distance moved, the radius to the wheels needs to be known. The circumference through the wheels is then easily calculated and the angle of rotation is then a ratio. The distance to move is calculated by equation (3.2) and the total number of interrupts can be calculated using equation (3.1). To rotate clockwise, the left motor is driven forward and the right is driven backwards. To rotate anti-clockwise, the directions are reversed

$$D_R = A \times \frac{C_b}{360} \quad (3.2)$$

Combining equations (3.1) and (3.2) gives:

$$\text{Interrupts} = A \times \frac{IPR}{C_w} \times \frac{C_b}{360} \quad (3.3)$$

Where A is the angle to rotate in degrees, IPR is the number of interrupts generated per full revolution of the wheel, C_w is the circumference of the wheel and C_b the $2\pi \times r_b$ and r_b is the distance from the centre of the robot to the centre of the wheel (see figure 3.7).

Maybe a figure to explain better?

The motor speed can be controlled by Pulse Width Modulation (PWM). The code sets up a low duty cycle PWM signal to drive the motors slowly. This removes the need for a controller to ensure the correct distance was moved.

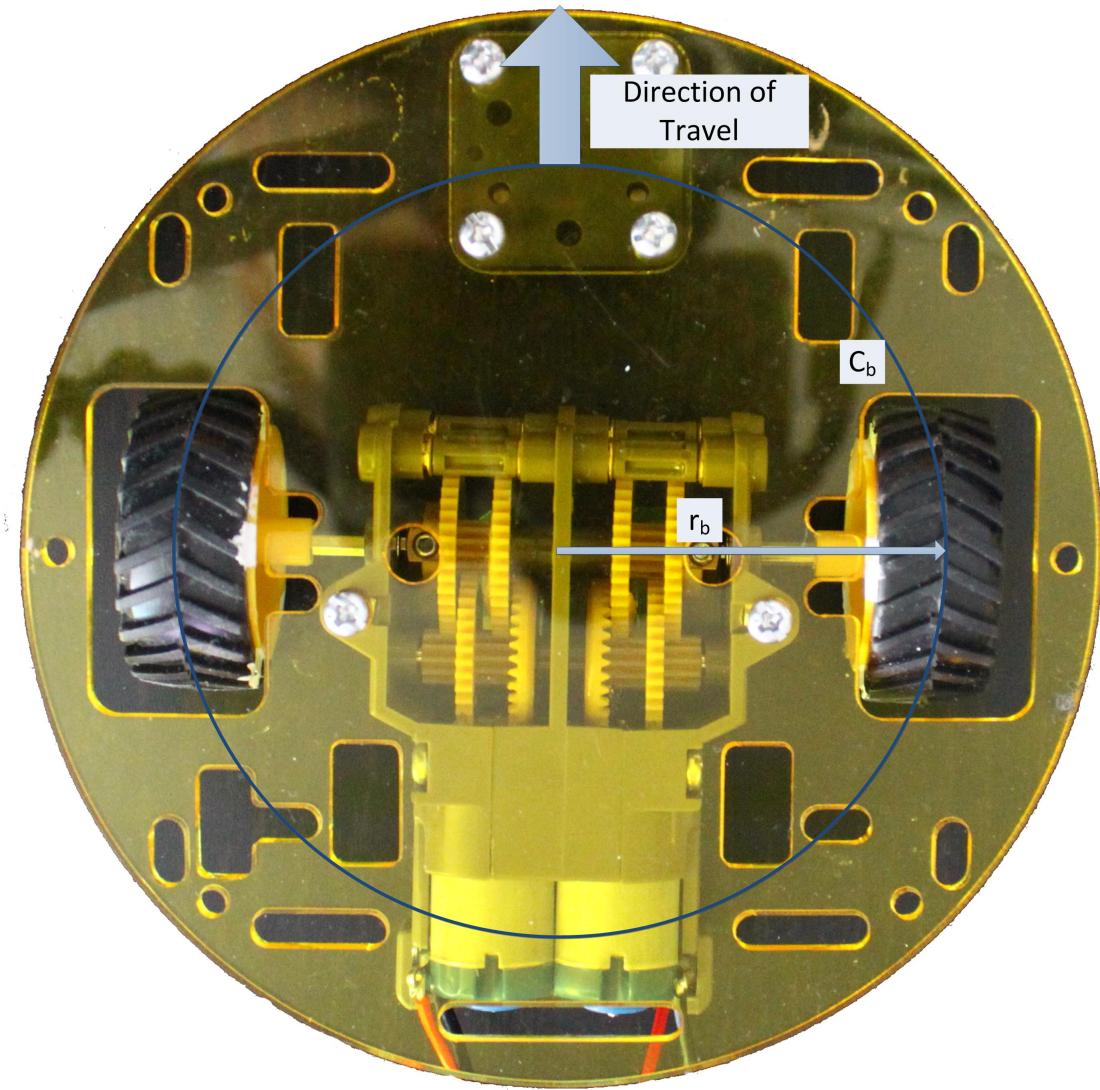
The final code can be seen in appendix G

3.3.3 Testing

Need to get the motors to work reasonably first

3.3.4 Conclusion

It doesn't work



(a) Top View of robot base showing dimensions of interest



(b) Side View of robot base showing dimensions of interest

Figure 3.7: Dimensions of Interest for Robot Movement

3.4 PCB Development

3.4.1 Circuit Design

The circuit diagram for Revision A can be seen in section [B.3](#). The schematic for the SDRAM and values and locations of decoupling capacitors were used from the schematic of the UC3C-EK development board ([Atmel Corporation, 2012c](#)).

3.4.2 PCB Design

The PCB was designed using EAGLE CAD Software. A four layer board was decided to be used to save space when routing Power. Layer 2 is a 3V3 plane and layer 3 is a ground plane. A ground plane is also on the top and bottom layers to help eliminate any ground bounce that could occur.

The SDRAM uses the EBI protocol. In high speed systems, care is often taken to equalise track lengths ([Liu and Lin, 2004](#)). The UC3C maximum clock frequency is 33MHz (with no wait states), which is not fast enough to cause any track equalisation problems. Care, however, was taken on the USB lines to ensure correct impedance and the tracks lengths matched to each other.

Tracks were routed in order of priority, starting with the UC3C, SDRAM and cameras, and then other devices were routed, I^2C MUX, SD card, motor drivers etc. As a precaution, spare pins from the UC3C were routed to a header (J8 and J9) so that additions could be done if a pinout or connection was found to be incorrect. Also, UART, I^2C and SPI connections were routed to headers J7, J4 and J5 respectively so logic analysers and COM Port could be attached easily for debugging.

Most of the passives used were 0603 size, but some 1206 capacitors were used for decoupling the voltage regulator and a 1206 diode was used for the analogue reference circuitry. LEDs were also 1206 size. All headers were 0.1" spaced and a mini B USB socket was used.

The layout of components was important. The cameras needed to be as far apart as possible and at the front of the PCB. The motor drivers were situated toward the back of the PCB and 0.1" headers were added to connect the motors to. The optosensors were positioned such that they could be mounted directly on the PCB and be in the correct position to sense the wheels. Mounting holes were also added

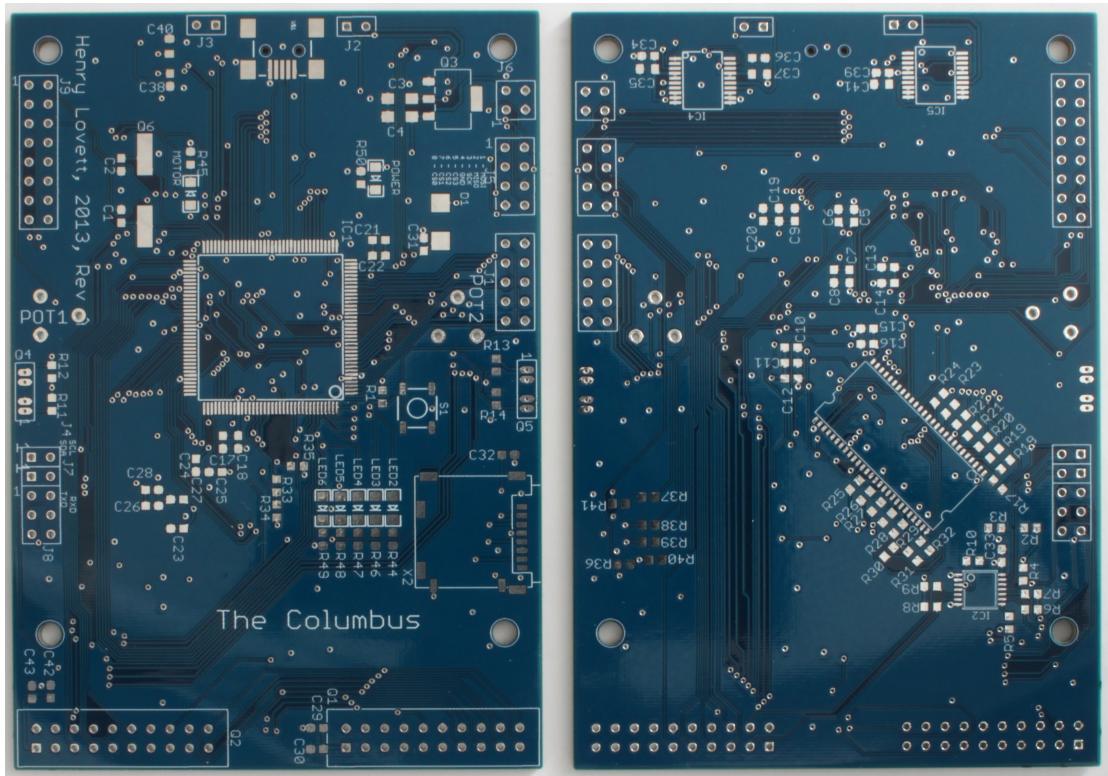


Figure 3.8: PCB with no components. Left: Top View. Right: Bottom View

onto the board so the PCB could be mounted on to the robot base easily. The overall dimensions of the PCB were $100\text{mm} \times 70\text{mm}$. A full list of components and cost of each is documented in Appendix D

Finally, the name “The Columbus” was decided on as the original application for the project was a mapping robot that would search out an unknown area, so the robot was named after Christopher Columbus who explored and navigated parts of the American continents which were unknown at the time. The Eagle CAD Diagram of the PCB can be seen in Appendix C. The PCB was manufactured by [Cart \(2013\)](#). The PCB cost £205 to manufacture and ship. A photo of the PCB can be seen in figure 3.8.

Considerations - Power consumption of devices not exceeding VReg

3.4.3 PCB Testing

A program was written to test all the devices on the PCB. The following tests are done:

1. UART Send and Receive

2. SD Card Test

3. All LEDs on and off

4. SDRAM Test

5. I^2C Test

6. Camera Test

7. Motor Test

The following sections explain the tests done to check the devices and protocols worked.

3.4.3.1 UART Test

When the test program begins, the microcontroller waits for a character input. All characters are echoed back. This enables the user to check the communications work. Once a carriage return key is received (13_{10}), the test program continues. Listing 3.1 shows the test code for the UART protocol.

Listing 3.1: UART Test Code

```

1 ///////////////////////////////////////////////////////////////////
2 // UART Test ///////////////////////////////////////////////////////////////////
3 ///////////////////////////////////////////////////////////////////
4 uint8_t ch;
5 while (true) {
6     ch = usart_getchar(DBG_USART); // get one input character
7     if (ch) {
8         print_dbg(ch); // echo to output
9     }
10    if(ch == 13)
11        break;
12 }
```

3.4.3.2 SD Card Test

The Atmel Software Framework ([Atmel Corporation, 2009](#)) provided drivers and code for SPI communications and use of a FAT32 File System. The code was configured to use the correct Chip Select pin for the SD Card and the correct SPI

Bus was also configured. The test consists of initialising the memory, reading the capacity of the card and printing it to the user.

The AVR then proceeds to delete any previous log file, create a new log file and writes “*Columbus Tester*” to it. The first 8 characters, which should be “*Columbus*” are read back and checked.

Listing 3.2: UART Test Code

```

1  ///////////////////////////////////////////////////////////////////
2  // SD Card Test ///////////////////////////////////////////////////
3  ///////////////////////////////////////////////////////////////////
4  print_dbg("\n\n\rSD Card Memory Test:\n\r");
5  // Test if the memory is ready - using the control access memory abstraction
6  // layer (/SERVICES/MEMORY/CTRL_ACCESS/)
7  if (mem_test_unit_ready(LUN_ID_SD_MMC_SPI_MEM) == CTRL_GOOD)
8  {
9      // Get and display the capacity
10     mem_read_capacity(LUN_ID_SD_MMC_SPI_MEM, &VarTemp);
11     print_dbg("OK:\t");
12     //printf_ulong((VarTemp + 1) >> (20 - FS_SHIFT_B_TO_SECTOR));
13     i = ((VarTemp + 1) >> (20 - FS_SHIFT_B_TO_SECTOR));
14     print_dbg_ulong(i);
15     print_dbg("MB\r\n");
16     print_dbg("SD Card Okay.\n\r");
17 }
18 else
19 {
20     // Display an error message
21     print_dbg("Not initialized: Check if memory is ready...\r\n");
22 }
23 nav_reset();
24 // Use the last drive available as default.
25 nav_drive_set(nav_drive_nb() - 1);
26 // Mount it.
27 nav_partition_mount();
28 nav_filelist_reset();
29 if (nav_filelist_findname((FS_STRING)LOG_FILE, false))
30 {
31     print_dbg("\n\rLog File Already Exists\n\rAttempting to delete...");
32     nav_setcwd((FS_STRING)LOG_FILE, true, false);
33     nav_file_del(false);

34     if (nav_filelist_findname((FS_STRING)LOG_FILE, false))
35         print_dbg("\n\rLog File Still Exists...");
36     else
37         print_dbg("\n\rLog File Deleted!");
38 }
39 print_dbg("\n\rCreating Log File.");

40 if (nav_file_create((FS_STRING)LOG_FILE) == true)
41     print_dbg("\n\rSuccess!");
42 else
43     print_dbg("\n\rNot worked...");
44 print_dbg("\n\rWriting to log file.");

```

```

46 Log_Write("Columbus Tester:\n\r", 18);
47 nav_filelist_reset();
48 nav_setcwd((FS_STRING)LOG_FILE, true, false);
49 file_open(FOPEN_MODE_R); //Open File
50 file_read_buf(Buffer, 8);
51 noErrors = 0;
52 if(Buffer[0] != 'C')
53     noErrors++;
54 if(Buffer[1] != 'o')
55     noErrors++;
56 if(Buffer[2] != 'l')
57     noErrors++;
58 if(Buffer[3] != 'u')
59     noErrors++;
60 if(Buffer[4] != 'm')
61     noErrors++;
62 if(Buffer[5] != 'b')
63     noErrors++;
64 if(Buffer[6] != 'u')
65     noErrors++;
66 if(Buffer[7] != 's')
67     noErrors++;
68 file_close();
69 if(noErrors == 0)
70     print_dbg("\n\rSD Card Read Successful\n\r");
71 else
72     print_dbg("\n\rSD Card Read Fail\n\r");
73 noErrors = 0;

```

This exercises all basic File I/O functions, creating, reading and writing and checks them on the device.

3.4.3.3 LED Test

All LEDs are turned on for 1 second, and then turned off. The user should check this occurs. It verifies that all the LEDs are functional and correctly mounted. The Power LED should be on when power is supplied to the PCB.

3.4.3.4 SDRAM Test

The SDRAM test consists of initialising the SDRAM, calculating the SDRAM Size, writing a unique test pattern to the whole memory, and then reading it back and checking it. The total number of errors are reported.

The test was adapted from an Example Application from the Atmel Software Framework ([Atmel Corporation, 2009](#)). The code can be seen in listing 3.3. It consists of two *for* loops. In the first, the iteration number is assigned to the

memory location. The second loop reads back the data and checks it is correct. An int, *noErrors*, is used to count errors.

Listing 3.3: SDRAM Test Code

```

1 ///////////////////////////////////////////////////////////////////
2 // SDRAM Test ///////////////////////////////////////////////////////////////////
3 ///////////////////////////////////////////////////////////////////
4 print_dbg("\n\n\rSDRAM Test:");
5 sdram_size = SDRAM_SIZE >> 2;
6 print_dbg("\n\rSDRAM size: ");
7 print_dbg_ulong(SDRAM_SIZE >> 20);
8 print_dbg(" MB\r\n");
9 // Determine the increment of SDRAM word address requiring an update of the
10 // printed progression status.
11 progress_inc = (sdram_size + 50) / 100;
12 // Fill the SDRAM with the test pattern.
13 for (i = 0, j = 0; i < sdram_size; i++)
14 {
15     if (i == j * progress_inc)
16     {
17         print_dbg("\rFilling SDRAM with test pattern:");
18         print_dbg_ulong(j++);
19         print_dbg("%");
20     }
21     sdram[i] = i;

22 }
23 print_dbg("\rSDRAM filled with test pattern      \r\n");
24 // Recover the test pattern from the SDRAM and verify it.
25 for (i = 0, j = 0; i < sdram_size; i++)
26 {
27     if (i == j * progress_inc)
28     {
29         print_dbg("\rRecovering test pattern from SDRAM: ");
30         print_dbg_ulong(j++);
31         print_dbg("%");
32     }
33     tmp = sdram[i];
34     if (tmp != i)//failed
35     {
36         noErrors++;
37     }
38 }
39 print_dbg("\rSDRAM tested: ");
40 print_dbg_ulong(noErrors);
41 print_dbg(" corrupted word(s)      \r\n");
42

```

3.4.3.5 I^2C Test

The I^2C test checks the bus for devices. It prints out a table showing the address of any devices that acknowledge a probe. A probe is a set up to write to the

address. If a device exists on the line, it should Acknowledge (Philips, 20012). The test is done three times, with no channel selected on the I^2C MUX, with channel 0 selected and with channel 1 selected. The two addresses expected at 21_{16} for the OV7670 Camera and 74_{16} for the I^2C MUX. The camera should only acknowledge when the I^2C MUX has the relevant channel selected. Listing 3.4 shows the test code for the I^2C bus and listing 3.4 shows the result from the full bus scan with channel 0 selected. The cameras are both checked to exist.

Listing 3.4: I^2C Test Code

```

1 ///////////////////////////////////////////////////////////////////
2 // TWI Test ///////////////////////////////////////////////////////////////////
3 ///////////////////////////////////////////////////////////////////
4 print_dbg("\n\n\rTWI Test:\n\r");
5 Log_Write("\n\n\rTWI Test:\n\r", 14);
6 for(k = 0; tkmp < 3; k++)
{
7
8     if(k == 0){
9         print_dbg("Scanning all Channels\n\r");
10    }
11    else if (k == 1){
12        //Channel 0
13        PCA9542A_Chан_Sel(I2C_CHANNEL_0);
14        print_dbg("\n\rScanning Channel 0\n\r");
15    }
16    else {
17        //Channel 1
18        PCA9542A_Chан_Sel(I2C_CHANNEL_1);
19        print_dbg("\n\rScanning Channel 1\n\r");
20    }

22    print_dbg("h 0 1 2 3 4 5 6 7 8 9 A B C D E F\n\r");
23    tmp = 0;
24    for(i = 0; i < 8; i++)
25    {
26        print_dbg_ulong(i);
27        print_dbg(" ");
28        for(j = 0; j < 16; j++){
29            int status = twim_probe(TWIM, tmp++);
30            if(status == STATUS_OK){
31                print_dbg("A");
32            }
33            else{
34                print_dbg("-");
35            }
36            print_dbg(" ");
37        }
38        print_dbg("\n\r");
39    }
40}
noErrors = 0;
//Check cameras exist
43 PCA9542A_Chан_Sel(I2C_CHANNEL_0);
44 if(twim_probe(TWIM, 0x21) != STATUS_OK)

```

```

45     print_dbg("\n\rCamera 0 Not Found;");
46     PCA9542A_Chan_Sel(I2C_CHANNEL_1);
47     if(twim_probe(TWIM, 0x21) != STATUS_OK)
48         print_dbg("\n\rCamera 1 Not Found;");

```

Listing 3.5: Result of I^2C bus scan with Channel 0 of the I^2C MUX selected

```

1 Scanning Channel 0
2 h 0 1 2 3 4 5 6 7 8 9 A B C D E F
3 0 - - - - - - - - - - - - - - - -
4 1 - - - - - - - - - - - - - - - -
5 2 - A - - - - - - - - - - - - - -
6 3 - - - - - - - - - - - - - - - -
7 4 - - - - - - - - - - - - - - - -
8 5 - - - - - - - - - - - - - - - -
9 6 - - - - - - - - - - - - - - - -
10 7 - - - - A - - - - - - - - - -

```

3.4.3.6 Camera Test

This test consists of initialising both cameras and checking it passes. Two photos are then taken and stored to the SD card. Success or Failure is displayed. Two images should exists on the SD card from the two cameras. Listing 3.6 shows the code to conduct this test.

Listing 3.6: Camera Test Code

```

1 ///////////////////////////////////////////////////////////////////
2 // Camera Test ///////////////////////////////////////////////////////////////////
3 ///////////////////////////////////////////////////////////////////
4 print_dbg("\n\rInitialising Cameras");
5 OV7670_Init();
6 FIFO_Reset(CAMERA_LEFT | CAMERA_RIGHT);
7 if(STATUS_OK == OV7670_Status.Error)
8 {
9     print_dbg("\n\rCamera Initialise Okay!");
10 }
11 else
12     print_dbg("\n\rCamara Initialise Fail.");
13
14 print_dbg("\n\rTaking Photos");
15
16 TakePhoto(CAMERA_LEFT | CAMERA_RIGHT);
17 while(Photos_Ready() == false)
18 ;
19
20 if(Store_Both_Images() == true)
21     print_dbg("\n\rImages Stored Successfully!");
22 else

```

```
23     print_dbg("\n\rImages Store Fail.");
```

3.4.3.7 Motor Driver Test

An extensive test of the motor driver is discussed in section 3.3.3. The test code in this application resets the motors so that they are aligned to a white tab on the wheel. This code can be seen in listing 3.7. The robot should move no further than 2cm to reach a white tab and the motors should drive forward. This test is useful here to ensure the motors are connected the correct way around and that the potentiometers are set to an appropriate level.

Listing 3.7: Motor Test Code

```
1 ///////////////////////////////////////////////////////////////////
2 // Motor Test ///////////////////////////////////////////////////////////////////
3 ///////////////////////////////////////////////////////////////////
4 print_dbg("\n\rMotor Testing:\n\rMotor Initialised");
5 Motor_Init();
6 Motors_Reset(); //reset the motors to test them
7 while(Motors_Moving() == true)
8     ;//wait for the motors to finish moving
```

3.4.4 PCB Faults

TCRT1010 Footprint

During the build and test of the PCB, a number of faults were found. Each is explained and the solution for the problem given.

3.4.4.1 SDRAM Footprint

The SDRAM footprint made was done exactly to the specification of the pad size and locations with no consideration for soldering to. This meant the chip fit exactly on to the footprint. This made soldering difficult as pads had to be preloaded with solder and the device's pins were heated and bound to the solder. The chip does not seat flat against the PCB. It also put the device at risk as more heat had to be used than usually necessary. Figure 3.9 shows the SDRAM chip against the footprint. There is no extra space on the pad to be able to easily solder the device.

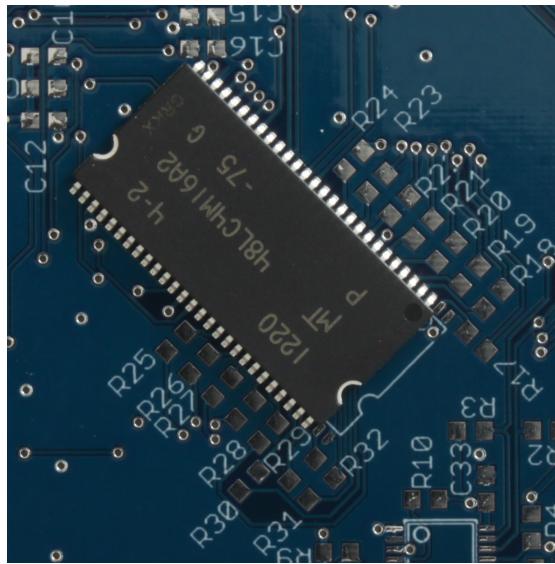


Figure 3.9: SDRAM Chip shown against its footprint.

To avoid this, existing footprints could be used from other libraries, or double checking the footprints made. The problem meant extra care during soldering had to be taken but has not impeded the operation of the device.

3.4.4.2 SDRAM Chip Select

The code was prototyped on the Atmel UC3C-EK development board prior to the PCB arriving. When the PCB was built, the code did not work, even with the Chip Select declaration changed. To diagnose this problem, the control lines of the SDRAM were probed with a logic analyser. On the UC3C-EK, the bus was busy with refresh cycles outside of SDRAM access. On the Columbus, no activity was seen.

The reason the correct control wasn't being seen was due to the UC3C device having a dedicated SDRAM controller, attached to only Chip Select line 1. The Columbus was designed to use chip select line 0. Chip select 1 was available on an external pin, and a via through the routing was close to a via connected to the SDRAM chip select line. Therefore, to overcome the problem, a small enameled wire was soldered to join the two vias together. This solved the problem and the correct signals were then seen on the control lines. The patch can be seen in figure 3.11(b).

This fault was caused by not reading the datasheet carefully and ignoring a proven circuit diagram.

3.4.4.3 SDRAM Data Line Resistors

Once the chip select problem was solved, data returned was unreliable. The SDRAM is word (32 bit) addressed, but accessed in 16 bits. This means read cycles are done per word read. Upon investigation of this problem, the 14th, 15th, 30th and 31st (top two bits of each 16 bit access) seemed to read as a 1 the majority of the time. This result wasn't repeatable and sometimes returned correct data. The other bits of the data were always correct. Table 3.3 shows some examples of the problematic data bits. The data written should match the data read back.

Table 3.3: A table showing examples of the incorrect data returned from the SDRAM

Data Written	Data Read
00000000 00000000 00000000 00000000	11000000 00000000 11000000 00000000
00001111 00001111 00001111 00001111	11001111 00001111 11001111 00001111

The problem was traced to resistors **R31** and **R32**. They were soldered on incorrectly so that the two data lines of the SDRAM were connected together and the two AVR GPIO pins were connected together. Data was then read back from, effectively, a high impedance line and therefore varied. Once the resistors were soldered correctly, the issue no longer persisted and the whole SDRAM test passed. By utilising the soldermask more, device orientations could be added to ensure correct placement. This can be extended to other devices, such as diodes and capacitors, especially in densely populated areas.

3.4.4.4 Camera Interrupt Line

As discussed in section 3.1, the OV7670 needs an interrupt line to synchronise quickly to the start of the frame and is done by using an interrupt line. The UC3C0512C has 9 external interrupt lines. On the PCB, interrupt lines 0 and 1 were used for this control.

Interrupt line 1 was easily configured and worked as expected. However, interrupt 0 did not seem to trigger the interrupt service routine. It was found that interrupt 0 was a “Non Maskable Interrupt” which has specific uses and cannot be used in to trigger a method.

The external interrupt 4 pin was wired to Junction 8 on the PCB. A wire was attached to the camera's VSYNC line and attached to the relevant pin on the

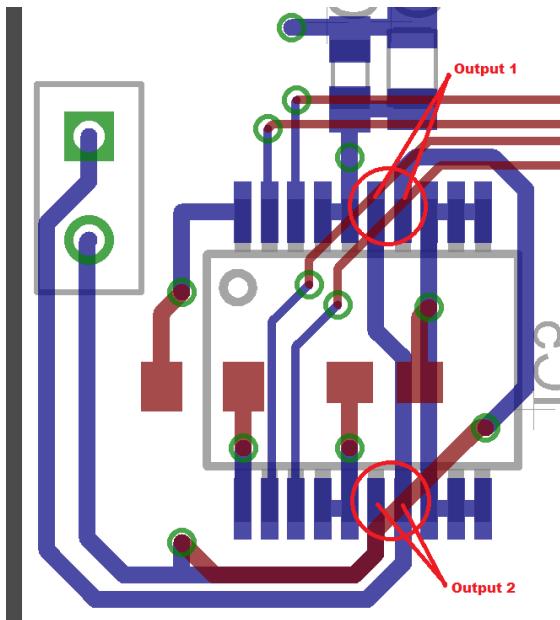


Figure 3.10: Motor Driver error. Outputs incorrectly connected

header. The operation was then easily obtained and the VSYNC line triggered correctly.

This issues would have been avoided with more understanding of the device before hand and checking the datasheet.

3.4.4.5 Motor Driver Pinout

An error was made in creating the device for the TB6593FNG Motor Driver in EAGLE. On the device, each motor output has two pins to drive each side of the motor. The pin assignment was mixed up when created and connected the two outputs together. Figure 3.10 shows the track errors on one of the motor drivers.

To solve this, pins 7 and 14 were lifted and removed so that output 1 and output 2 were not connected together. The devices were not damaged in the process of testing this and the motors functioned correctly after this. Double checking the footprints made against the datasheet would have avoided this problem. No impedance to the operation of the drivers has been seen, but the patch may hinder the devices ability to sink current to the motors.

3.4.5 PCB Conclusions

A number of faults were made in the PCB design. They are:

- SDRAM footprint
- SDRAM chip select line
- SDRAM data line resistors
- Camera interrupt line
- Motor driver pinout

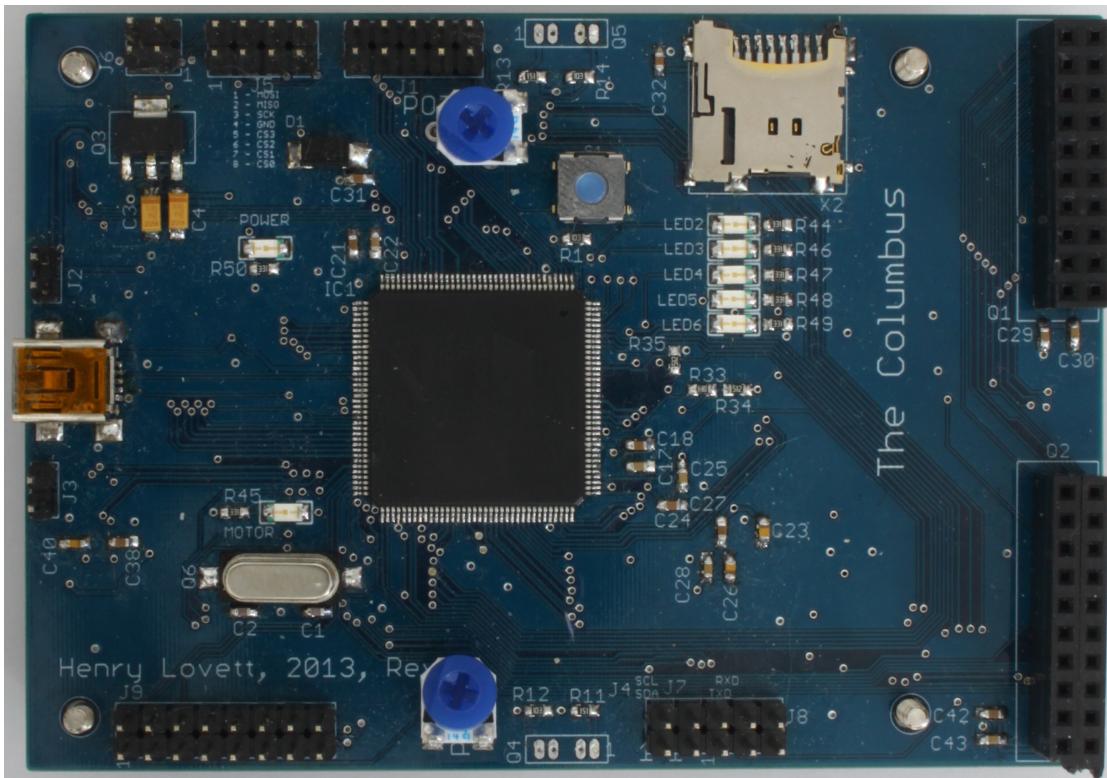
Three of the faults could have been avoided by consulting the datasheet more carefully during the circuit design stage. The footprint error was due to not being experienced in designing footprints and the data line resistors was a mistake due to lack of attention being paid.

For future PCBs, more care will be taken in circuit design, with prototyping of circuits with the hardware that will be used. This will highlight any pin specific operations (e.g. the non maskable interrupt) and reduce debugging post production. The effectiveness of a soldermask is also apparent, so more time spent on utilising this would be helpful during assembly.

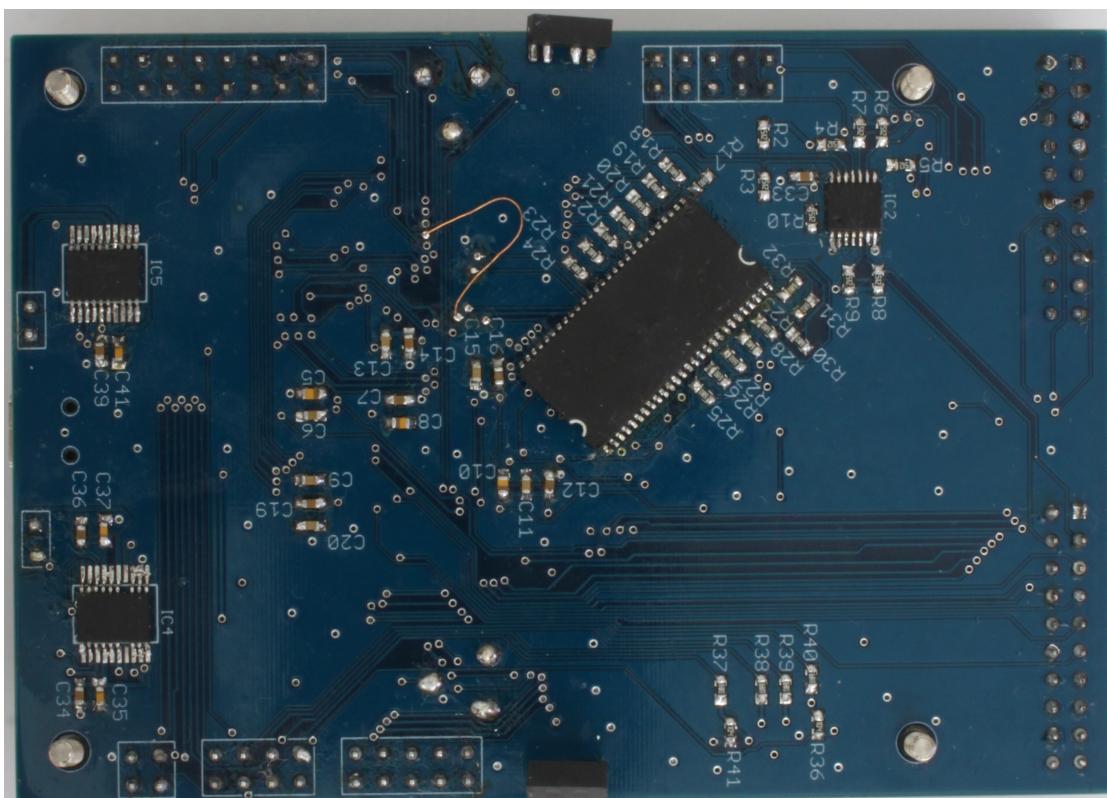
The PCB itself, was a success. It was a complex PCB with many potential things that could have gone wrong. It was the first PCB I had designed and was a four layer board, using some devices that I did not have experience with. All devices are functional (with a few small modifications) on the PCB so firmware development could continue with all hardware able to be used.

3.5 Conclusions

Overall Conclusions of the Hardware design



(a) Top view of built PCB



(b) Bottom view of built PCB with SDRAM chip select patch

Figure 3.11: Pictures of the built PCB.

Chapter 4

Investigation into Vision Algorithms

4.1 Matching Algorithms

In computer vision, there are many different ways of comparing two similar images. These include the sum of absolute differences (S.A.D.) ([Hamzah et al. \(2010\)](#)), the sum of squared differences (S.S.D.)([Mrovlje and Vrančić \(2008\)](#)) and normalised cross correlation (N.C.C.)([Zhao et al. \(2006\)](#)). Each of these methods will be explained and tested to compare them. All testing will use images seen in figure [4.1](#). Each test uses the same size window (50×50) to compare the two images.



(a) Left Image

(b) Right Image

Figure 4.1: Stereoscopic Test Images from MATLAB Examples

4.1.1 Sum of Absolute Differences

Given two identically sized two dimensional matrices, A, B , of dimensions I, J , SAD is defined as

$$SAD = \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} |A[i, j] - B[i, j]| \quad (4.1)$$

This method subtracts the observed window from the expected. All differences are then added together. This algorithm is simple and requires a small amount of computation. The algorithm returns values where a small result means the two images are well matched.

4.1.2 Sum of Squared Differences

$$SSD = \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} (A[i, j] - B[i, j])^2 \quad (4.2)$$

This is very similar to S.A.D. but adds more complexity by squaring each difference. This removes the ability of equally different but opposite differences cancelling each other out (grey to white of one pixel will cancel out a white to grey difference in the other with SAD). Again, a low result is a match in this case.

test effect of box size?

4.1.3 NCC

$$NCC = \frac{1}{n} \sum_{i,j} \frac{(A[i, j] - \bar{A})(B[i, j] - \bar{B})}{\sigma_A \cdot \sigma_B} \quad (4.3)$$

Where n is the number of pixels in A and B ,
 σ is the standard deviation of the image, and
 \bar{A} is the average pixel value.

NCC is very similar to cross correlation, but normalised to reduce the error if one image is brighter than the other. This is common in computer vision ([Tsai and Lin \(2003\)](#)) and cross correlation is often used in digital signal processing, so fast algorithms have been made to calculate this.

Unlike S.S.D. and S.A.D., the normalised cross correlation gives a high value for a match. The downside to this algorithm comes with the complexity of the equation as it contains division and the square root of a number in order to calculate the standard deviation. These operations are rarely implemented in hardware and are time consuming to carry out in software. They also require floating point registers and operate slowly on a microcontroller without any.

4.1.4 Comparison

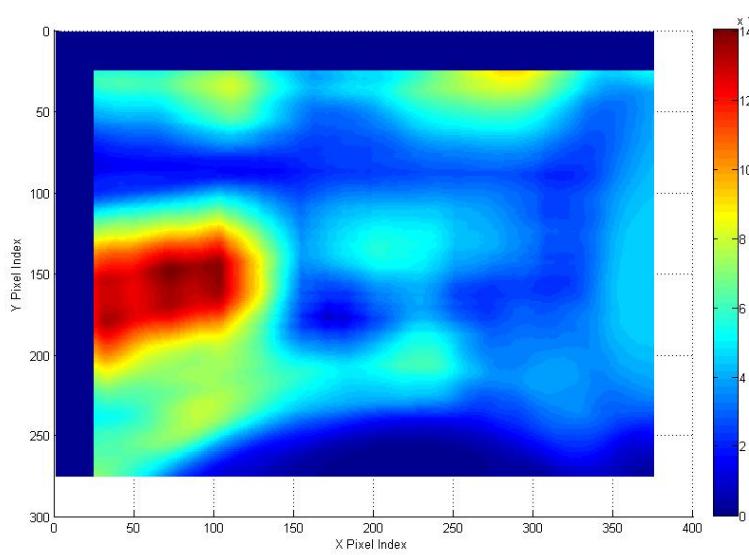
To compare these equations, a 50 by 50 window taken from the right picture was compared with the left image over the entire valid range. The coordinates on the graph give the centre pixel of the calculation.

Each graph shows the correct area being identified as a match, but this also highlights the downfalls of the SAD and SSD. The figures in figure 4.2 are rotated to match the orientation of the images in figure 4.1. Each of the images is tested by attempting to match the desk phone from the right image to the entirety of the left image. The actual match should be around (170, 176). An exact result cannot be estimated as the images are not matched perfectly - there isn't an exact integer of pixel difference between the images. This is the sub pixel problem ([Haller and Nedevschi \(2012\)](#)).

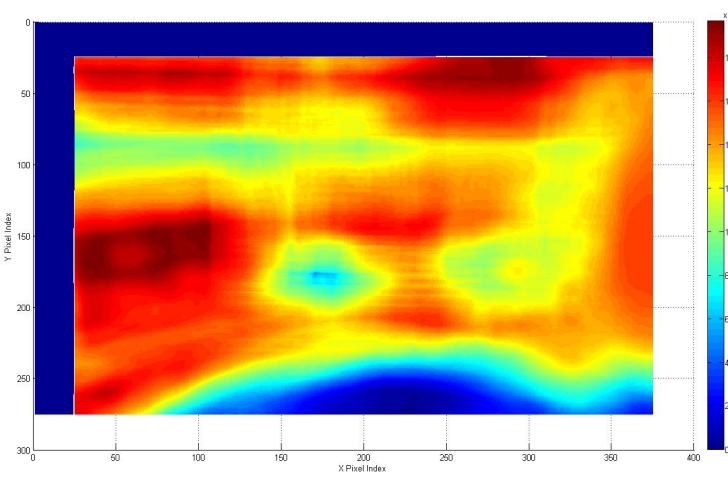
SAD results in figure 4.2(b) show large areas of matching. A minimum occurs around the location expected(170, 175) of a value of 5.66×10^4 . However, along the bottom of the image, where a dark area occurs below the desk in the lower part of figures 4.1, the SAD algorithm detects a greater comparison, with the lowest value in this area being 3370 at (227, 275). This creates a false detection here.

SSD shows matches in the same two areas: where a match should occur and the dark area beneath the desk. The minimum value where the match should occur is 4.355×10^5 at location (170, 176). However, there is a large match correlation between the dark area under the desk where the actual lowest value of 2.768×10^4 occurs at (225, 274). This, again, is a false match and is a downfall of this algorithm.

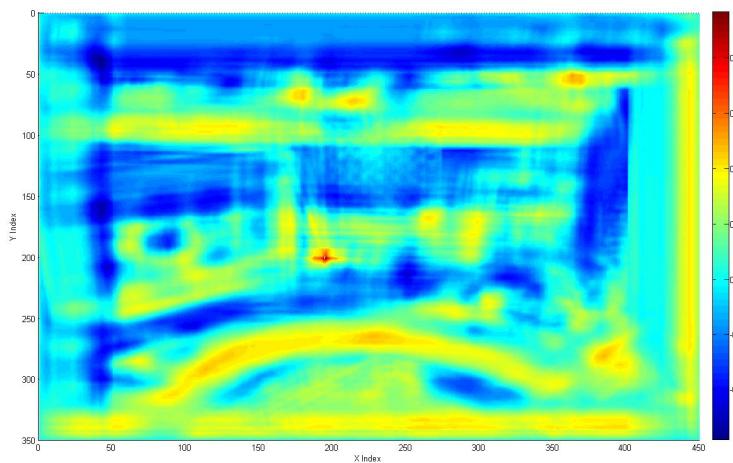
The NCC results are visible in figure 4.2(c). A match can be seen at coordinate (195, 201) with a peak value of 0.9654. The coordinate is different to the previous results because the cross correlation works over the boundary of the image creating more results. The dimensions of the image are 300×400 , but the NCC returns



(a) S.A.D. Results (Low match)



(b) S.S.D. Results (Low match)



(c) N.C.C. Results (High match)

Figure 4.2: Result Graphs of Comparison Algorithms

an data set of dimensions 350×450 when using a window size of 50×50 . To get the actual match, half of the box size must be subtracted from the returned coordinate. This means the match occurs at $(170, 176)$. With this algorithm, there is no area of the image which is close to a false detection.

4.1.5 Conclusion

It can be seen that there is a direct correlation between the complexity of the matching algorithm to the reliability of the match returned. In brightly lit, colourful environments absent of dark colours, SAD and SSD should provide a reliable result, but this cannot be guaranteed to always be the case. Therefore further development of the matching algorithm will start with using the normalised cross correlation. A comprise between complexity and reliability needs to be reached, where reliability is the more desirable of the two. Cross correlation is also a large area of research, so optimised algorithms do exist.

4.2 Range Finding

4.2.1 Derivations

By using two images separated by a horizontal distance, B , the range of an object can be found given some characteristics of the camera. The following are derivations of the equations used to calculate distance.

The problem is broken down into three parts:

1. Object is between the cameras (Figure 4.3)
2. Object is in left or right hand sides of both images (Figure 4.4)
3. Object is directly in front of a camera (Figure 4.5)

4.2.1.1 Object is between the Cameras

Derivation from [Mrovlje and Vrančić \(2008\)](#).

$$B = B_1 + B_2 = D \tan(\varphi_1) + D \tan(\varphi_2) \quad (4.4)$$

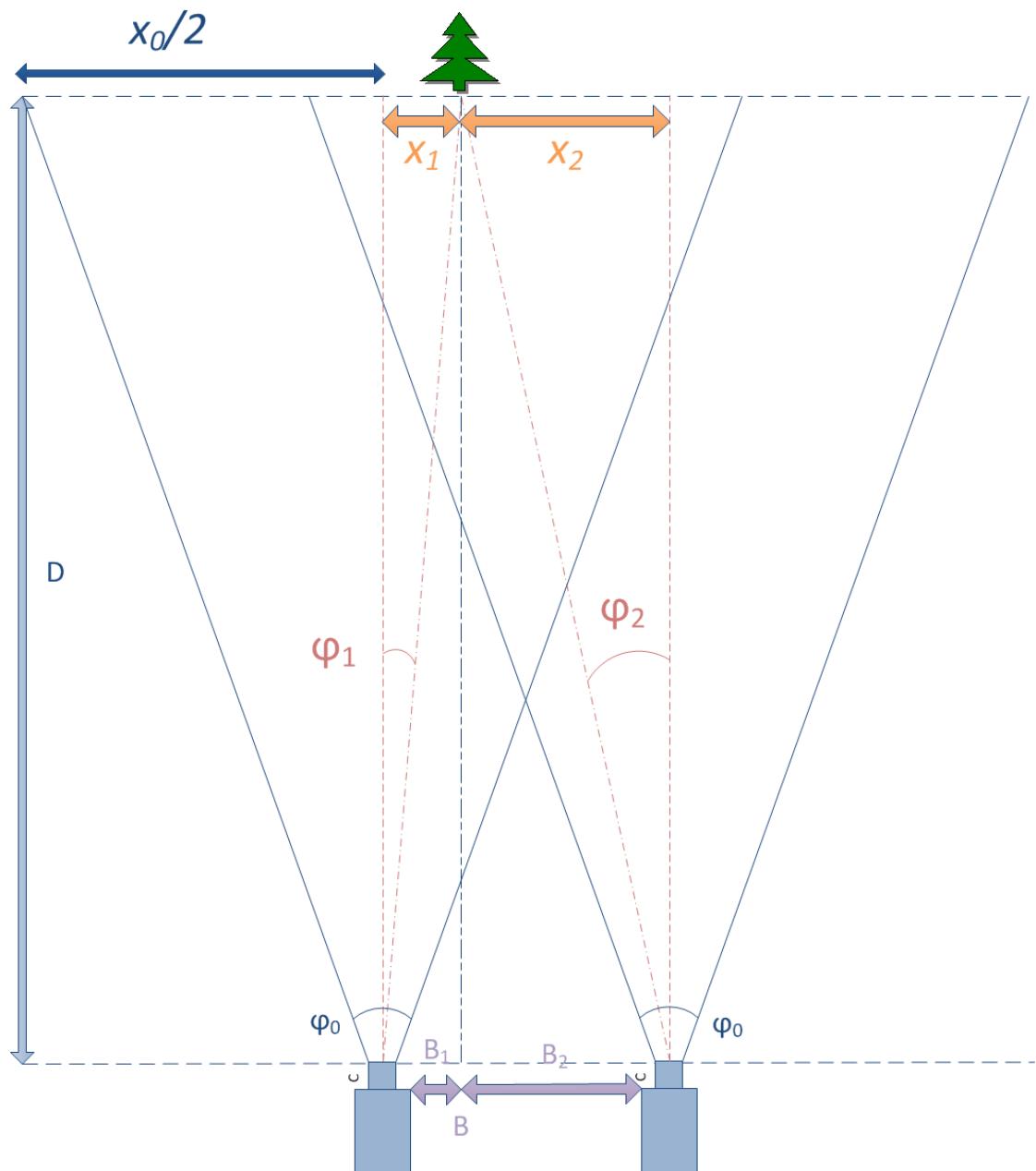


Figure 4.3: Problem 1 - Object is between the Cameras

$$D = \frac{B}{\tan(\varphi_1) + \tan(\varphi_2)} \quad (4.5)$$

$$D \tan\left(\frac{\varphi_0}{2}\right) = \frac{x_0}{2} \quad (4.6)$$

$$D \tan(\varphi_1) = x_1 \quad (4.7)$$

Dividing (4.7) by (4.6)

$$\frac{\tan(\varphi_1)}{\tan(\frac{\varphi_0}{2})} = \frac{2x_1}{x_0} \quad (4.8)$$

$$\tan(\varphi_1) = \frac{2x_1 \tan(\frac{\varphi_0}{2})}{x_0} \quad (4.9)$$

This can also be shown for the right camera:

$$\tan(\varphi_2) = \frac{-2x_2 \tan(\frac{\varphi_0}{2})}{x_0} \quad (4.10)$$

Substitution equations (4.9) and (4.10) into (4.5) gives

$$D = \frac{Bx_0}{2 \tan(\frac{\varphi_0}{2})(x_1 - x_2)} \quad (4.11)$$

4.2.1.2 Object is to the same side in each camera

Derivation is based on the derivation from Tjandranegara (2005). Using figure 4.4:

$$D \cdot \tan(\varphi_1) = x_1 \quad (4.12)$$

$$D \cdot \tan\left(\frac{\varphi_0}{2}\right) = \frac{x_0}{2} \quad (4.13)$$

$$\frac{\tan(\varphi_1)}{\tan(\frac{\varphi_0}{2})} = \frac{2x_1}{x_0} \quad (4.14)$$

$$\varphi_1 = \arctan\left(\frac{2x_1}{x_0} \tan\left(\frac{\varphi_0}{2}\right)\right) \quad (4.15)$$

and similarly

$$\varphi_2 = \arctan\left(\frac{2x_2}{x_0} \tan\left(\frac{\varphi_0}{2}\right)\right) \quad (4.16)$$

$$\theta = \varphi_2 - \varphi_1 \quad (4.17)$$

Using the sine equality rule:

$$\frac{R}{\sin(\frac{\pi}{2} - \varphi_2)} = \frac{B}{\sin(\theta)} \quad (4.18)$$

$$R = B \cdot \frac{\sin(\frac{\pi}{2} - \varphi_2)}{\sin(\theta)} = B \frac{\cos(\varphi_2)}{\sin(\theta)} \quad (4.19)$$

$$D = \cos(\varphi_1) \cdot R \quad (4.20)$$

Substituting (4.17) into (4.19), and then into (4.20):

$$D = B \cdot \frac{\cos(\varphi_2) \cdot \cos(\varphi_1)}{\sin(\varphi_2 - \varphi_1)} \quad (4.21)$$

Where φ_1 is defined in equation (4.15) and φ_2 is defined in equation (4.16).

4.2.1.3 Object is in front of a camera

The distance, D , in this problem is given by:

$$D = B \tan\left(\frac{\pi}{2} - \varphi_2\right) \quad (4.22)$$

Where φ_2 can be found from equation 4.16.

4.2.2 Summary

There are three situations that can occur. These are listed below with their equations.

Object is between the two cameras:

$$D = \frac{Bx_0}{2 \tan(\frac{\varphi_0}{2})(x_1 - x_2)} \quad (4.23)$$

Object is to the same side in both images:

$$D = B \cdot \frac{\cos(\varphi_2) \cdot \cos(\varphi_1)}{\sin(\varphi_2 - \varphi_1)} \quad (4.24)$$

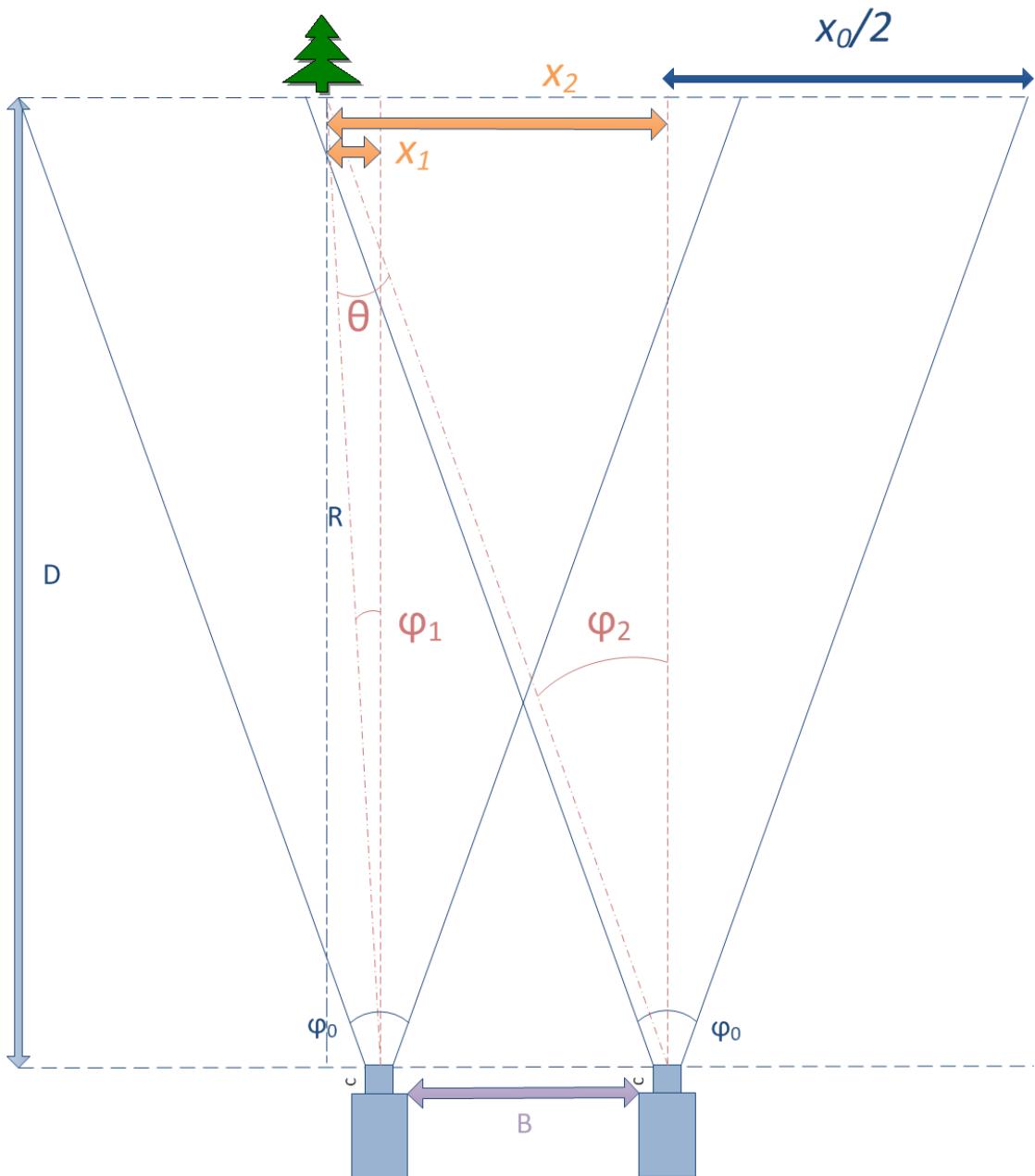


Figure 4.4: Problem 2 - Object is to the same side in both cameras

Object is directly in front of a camera:

$$D = B \tan \left(\frac{\pi}{2} - \varphi_2 \right) \quad (4.25)$$

Where φ_1 is defined in equation (4.15) and φ_2 is defined in equation (4.16).

When the images have been matched, these equations can be used to calculate the range to an object.

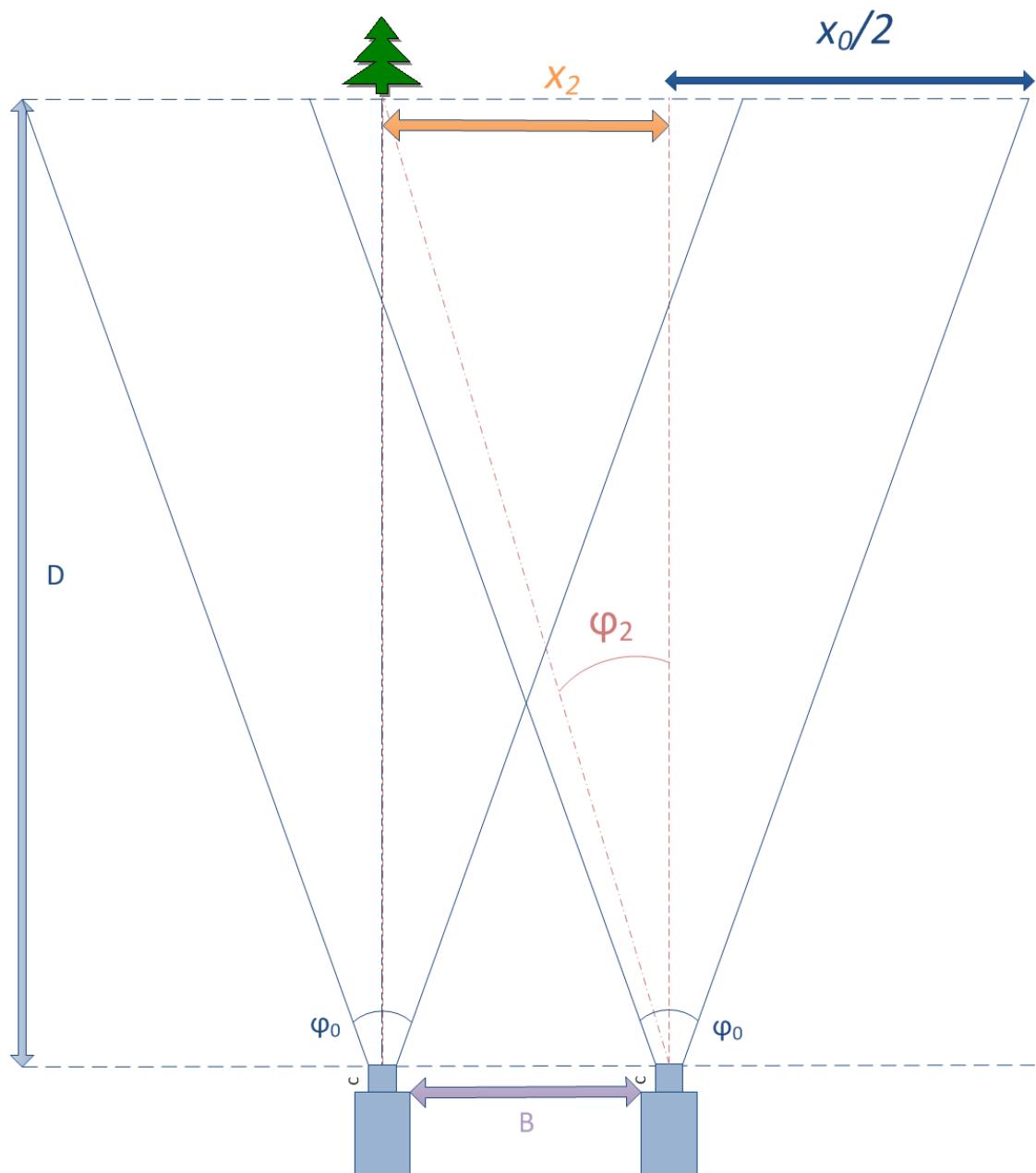


Figure 4.5: Problem 3 - Object is directly in front of a camera

4.3 Fourier Transform

4.3.1 Background Research and the FFT

The Fourier Transform is a common tool in signal processing. It transforms a time based signal to the frequency domain showing the frequency components contained in the signal as a complex number, which is often displayed as magnitude and

phase. The Fourier Transform is defined in equation (4.26) and two examples of signals and their Fourier Transforms are shown in figures 4.6 and 4.7.

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft} dt \quad (4.26)$$

Uses of FT in signal processing

The equation for the Fourier transform in equation (4.26) is for continuous time. A discrete Fourier transform (DFT) exists for finite, equally spaced samples. This is commonly used in digital systems and is defined in equation (4.27). There exists a Fast Fourier Transform (FFT) which gives exactly the same results as the DFT, but is optimised in terms of number of multiplications done. The FFT will be used in implementation due to availability of code and speed of use.

$$X[k] = \sum_0^{N-1} x[n]e^{-j\Omega_0 kn} \quad (4.27)$$

Where Ω_0 is the sample frequency

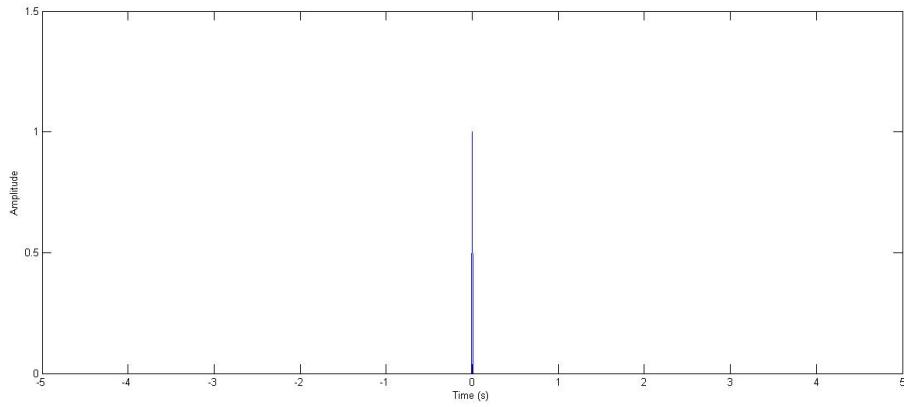
Why this is relevant to my project - what am I using it for?

A property of the Fourier Transform of interest is the convolution theorem which states that convolution in time is multiplication in frequency and is defined mathematically in equation (4.28). As discussed in section 4.1.3, cross correlation is very similar to convolution. Convolution is defined in equation (4.29). With images, $f(t)$ is a real signal, its conjugate is exactly the same, $f(t) \equiv f^*(t)$ given that $f(t) \in \Re$.

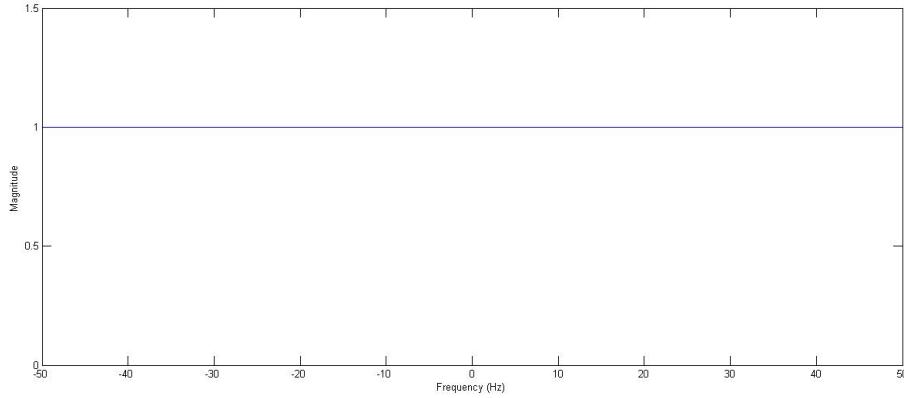
$$\int_{-\infty}^{\infty} f(\tau)g(t - \tau)d\tau = f(t) * g(t) = X(f) \cdot Y(f) \quad (4.28)$$

$$\int_{-\infty}^{\infty} f^*(\tau)g(t + \tau)d\tau = f(t) \star g(t) = X(f) \cdot Y(f) \quad (4.29)$$

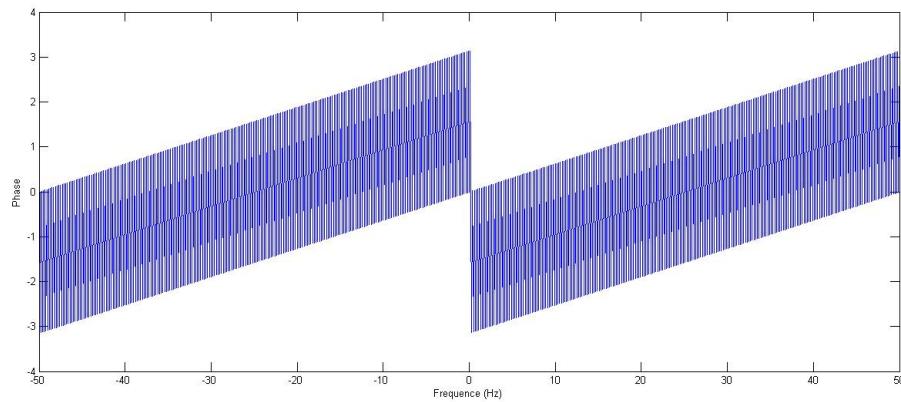
$$f(t) \star g(t) = f(t) * g(-t) = F(f) \cdot G(-f) \quad (4.30)$$



(a) A graph showing a Dirac Function

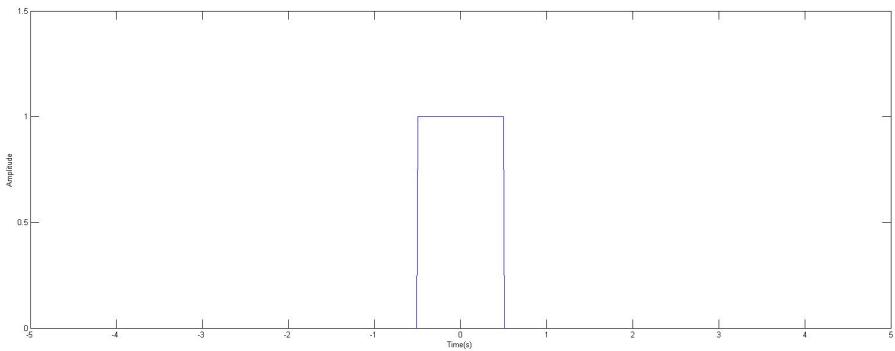


(b) A graph showing the magnitude of the Fourier transform of the Dirac Function

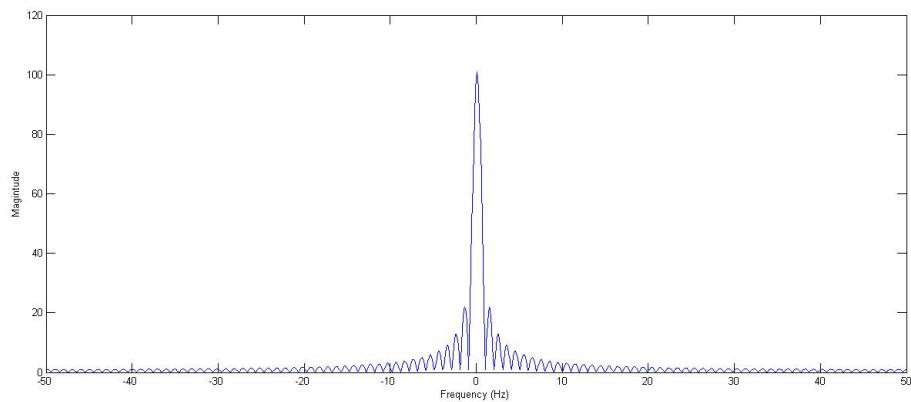


(c) A graph showing the phase of the Fourier transform of the Dirac Function

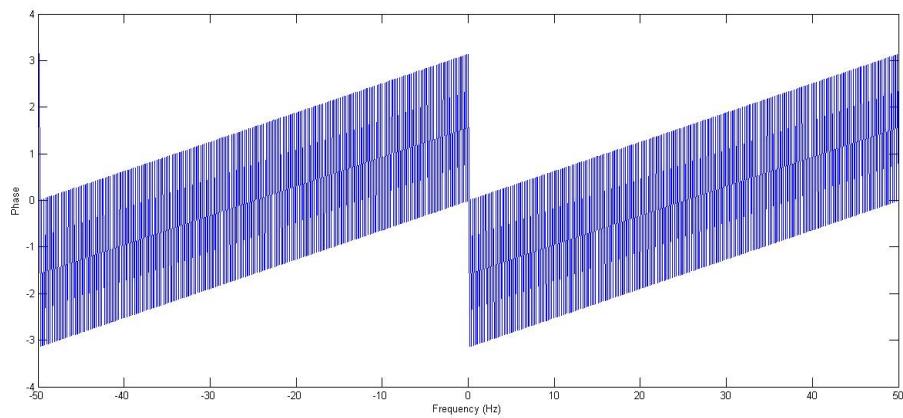
Figure 4.6: A Dirac signal and the phase and magnitude of its Fourier Transform



(a) A graph showing rectangular pulse



(b) A graph showing the magnitude of the Fourier transform of the rectangular pulse



(c) A graph showing the phase of the Fourier transform of the rectangular pulse

Figure 4.7: A 2D Rectangular pulse and the phase and magnitude of its Fourier Transform

example of convolution used as correlation. Include some pretty graphs

4.3.2 Two Dimensional Fast Fourier Transform

Definition

A two dimensional Fourier transform exists for analysing two dimensional signals, namely in this application, an image. The Fourier Transform is shown in equation (4.31) and the discrete version is shown in (4.32)

$$F(u, v) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) e^{-2\pi j(xu+yv)} dx dy \quad (4.31)$$

$$F(u, v) = \frac{1}{N} \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) e^{-\frac{2\pi j(xu+yv)}{N}} \quad x, y, u, v \in \{0 \dots N-1\} \quad (4.32)$$

Examples

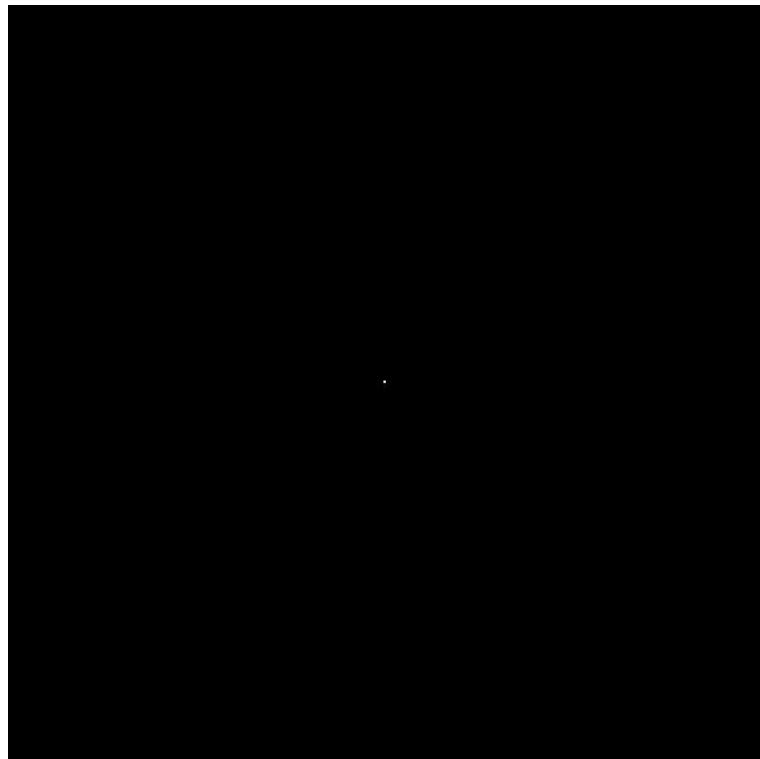
Figures 4.8 and 4.9 show the two dimensional equivalent test signals of figures 4.6(a) and 4.7(a) and the phase and magnitudes of their Fourier Transforms. There is a direct similarity between the 1D and 2D spectra; the magnitudes of the Dirac (figures 4.6(b) and 4.8(b)) are both constant values and the rectangular pulses both have a modulus sinc function magnitude (figures 4.7(a) and 4.9(a)).

2D FFT and restrictions

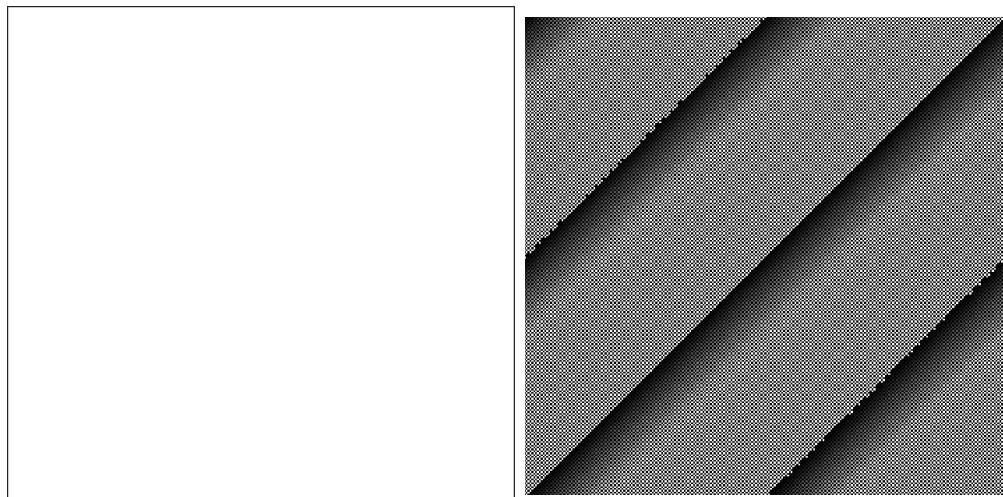
The 2D Fourier transform can also be optimised to a fast Fourier transform algorithm in a similar way as the 1D case. The algorithm, sometimes referred to as the Butterfly transform, is briefly discussed in Nixon and Aguado (2012) where it is explained that the algorithm can be easily applied to images with equal dimensions that are a power of 2. The algorithm utilises the separability property of the Fourier transform.

The 2D FFT can be implemented using a 1D FFT as follows:

1. Calculate the 1D FFT of each of the rows of the 2D data. (An FFT of data of length n returns an array, also of length n)

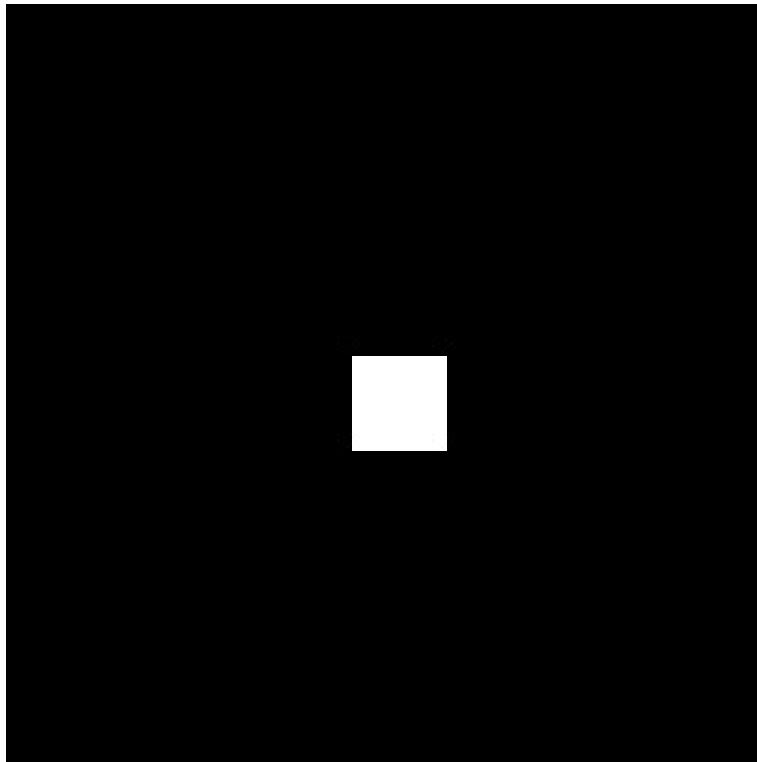


(a) An image of a 2D Dirac Function

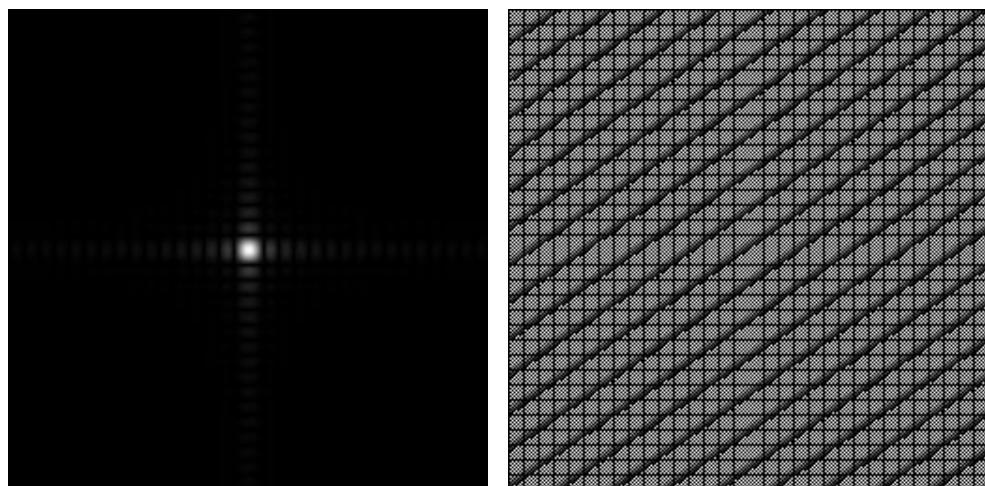


(b) An image of the magnitude of the Fourier transform of the 2D Dirac Function (c) An image of the phase of the Fourier transform of the 2D Dirac Function

Figure 4.8: A 2D Dirac signal and the phase and magnitude of its Fourier Transform



(a) An image of the 2D rectangular pulse



(b) An image of the magnitude of the Fourier transform of the 2D rectangular pulse

(c) An image of the phase of the Fourier transform of the 2D rectangular pulse

Figure 4.9: A 2D Rectangular Pulse signal and the phase and magnitude of its Fourier transform

2. Calculate the 1D FFT of each of the columns of the 2D data returned from the previous step.

Total number of FFTs done is $2n$ where n is the height/width of the image.

Maybe make a figure to help explain?

4.3.3 Implementing the FFT

Include and explain code

The Atmel Software Framework ([Atmel Corporation, 2009](#)) included a digital signal processing library. This contained functions to compute the FFT of a real or complex array, the inverse FFT, magnitude and phase of complex data. Further restrictions are imposed by the DSP library used as the data must be an even power of 2, and that the data is in fixed point notation. This gives a usable dimension of 256×256 for processing images on the AVR. Though the height of an image from the OV7670 camera is 240, the image can be transformed so that it repeats for 16 rows at the bottom as the Fourier transform works on an assumption of the data repeating itself.

The function *FFT2DCOMPLEX* in Appendix [G.1.1.5](#) is the realisation of a two dimensional fast Fourier transform on the microcontroller. The FFT function requires the data to be 4 byte aligned (A_ALIGNED) and of type *dsp16_complex_t*. The data must be given in fixed point notation and it is returned in fixed point notation. A 16 bit representation was chosen over 32 bit due to being more functions for 16 bit data available.

4.3.4 Testing of the FFT on AVR

Show results of some test signals

4.3.4.1 1D FFT Test

A Dirac function and a rectangular pulse were used as test signals.

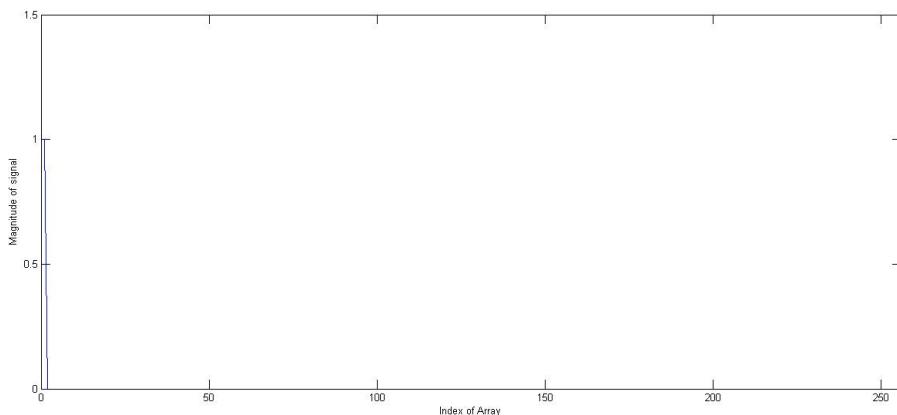


Figure 4.10: Input Dirac Signal for AVR fast Fourier transform

Figure 4.10 shows the input signal given to the AVR. It is a 256 long array of a Dirac function. This was then converted to the internally defined fixed point notation and passed through the Fourier transform method. The resulting complex array was then saved to a Comma Separated Value file and read into MATLAB. Figure 4.11 shows the calculated phase and magnitude plots of the output complex array. The magnitude is relatively flat and around the value of 1. In comparison with figure 4.6(b), they are relatively similar. The phase, however, seems to be very different. Figure 4.6(c) shows what was expected, but the two phase results seem not to match. This could be due to MATLAB having more accurate algorithms and a more accurate representation than the 16 bit fixed point used on the AVR. However, using a function in the DSP library to calculate the magnitude, the spectrum in figure 4.12 is obtained. This, though not exactly 1 as expected, is completely flat. It is computed from the same transformed data. It suggests that there is some internal compensation in the algorithms. The actual value in figure 4.12 is 0.9897 to 4 decimal places giving an overall error of 1.03%.

4.3.4.2 2D FFT Test

Elapsed Time to do FT

Need to implement grey scaling method before being able to do this

Show results of actual photo being transformed

Compare to MATLAB results

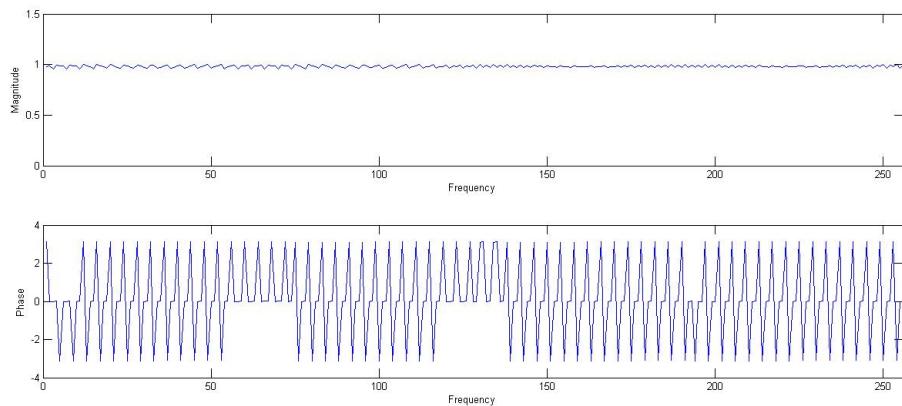


Figure 4.11: Output phase and magnitude of the complex output from AVR fast Fourier transform of a Dirac function

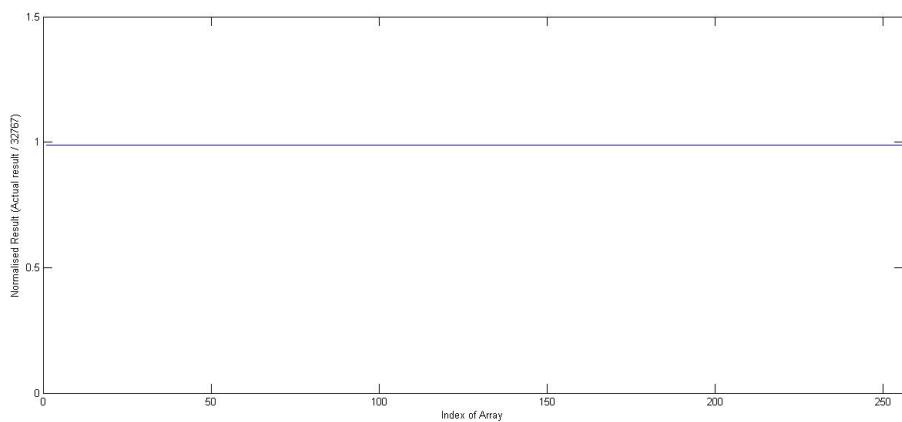


Figure 4.12: Maginitude calculated by the AVR of the Fourier transform of a Dirac function

4.4 Low Level Vision Algorithms

4.4.1 Noise Reduction

Why

Noise exists in all signals. Two noise sources for the camera image is random noise in the sensor, and quantisation noise. It generates a compromise between noise and resolution that has to be made. Large amounts of noise reduction will blur edges and therefore reduce the quality of the image and make it harder to match. This section will investigate some noise reduction methods, and test if the application of them increases the reliability of matching using the Normalised Cross Correlation method discussed in section 4.1.3.

Theory

Examples

Does it improve the reliability of matching? Vary noise amount in images?
and test

4.4.2 Edge Detection

Why

Theory

Examples

Does it improve the reliability of matching?

Chapter 5

Results

5.1 Results

A full test of the system I have got

Summary of good and bad WITH EVIDENCE

Chapter 6

Conclusions and Further Work

What I have accomplished

What could be changed to make it better

Suggestions for further work

Appendix A

Gantt Chart



Figure A.1: Gantt Chart of how time will be spent in the areas of the project

Appendix B

Circuit Diagrams

B.1 OV7670 Breakout Board Schematic

B.2 Il Matto and Dual Camera Schematic

B.3 The Columbus Circuit Diagram

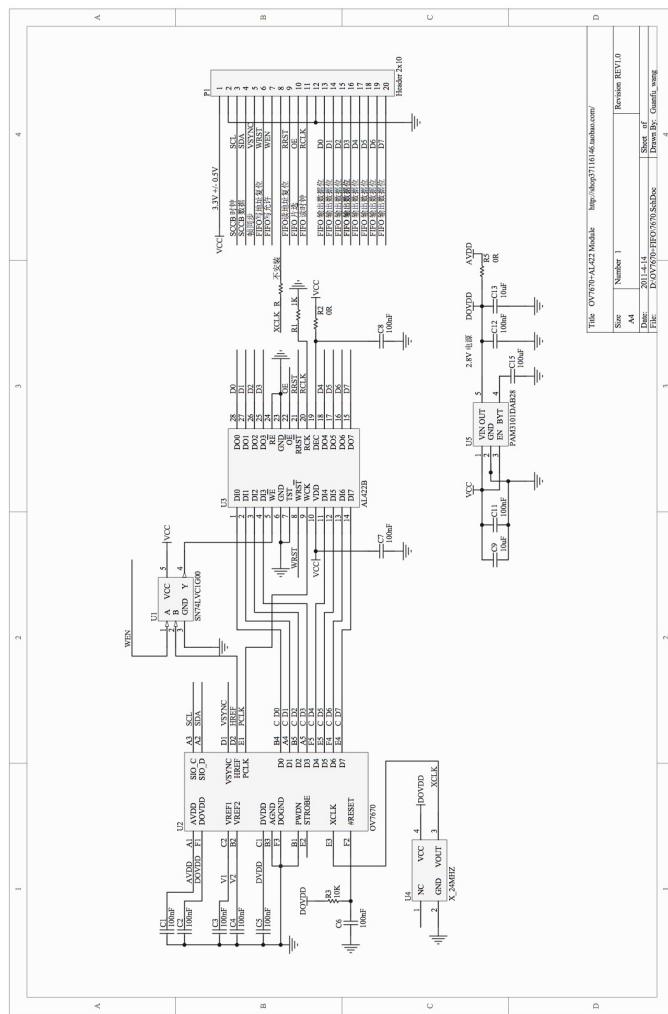


Figure B.1: The circuit diagram for the OV7670 breakout board

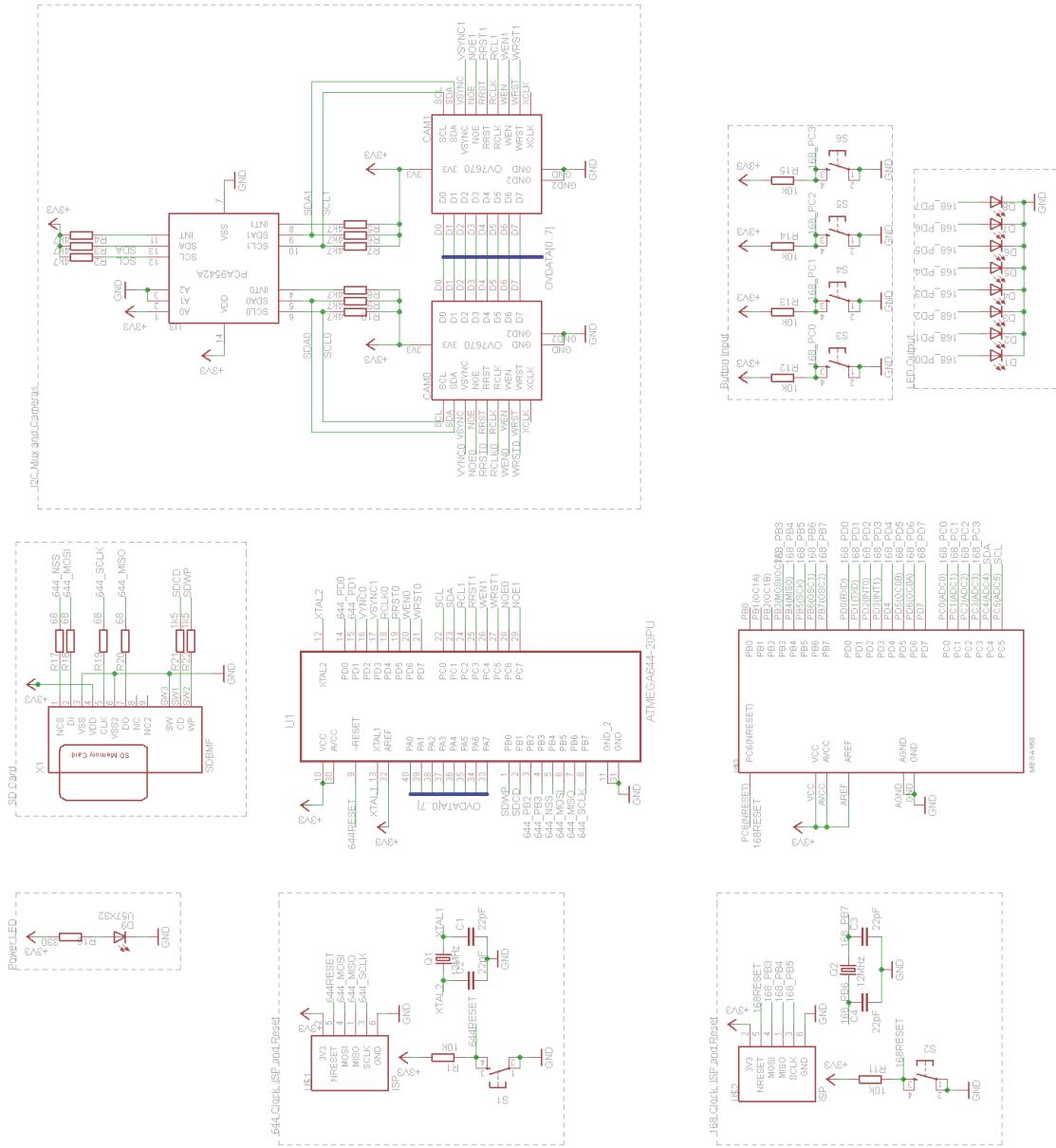


Figure B.2: The circuit diagram for Dual Cameras using the Il Matto Board

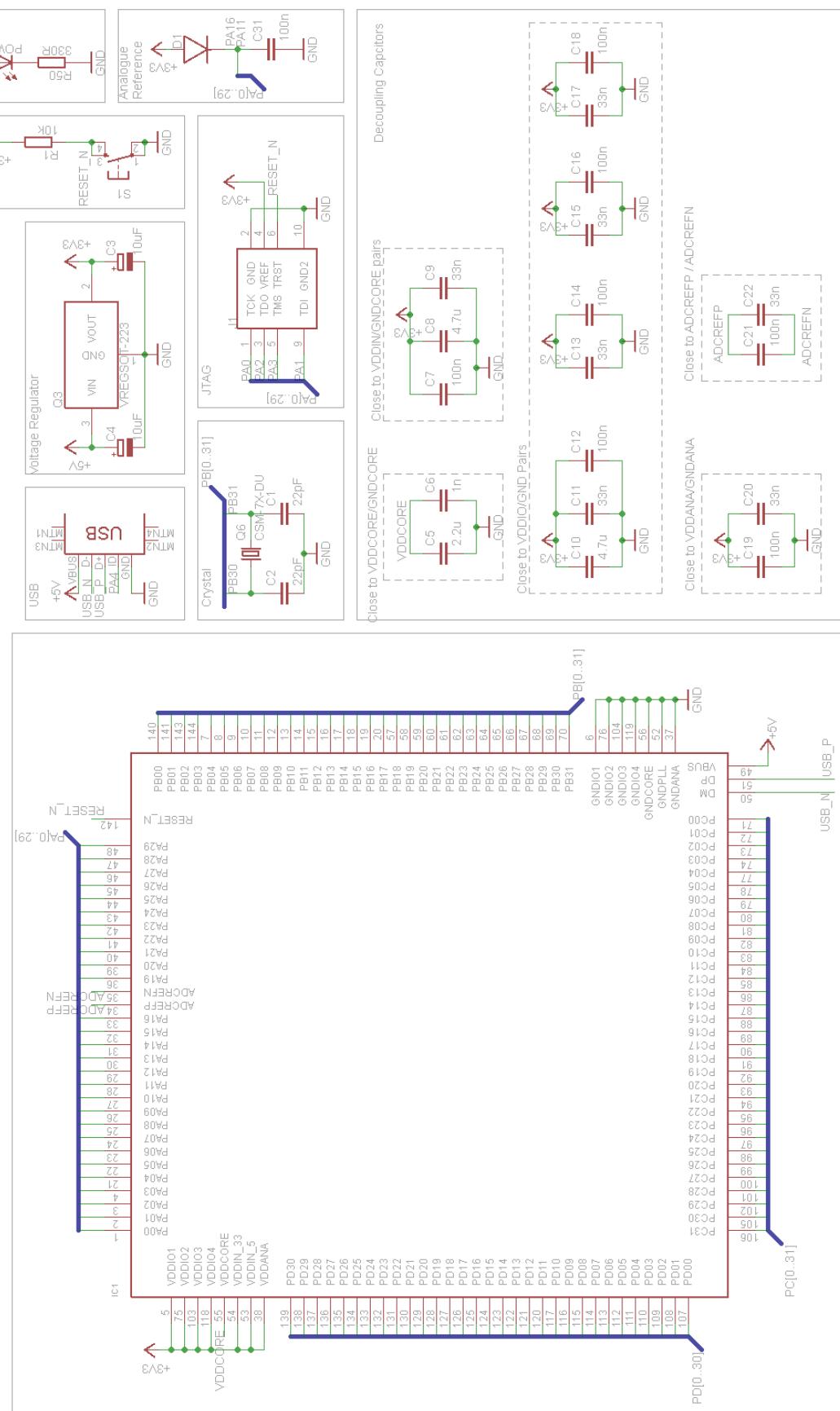


Figure B.3: The Columbus Circuit Diagram Page 1

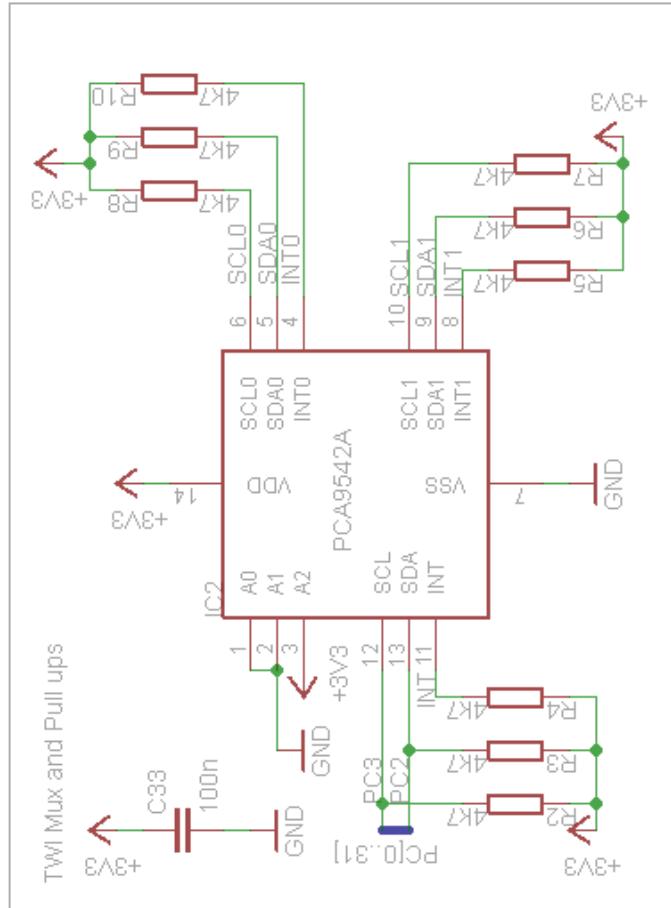
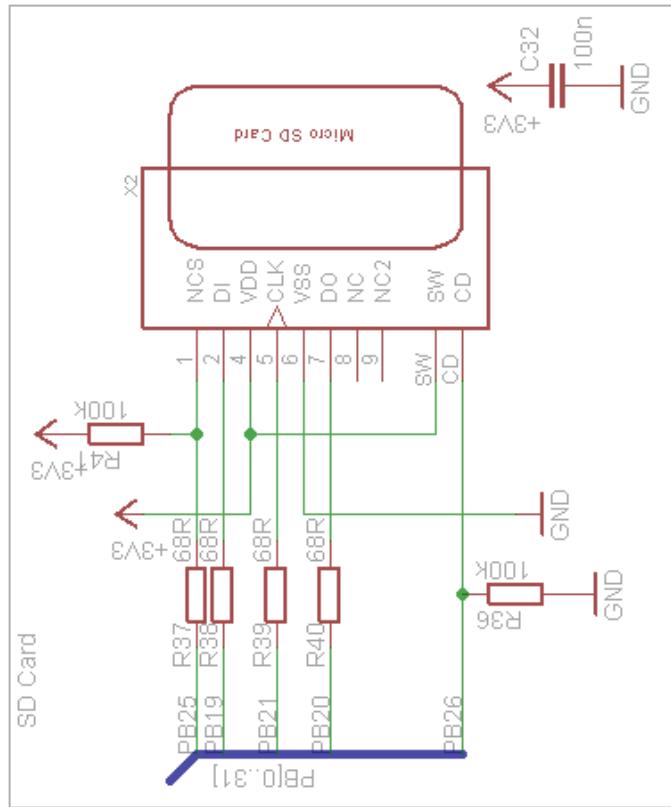


Figure B.4: The Columbus Circuit Diagram Page 2

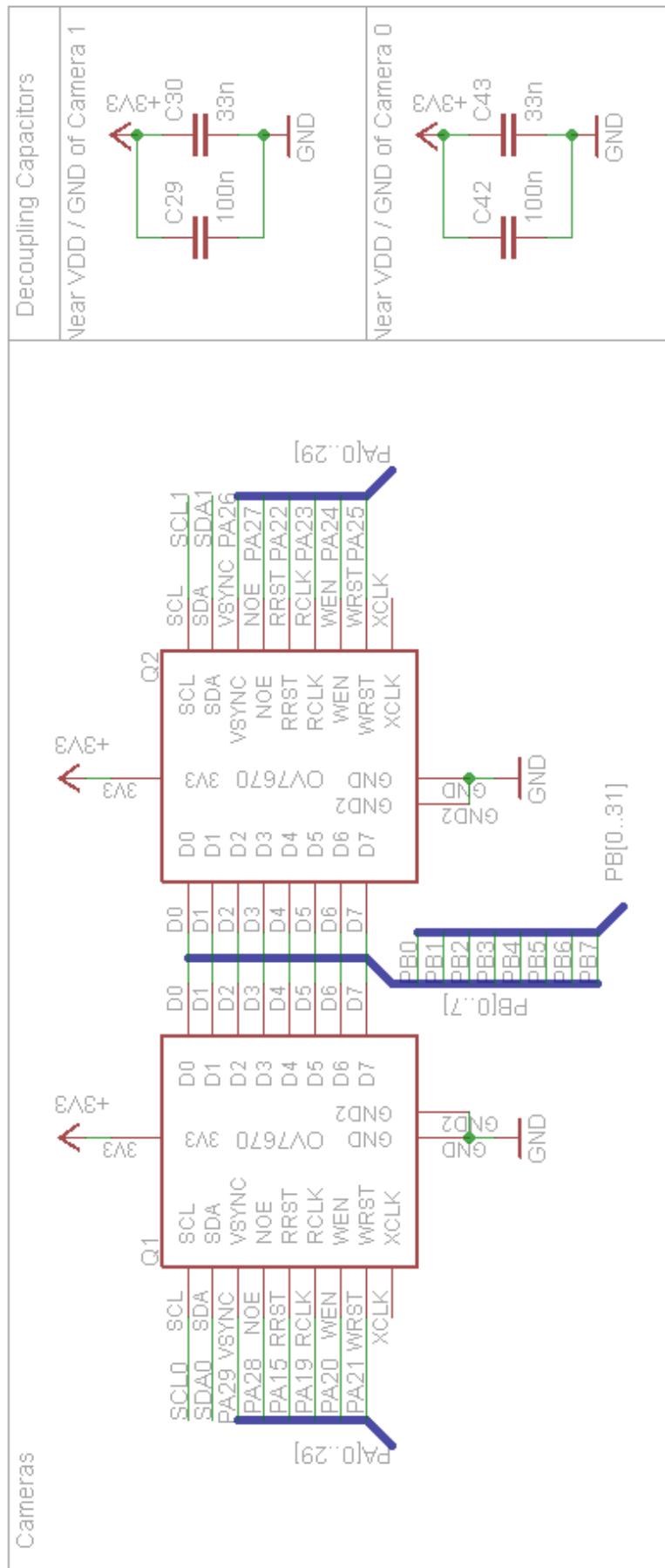


Figure B.5: The Columbus Circuit Diagram Page 3

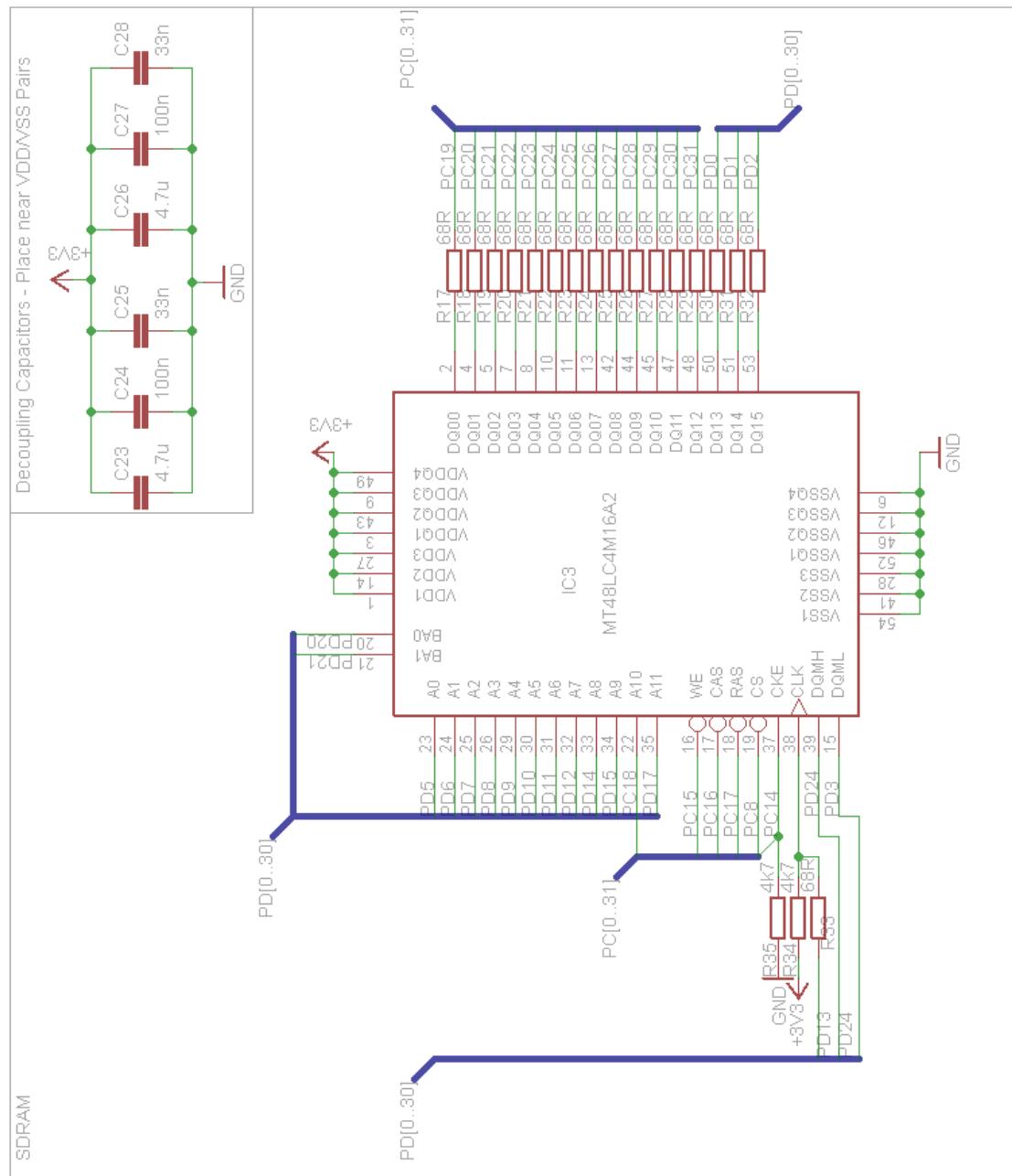


Figure B.6: The Columbus Circuit Diagram Page 4

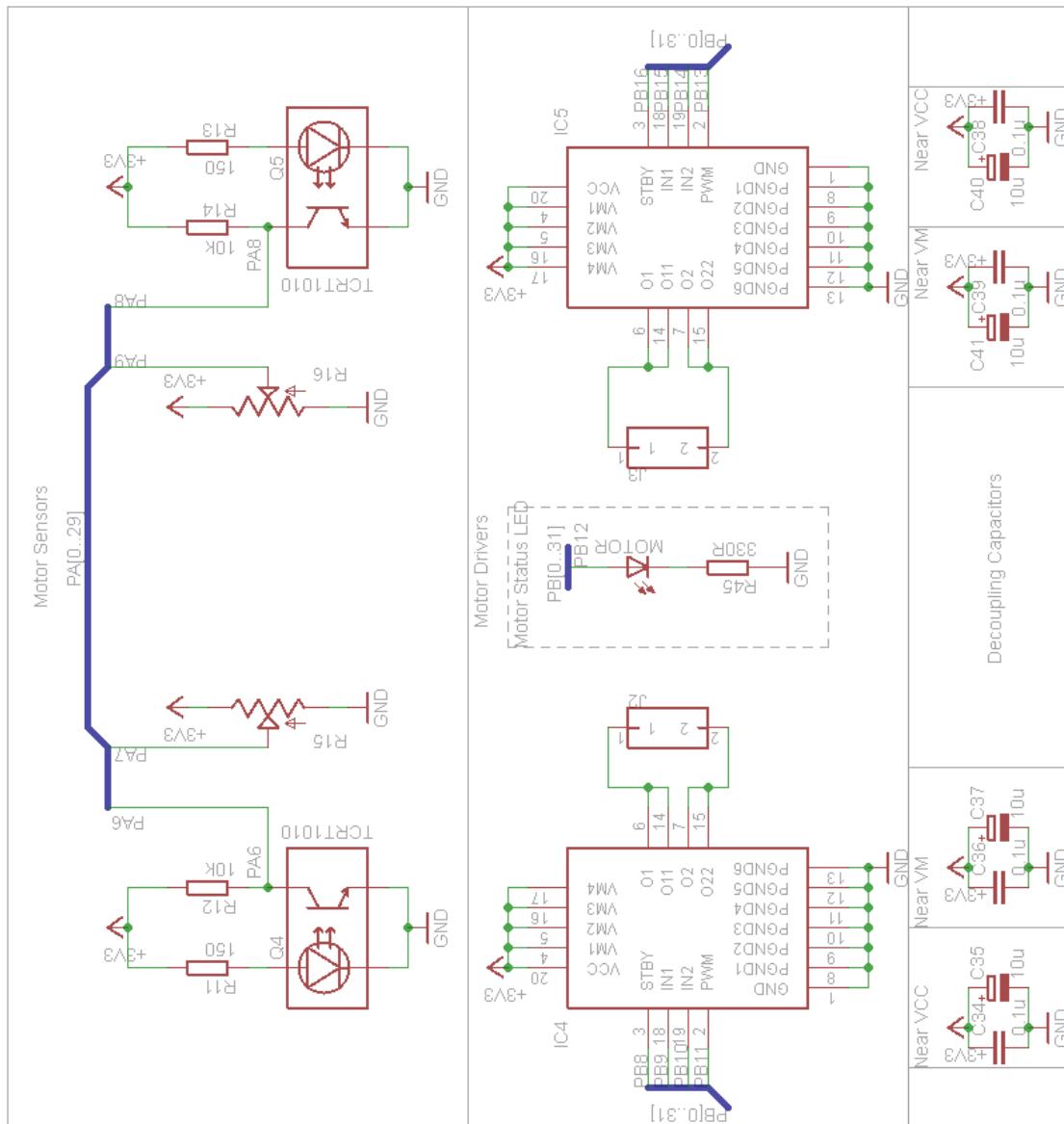


Figure B.7: The Columbus Circuit Diagram Page 5

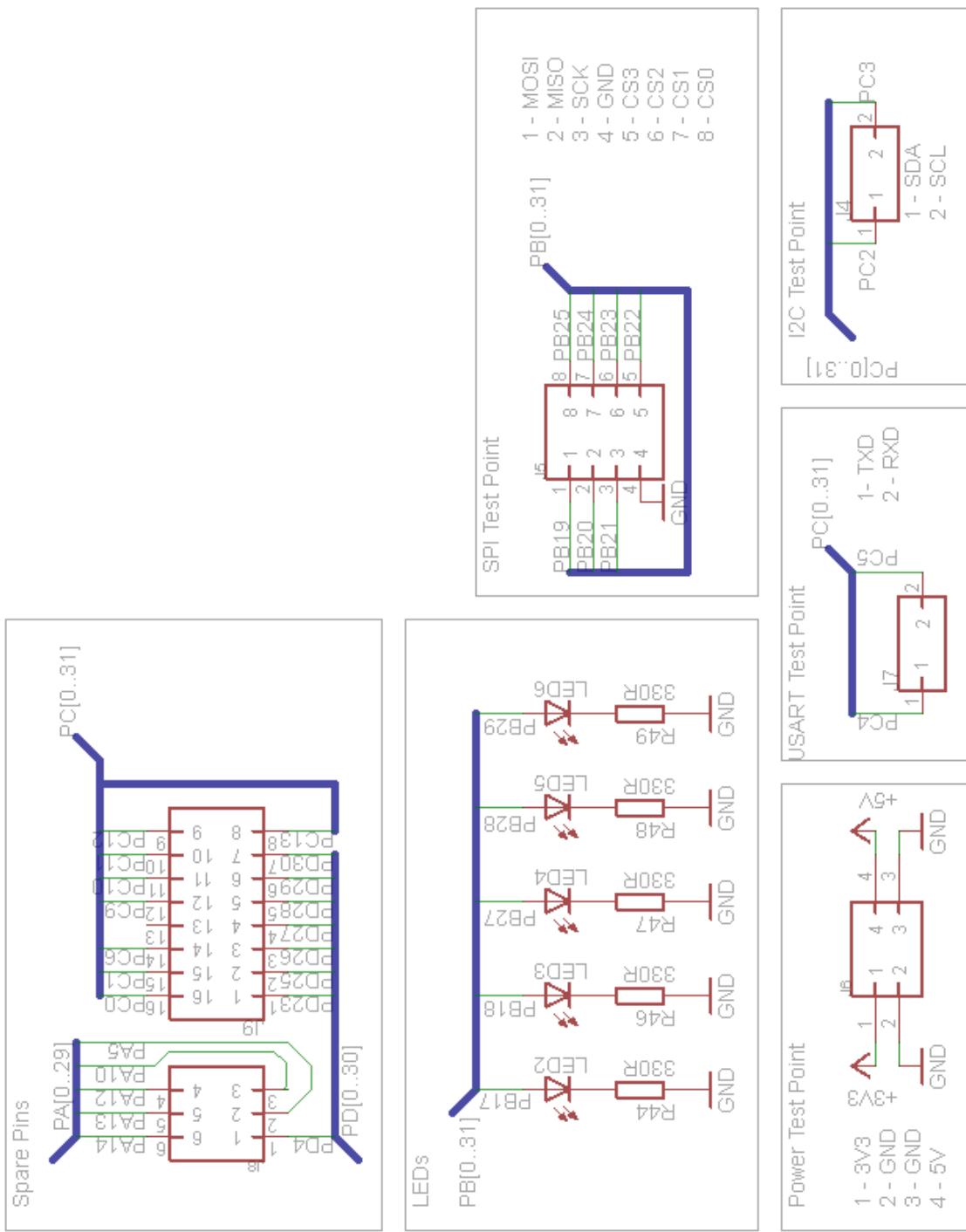


Figure B.8: The Columbus Circuit Diagram Page 6

Appendix C

PCB Design

C.1 PCB Top Side

C.2 PCB Bottom Side

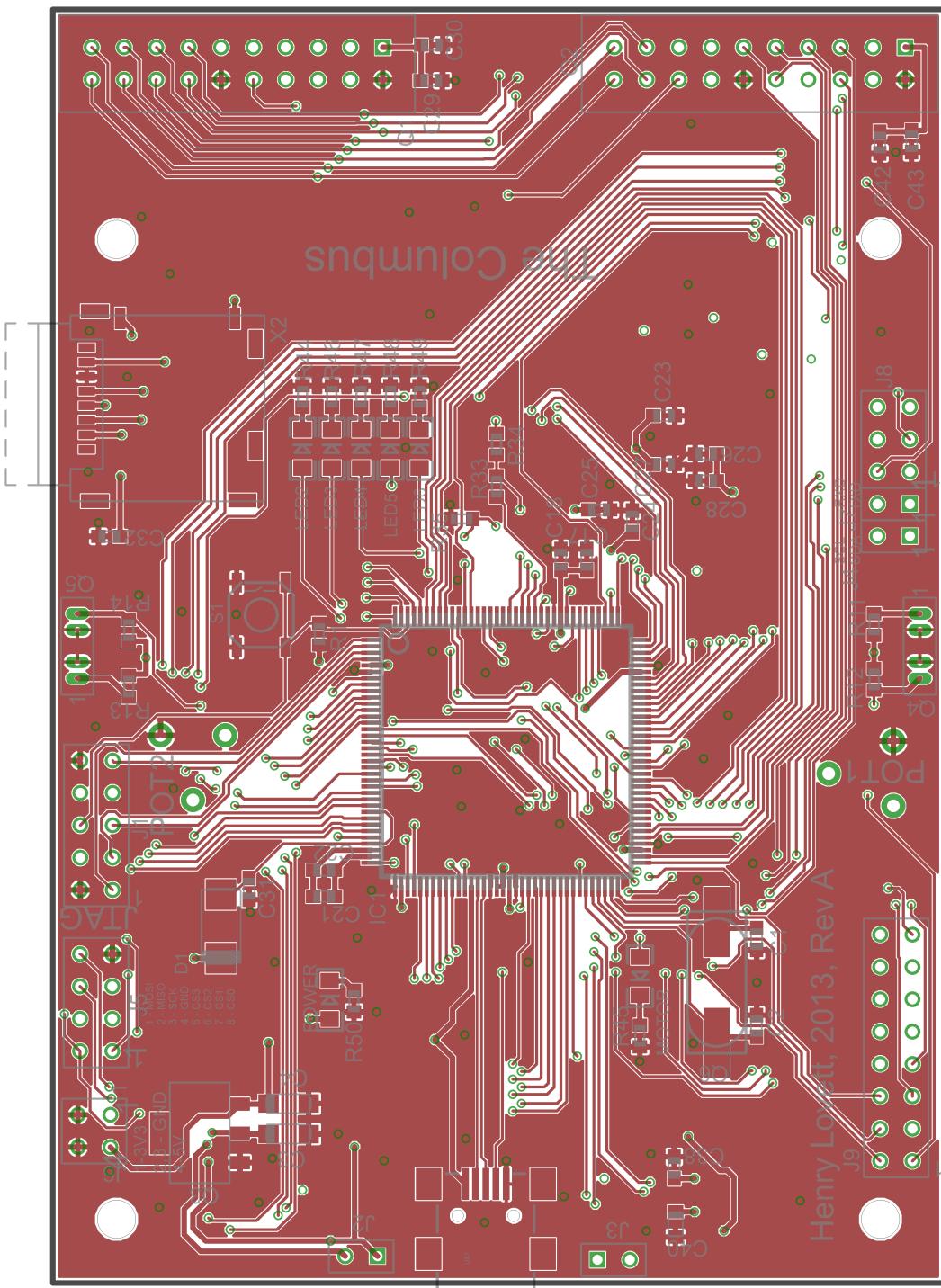


Figure C.1: The Top side of the CAD Design of the PCB

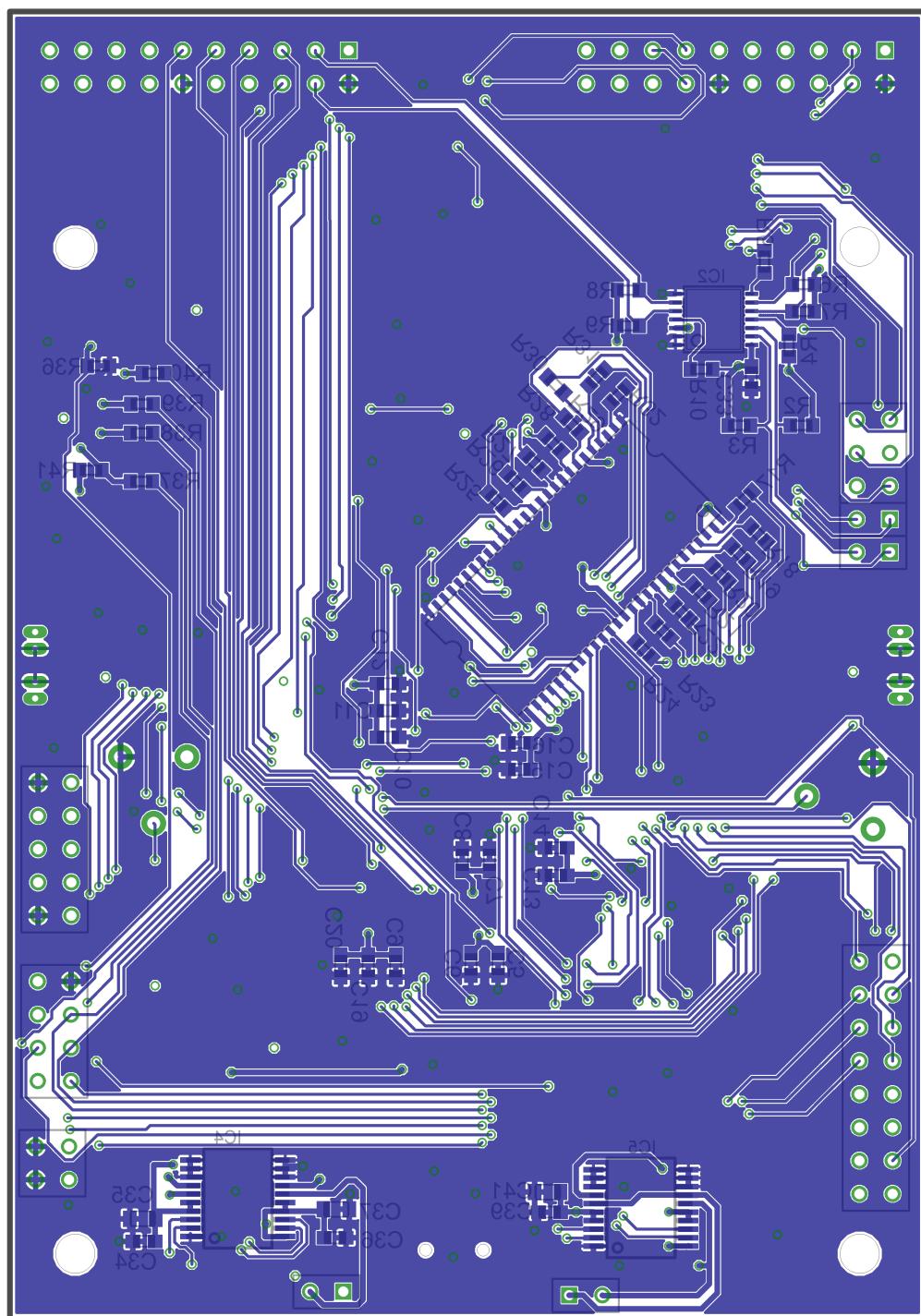


Figure C.2: The Bottom side of the CAD Design of the PCB

Appendix D

Costings

Component	Cost per unit (£)	Quantity	Cost (£)	Source
PCB	205	1	205	PCBCart
Capactiors	0.155	43	6.67	Farnell
Clock	1.48	1	1.48	Farnell
Diode	0.48	1	0.48	Farnell
Headers	0.51	5	2.55	Farnell
I2C Mux PCA9542A	0.81	1	0.81	Farnell
LEDs	0.158	7	1.11	Farnell
Micro SD Card	4	1	4.00	Amazon
Micro SD Card Connector	2.04	1	2.04	Farnell
AT32UC3C0512C	15.39	1	15.39	Farnell
TB6593FNG	1.07	2	2.14	Farnell
Motors	0.42	2	0.84	Rapid
TCRT1010	0.94	2	1.88	Farnell
OV7670	17	2	34.00	
Potentiometer	0.43	2	0.86	Farnell
Resistors	0.066	46	3.04	Farnell
MT48LC4M16A2P	3.24	1	3.24	Farnell
Switch	0.45	1	0.45	Farnell
USB Socket	0.84	1	0.84	Farnell
LM1117MP	1.03	1	1.03	Farnell
Total Cost			£287.84	

Table D.1: A table of all components used and their costs.

Appendix E

Contents of Files

Appendix F

Bitmap File Format

F.1 Bitmap File Format

Table F.1: Format of a Bitmap file with values used, to write an image from the camera to an SD Card

Section	Field	Description	Size (Bytes)	Value (hex)
Bitmap Header	Signature	Declares the file is a Bitmap Image	2	424D
	File Size	Size of the whole file including headers	4	36580200 (153654) ¹
	Reserved		4	00000000
	Offset to Pixel Array	The address of the start of the pixel data from the beginning of the file	4	36000000
DIB (Device Independent Bitmap) Header	Size	Size of the DIB Header (dictates the version)	4	7C000000
	Width	Width of the image (320 pixels)	4	40010000

Continued on next page

¹This is different to the 225kB stated in Table 3.1 due to omitting many optional fields

Table F.1 – continued from previous page

Section	Field	Description	Size (Bytes)	Value (hex)
	Height	Height of the image (240 pixels)	4	F0000000
	Planes	Number of colour planes	2	0100
	Bit Count	Number of bits per pixel	2	1000
	Compression	Compression Being Used, RGB Bit Fields	4	03 00 00 00
	Image Size	Size of the image	4	00 86 25 00
	X Resolution	Horizontal resolution in pixels per metre	4	13 0B 00 00
	Y Resolution	Vertical resolution in pixels per metre	4	13 0B 00 00
	Colours in Table	Number of colours in the colour table (not used)	4	00 00 00 00
	Important Colours	Number of Important Colours (0 means all colours are important)	4	00 00 00 00
	Red Mask	Bit mask of Red field	4	00 F8 00 00
	Green Mask	Bit mask of Green field	4	E0 07 00 00
	Blue Mask	Bit mask of Blue field	4	1F 00 00 00
	Alpha Mask	Bit mask of Alpha field	4	00 00 00 00
	Colour Space Type	Colour Space of the DIB	4	01 00 00 00
	Colour Space Endpoints	Sets endpoints for colours within the bitmap (not used)	36	Whole Field = 0
	Gamma Red	Gamma Value of Red Field (not used)	4	00 00 00 00

Continued on next page

Table F.1 – continued from previous page

Section	Field	Description	Size (Bytes)	Value (hex)
	Gamma Green	Gamma Value of Green Field (not used)	4	00 00 00 00
	Gamma Blue	Gamma Value of Blue Field (not used)	4	00 00 00 00
	Intent	Enum dictating the intent of the image (Picture)	4	03 00 00 00
	ICC Profile Data	Offset from the file start to the ICC Colour Profile (Not Used)	4	00 00 00 00
	ICC Profile Size	Size of the ICC Colour Profile (not used)	4	00 00 00 00
	Reserved		4	00 00 00 00
Image Data Format	Each field contains all the pixel data	Padding is used to make the table width a multiple of 4 (Not always needed)		
Pix[0, h-1]	Pix[1, h-1]	...	Pix[w-1, h-1]	Padding
:	:	:	:	:
Pix[0, 1]	Pix[1, 1]	...	Pix[w-1, 1]	Padding
Pix[0, 0]	Pix[1, 0]	...	Pix[w-1, 0]	Padding

Appendix G

Source Code

G.1 C Code for AVR

G.1.1 The Columbus Source Code

G.1.1.1 main.c

..../Code/The_Columbus/ColumbusTest/src/main.c

```
1  /**
2  * \file
3  *
4  * \brief Empty user application template
5  *
6  */
7
8  /*
9  * Include header files for all drivers that have been imported from
10 * Atmel Software Framework (ASF).
11 */
12
13 #include <asf.h>
14 #include <conf_board.h>
15 #include "CustomDevices/CustomDevices.h"
16 #include "conf_sd_mmc_spi.h"
17 #include "fat.h"
18 #include "file.h"
19 #include "navigation.h"
20 #include "fastmath.h"
21 #include "delay.h"
22
23 //REF : http://www.chris.com/ASCII/index.php?art=transportation/nautical
```



```
64 #define COMMAND_BUFFER_SIZE    32
65 int main (void)
66 {
67     Image_t image;
68     unsigned long i, j, tmp = 0;
69     char *Ptr;
70 //  volatile unsigned long *sdram = SDRAM;
71     char CommandBuffer[COMMAND_BUFFER_SIZE];
72     int *Working_Buffer = NULL;
73     int SizeOfWorking_Buffer = 0;
74     A_ALIGNED dsp16_complex_t *ComplexBuffer;
75     int SizeOfComplex_Buffer = 0;
76     Columbus_Status.SD_Card = &SD_Status;
77     Columbus_Status.Cameras = &OV7670_Status;
78     Columbus_Status.I2CMux = &PCA9542A;
79     Columbus_Status.SD_Card = &SD_Status;
80     Columbus_Status.Motors = &Motor_Control;
81     board_init();
82     print_dbg("\n\r");
83     print_dbg(THE);
84     print_dbg(COLUMBUS);
85     print_dbg(ASCII_SHIP);
86     System_Test();

88 if(Columbus_Status.Status != STATUS_OK)
89 {
90     while(1)
91     {
92         LED2_SET;
93         LED3_SET;
94         LED4_SET;
95         LED5_SET;
96         LED6_SET;
97         delay_ms(500);
98         LED2_CLR;
99         LED3_CLR;
100        LED4_CLR;
101        LED5_CLR;
102        LED6_CLR;
103        delay_ms(500);
104    }//inifinte loop
105 }

108 print_dbg("\n\rColumbus Ready!");
109 // Insert application code here, after the board has been initialized.
110 while(1)
111 {
112     print_dbg(PROMPT);
113     Get_Line(CommandBuffer);
114     Ptr = CommandBuffer;
115     switch(*Ptr++)
116     {
117         case '?':
118             print_dbg(HELP);
119             break;
```

```
121     case '1'://1d FFT (w/ memallocs)
122         print_dbg("\r1D FFT;");
123         SizeOfComplex_Buffer = FFT_SIZE;
124         ComplexBuffer = mspace_malloc(sdram_msp, SizeOfComplex_Buffer *
125                                         sizeof(ComplexBuffer));
126         FFT1D(Working_Buffer, ComplexBuffer);
127         break;
128     case '2':
129         print_dbg("\r2D FFT;");
130         FFT2Dabs(Working_Buffer);
131         break;
132     case '3':
133         print_dbg("\rComplex FFT2D:");
134         SizeOfComplex_Buffer = FFT_SIZE * FFT_SIZE;
135         ComplexBuffer = mspace_malloc(sdram_msp, SizeOfComplex_Buffer *
136                                         sizeof(ComplexBuffer));
137         FFT2DCOMPLEX(Working_Buffer, ComplexBuffer, SizeOfWorking_Buffer);
138         break;
139
140     case 'B':
141         print_dbg("\rReading Bitmap;");
142         ReadBitmap("Image_R_0.bmp", &image);
143         print_dbg("\n\rBitmap Data Returned:\n\rImage Height = ");
144         print_dbg_ulong(image.Height);
145         print_dbg("\n\rImage Width = ");
146         print_dbg_ulong(image.Width);
147         break;
148
149     case 'c':
150         print_dbg("\rConverting Working Buffer to Fixed Point");
151         for(i = 0; i < SizeOfWorking_Buffer ; i++)
152         {
153             Working_Buffer[i] = DSP16_Q (Working_Buffer[i]);
154         }
155         break;
156
157     case 'C':
158         print_dbg("\rConverting Working Buffer back from Fixed Point");
159         j = DSP16_Q(1);
160         for(i = 0; i < SizeOfWorking_Buffer ; i++)
161         {
162             Working_Buffer[i] = Working_Buffer[i] / j;
163         }
164         break;
165
166     case 'D':
167         print_dbg("\rFreeing Working Buffer");
168         mspace_free(sdram_msp, Working_Buffer);
169         break;
170
171     case 'i':
172         print_dbg("\rImage info:");
173         print_dbg("\n\rImage Pointer = ");
174         print_dbg_ulong(image.ImagePtr);
175         print_dbg("\n\rImage Height = ");
176         print_dbg_ulong(image.Height);
177         print_dbg("\n\rImage Width = ");
178         print_dbg_ulong(image.Width);
```

```
177         break;

179     case 'I':
180         print_dbg("\rInverse Fourier Transform;");
181         IFFT2D(ComplexBuffer);
182         break;

184     case 'k':
185         print_dbg("\rComplex Buffer:\n\r[");
186         for (i = 0; i < SizeOfComplex_Buffer; i++)
187         {
188             print_dbg_ulong(ComplexBuffer[i].real);
189             print_dbg(" + j");
190             print_dbg_ulong(ComplexBuffer[i].imag);
191             print_dbg(", ");
192         }
193         print_dbg("]\n\r");
194         break;
195     case 'M': //Motor Related
196         while(*Ptr == ' ')
197             Ptr++; //Find next non - space char

199         switch(*(Ptr++))
200         {
201             case 'q': // Reset Motors
202                 print_dbg("\rResetting Motors");
203                 Motors_Reset();
204                 break;

206             case 'F': //Move Forward
207                 while(*Ptr == ' ')
208                     Ptr++; //Find next non - space char
209                     i = atoi(Ptr);
210                     Motors_Move(i);
211                     break;
212             case 'T':
213                 while(*Ptr == ' ')
214                     Ptr++; //Find next non - space char
215                     i = atoi(Ptr);
216                     Motors_Rotate(i);
217                     break;
218             case 'l':
219                 Motor_Stop(MOTOR_L);
220                 break;
221             case 'L':
222                 Columbus_Status.Motors->Left_Count = INTERRUPTS_PER_REVOLUTION +
223                 1;
223                 Columbus_Status.Motors->Left_State = FORWARD;
224                 Motor_Start(MOTOR_L);
225                 Motors_Execute();
226                 break;
227             case 'r':
228                 Motor_Stop(MOTOR_R);
229                 break;
230             case 'R':
231                 Columbus_Status.Motors->Right_Count = INTERRUPTS_PER_REVOLUTION +
232                 1;
232                 Columbus_Status.Motors->Right_State = FORWARD;
```

```
233     Motor_Start(MOTOR_R);
234     Motors_Execute();
235     break;
236     default:
237         print_dbg("\rCommand Not Recognised");
238         break;
239     }

241     break;

243 case 'p':
244     print_dbg("\rPreparing Image;");
245     PrepareImage(&image);
246     print_dbg("\rImage Prepared!");
247     break;

249 case 'P'://take a photo
250     FIFO_Reset(CAMERA_LEFT | CAMERA_RIGHT);
251     print_dbg("\rTaking Photos");
252     if(TakePhoto(CAMERA_LEFT | CAMERA_RIGHT) == CAMERAS_BUSY){
253         print_dbg("Cameras Busy");
254         break;
255     }
256     while(Photos_Ready() == false)
257     ;
258
259     if(Store_Both_Images() == true)
260         print_dbg("\n\rImages Stored Successfully!");
261     break;

263 case 'r':
264     if (Working_Buffer == 0)
265     {
266         print_dbg("\rWorking Buffer Not Initialised");
267         break;
268     }
269     print_dbg("\rWorking Buffer:\n\r[");
270     for(i = 0; i < SizeOfWorking_Buffer; i++)
271     {
272         print_dbg_ulong(Working_Buffer[i]);
273         print_dbg(", ");
274     }
275     print_dbg("\b\b]\n\r");
276     break;
277 case 'R':
278     Working_Buffer = mspace_malloc(sdram_msp, FFT_SIZE);
279     SizeOfWorking_Buffer = FFT_SIZE;
280     print_dbg("\rReading in signal.bin");
281     ReadSignal(Working_Buffer);
282     break;

284 case 's'://save the working buffer
285     print_dbg("\rSaving Working Buffer;");
286     SaveBuff(Working_Buffer, SizeOfWorking_Buffer);
287     break;
288 case 'd':
289     print_dbg("\rSaving Working Buffer as CSV;");
```

```
290     SaveBuff_CSV("Buffer_result.csv", Working_Buffer, SizeOfWorking_Buffer
291 );
292     break;
293 case 'g':
294     print_dbg("\rSaving Complex Buffer as CSV");
295     SaveCBuff_CSV("Buffer_Complex.csv", ComplexBuffer,
296     SizeOfComplex_Buffer);
297     break;
298 case 'f':
299     Working_Buffer = mspace_malloc(sdram_msp, FFT_SIZE);
300     SizeOfWorking_Buffer = FFT_SIZE;
301     print_dbg("\rReading in Buffer.csv");
302     Read_CSV("Buffer.csv", Working_Buffer, SizeOfWorking_Buffer);
303     print_dbg("\n\rComplete!");
304     break;
305
306 case 'S':
307     print_dbg("\rSaving Bitmap;");
308     SaveBitmap(image.ImagePtr, image.Width, image.Height, "ResavedImage.
309 bmp");
310     print_dbg("\rSaved Bitmap!;");
311     break;
312
313 case 'T':
314     print_dbg("\rReading in 2D Signal");
315     Working_Buffer = mspace_malloc(sdram_msp, FFT_SIZE * FFT_SIZE);
316     SizeOfWorking_Buffer = FFT_SIZE * FFT_SIZE;
317     Read2DSignal(Working_Buffer);
318     break;
319 case 'v':
320     print_dbg("\rColumbus Status:");
321     print_dbg("\n\rSD Card:\n\rStatus: ");
322     print_dbg_ulong(Columbus_Status.SD_Card->Status);
323     print_dbg("\n\rMemory Size : ");
324     print_dbg_ulong(Columbus_Status.SD_Card->Memory_size);
325     print_dbg("\n\rMotors:");
326     print_dbg("\n\rLeft State : ");
327     print_dbg_ulong(Columbus_Status.Motors->Left_State);
328     print_dbg("\n\rLeft Count : ");
329     print_dbg_ulong(Columbus_Status.Motors->Left_Count);
330     print_dbg("\n\rRight State : ");
331     print_dbg_ulong(Columbus_Status.Motors->Right_State);
332     print_dbg("\n\rRight Count : ");
333     print_dbg_ulong(Columbus_Status.Motors->Right_Count);
334     print_dbg("\n\rCameras:");
335     print_dbg("\n\rStatus : ");
336     print_dbg_ulong(Columbus_Status.Cameras->Status);
337     print_dbg("\n\rVSYNC0 State : ");
338     print_dbg_ulong(Columbus_Status.Cameras->VSYNC0_State);
339     print_dbg("\n\rVSYNC1 State : ");
340     print_dbg_ulong(Columbus_Status.Cameras->VSYNC1_State);
341     print_dbg("\n\rI2C Mux:");
342     print_dbg("\n\rStatus : ");
343     print_dbg_ulong(Columbus_Status.I2CMux->Status);
344     print_dbg("\n\rChannel Selected : ");
345     print_dbg_ulong(Columbus_Status.I2CMux->ChannelSelected);
346     break;
347 case 'o':
```

```

345     print_dbg("\r1 in Fixed point = ");
346     i = DSP16_Q(1);
347     print_dbg_ulong(i);
348     break;
349 //    case 'o'://testing storing a complex
350 //        print_dbg("\rFreeing Complex Buffer");
351 //        mspace_free(sdram_msp, ComplexBuffer);
352 //        print_dbg("\n\rAssiging Space to the Complex Buffer;");
353 //        SizeOfComplex_Buffer = 10;
354 //        ComplexBuffer = mspace_malloc(sdram_msp, 10*sizeof(ComplexBuffer));
355 //        if(ComplexBuffer == NULL)
356 //        {
357 //            print_dbg("\n\rAssign Failed;");
358 //            break;
359 //        }
360 //        for(i = 0; i < SizeOfComplex_Buffer; i++)
361 //        {
362 //            ComplexBuffer[i].imag = i;
363 //            ComplexBuffer[i].real = i;
364 //        }
365 //        for(i = 0; i < SizeOfComplex_Buffer; i++)
366 //        {
367 //            print_dbg("\n\r");
368 //            print_dbg_ulong(ComplexBuffer[i].real);
369 //            print_dbg(" + j ");
370 //            print_dbg_ulong(ComplexBuffer[i].imag);
371 //        }
372 //        print_dbg("\n\rFreeing Complex Buffer");
373 //        mspace_free(sdram_msp, ComplexBuffer);
374 //        SizeOfComplex_Buffer = 0;
375 //        break;

377     default:
378         print_dbg("\rCommand Not Recognised;");
379         break;
380     }
381 }
382 }
```

G.1.1.2 Bitmap.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/Bitmap.c

```

11             0xF0, 0x00, 0x00, 0x00, //Height - 240
12             0x01, 0x00,           //Planes
13             0x10, 0x00,           //Bits per Pixel
14             0x03, 0x00, 0x00, 0x00, //Compression
15             0x00, 0x58, 0x02, 0x00, //Size of Raw Data
16             0x13, 0x0B, 0x00, 0x00, //Horizontal Resolution
17             0x13, 0x0B, 0x00, 0x00, //Vertical Resolution
18             0x00, 0x00, 0x00, 0x00, //Colours in Palette
19             0x00, 0x00, 0x00, 0x00, //Important Colours
20             0x00, 0xF8, 0x00, 0x00, //Red Mask
21             0xE0, 0x07, 0x00, 0x00, //Green Mask
22             0x1F, 0x00, 0x00, 0x00, //Blue Mask
23             0x00, 0x00, 0x00, 0x00, //Alpha Mask
24             0x01, 0x00, 0x00, 0x00, //Colour Space Type
25             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
26             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
27             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
28             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
29             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
30             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
31             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
32             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
33             0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
34             0x00, 0x00, 0x00, 0x00, //Gamma Red
35             0x00, 0x00, 0x00, 0x00, //Gamma Green
36             0x00, 0x00, 0x00, 0x00, //Gamma Blue
37             0x03, 0x00, 0x00, 0x00, //Intent - Photo
38             0x00, 0x00, 0x00, 0x00, //ICC Profile Data
39             0x00, 0x00, 0x00, 0x00, //ICC Profile Size
40             0x00, 0x00, 0x00}; //Reserved

42 const uint8_t BMPHeader[BMPHEADERSIZE] = { 0x42, 0x4D,
43                                         0x8A, 0x58, 0x02, 0x00, //Size
44                                         0x00, 0x00, 0x00, 0x00, //Reserved
45                                         0x8A, 0x00, 0x00, 0x00 //Offset to Pixel Array
46 };

```

G.1.1.3 CustomDevices.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/CustomDevices.h

```

1  /*
2  *  CustomDevices.h
3  *
4  *  Created: 16/02/2013 14:30:50
5  *  Author: hslovett
6  */
7
8
9 #ifndef CUSTOMDEVICES_H_
10 #define CUSTOMDEVICES_H_
11
12 //Camera
13 #include "CustomDevices/OV7670.h"

```

```

14 //I2C Mux
15 #include "CustomDevices/PCA9542A.h"
16 //MotorDriver
17 #include "CustomDevices/MotorDriver.h"
18 //SDCard
19 #include "CustomDevices/SD_Card.h"
20 //Image Processing Functions
21 #include "CustomDevices/ImageProcessor.h"

23 typedef struct {
24     int Status;
25     SD_Status_t *SD_Card;
26     Motor_Control_t *Motors;
27     OV7670_t *Cameras;
28     PCA9542A_t *I2CMux;
29 } Columbus_Status_t;

31 #define SD_ERR      0x1
32 #define CAM_ERR     0x2
33 #define I2CMux_ERR  0x4

35 #define FFT_SIZE 256

37 mspace sdram_msp;
38 Columbus_Status_t Columbus_Status;
39 //TWI Methods
40 void twim_init (void);
41 void System_Test();
42 #endif /* CUSTOMDEVICES_H_ */

```

G.1.1.4 ImageProcessor.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/ImageProcessor.h

```

1 /*
2  * ImageProcessor.h
3  *
4  * Created: 28/02/2013 17:46:37
5  * Author: hslovett
6  */

9 #ifndef IMAGEPROCESSOR_H_
10 #define IMAGEPROCESSOR_H_

12 #define BMP_FORMAT_RGB565      1
13 #define BMP_FORMAT_RGB555      2
14 #define BMP_FORMAT_GREYSCALE   3
15 #define BMP_FORMAT_1xUINT      4
16 #define BMP_FORMAT_2xUINT8T    5
17 typedef struct {
18     uint16_t *ImagePtr;
19     int Height;
20     int Width;

```

```

21     uint8_t Format;
22 } Image_t;

26 void FFT1D( int *Signal, dsp16_complex_t *ComplexBuffer);
27 int FFT2Dabs(int *Signal);
28 int log_2(int i);

30 void FFT2DCOMPLEX( int *Signal, dsp16_complex_t *ComplexBuffer, int size );
31 void PrepareImage(Image_t *Image);
32 //int* IFFT2D (dsp16_complex_t *Result, dsp16_complex_t *Input);
33 void IFFT2D (dsp16_complex_t *Signal); /*Need to test this! */;
34 int FFT1D_Abs( int *Signal);
35 #endif /* IMAGEPROCESSOR_H_ */

```

G.1.1.5 ImageProcessor.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/ImageProcessor.c

```

1  /*
2   * ImageProcessor.c
3   *
4   * Created: 28/02/2013 17:46:50
5   * Author: hslovett
6   */
7  #include <asf.h>
8  #include "CustomDevices/CustomDevices.h"

10 //##define FFT_SIZE 64*/
11 //Returns log base 2 of i - checks if it is an integer power of 2
12 int log_2(int i)
13 {
14     int ret = 0;
15     if((i & (i - 1)) != 0)
16     {
17         return -1;
18     }
19     while((i & 1) == 0) //while the bit isn't in the lowest bit (already
20         established this is a integer power of 2)
21     {
22         i >>= 1;
23         ret++;
24     }

25     return ret;
26 }
27 //*****
28 // Method:      FFT2DCOMPLEX
29 // FullName:   FFT2DCOMPLEX
30 // Access:    public
31 // Returns:   int*
32 // Qualifier:
33 // Parameter: int * Signal

```

```

34 // Parameter: A_ALIGNED dsp16_complex_t * ComplexBuffer
35 // Parameter: int size
36 //*****
37 void FFT2DCOMPLEX( int *Signal, dsp16_complex_t *ComplexBuffer, int size )
38 {
39     int i, j = 0;
40     int Ptr;
41     Ptr = 0;
42     A_ALIGNED dsp16_complex_t Input_C_1D[FFT_SIZE];
43     A_ALIGNED dsp16_complex_t Result_C_1D[FFT_SIZE];
44     A_ALIGNED dsp16_complex_t Result_C_2D[FFT_SIZE*FFT_SIZE];
45     A_ALIGNED dsp16_t Input_R_1D[FFT_SIZE];
46     //Stage 1 - FFT Real values from Signal. Store VERTICALLY in Result_2D
47     for(i = 0; i < FFT_SIZE; i++){ //for each row
48         for(j = 0; j < FFT_SIZE; j++){
49             Input_R_1D[j] = Signal[Ptr++]; //copy the data across
50         }
51         //Do the FFT
52         dsp16_trans_realcomplexfft(Result_C_1D, Input_R_1D, log_2(FFT_SIZE));
53         //Copy data into 2D result TRANSPOSED
54         for(j = 0; j < FFT_SIZE; j++){
55             Result_C_2D[i + (j * FFT_SIZE)].imag = Result_C_1D[j].imag * FFT_SIZE;//scale back up
56             Result_C_2D[i + (j * FFT_SIZE)].real = Result_C_1D[j].real * FFT_SIZE;
57         }
58     }
59     //Stage 2 - FFT Complex Values from Result_2D, put back into Rows
60     for(i = 0; i < FFT_SIZE; i++){//for each row
61         for(j = 0; j < FFT_SIZE; j++){//copy the data across
62             Input_C_1D[j].imag = Result_C_2D[j + i * FFT_SIZE].imag;
63             Input_C_1D[j].real = Result_C_2D[j + i * FFT_SIZE].real;
64         }
65         //Do Fourier
66         dsp16_trans_complexfft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
67         //Copy back
68         for(j = 0; j < FFT_SIZE; j++){
69             ComplexBuffer[i + j * FFT_SIZE].imag = Result_C_1D[j].imag;
70             ComplexBuffer[i + j * FFT_SIZE].real = Result_C_1D[j].real;
71         }
72     }
73     return;
74 }

77 //One Dimensional Fast Fourier Transform
78 int FFT1D_Abs( int *Signal)
79 {
80     int log2Size, i =0;
81     A_ALIGNED dsp16_complex_t vect1[FFT_SIZE];
82     A_ALIGNED dsp16_t vect2[FFT_SIZE];
83     for(i = 0; i < FFT_SIZE; i++)
84     {
85         vect2[i] = (dsp16_t)Signal[i];
86     }
87     dsp16_trans_realcomplexfft(vect1, vect2, log_2(FFT_SIZE));
88     for(i = 0; i < FFT_SIZE; i++)
89     {
90         vect1[i].imag = vect1[i].imag * FFT_SIZE;

```

```

91         vect1[i].real = vect1[i].real * FFT_SIZE;
92     }
93     dsp16_vect_complex_abs(vect2, vect1, FFT_SIZE);
94     for(i = 0; i < FFT_SIZE; i++)
95     {
96         Signal[i] = vect2[i]; // * FFT_SIZE;
97     }
98
99     return Signal;
100 }
101 //One Dimensional Fast Fourier Transform returning complex values
102 void FFT1D( int *Signal, dsp16_complex_t *ComplexBuffer)
103 {
104     int log2Size, i = 0;
105     A_ALIGNED dsp16_complex_t vect1[FFT_SIZE];
106     A_ALIGNED dsp16_t vect2[FFT_SIZE];
107     for(i = 0; i < FFT_SIZE; i++)
108     {
109         vect2[i] = (dsp16_t)Signal[i];
110     }
111     dsp16_trans_realcomplexfft(vect1, vect2, log_2(FFT_SIZE));
112     for(i = 0; i < FFT_SIZE; i++)
113     {
114         ComplexBuffer[i].imag = vect1[i].imag * FFT_SIZE;
115         ComplexBuffer[i].real = vect1[i].real * FFT_SIZE;
116     }
117 }
118 int FFT2Dabs( int *Signal )
119 {
120     int i, j = 0;
121     int Ptr;
122     Ptr = 0;
123     A_ALIGNED dsp16_complex_t Input_C_1D[FFT_SIZE];
124     A_ALIGNED dsp16_complex_t Result_C_1D[FFT_SIZE];
125     A_ALIGNED dsp16_complex_t Result_C_2D[FFT_SIZE*FFT_SIZE];
126     A_ALIGNED dsp16_t Input_R_1D[FFT_SIZE];
127
128     //Stage 1 - FFT Real values from Signal. Store VERTICALLY in Result_2D
129     for(i = 0; i < FFT_SIZE; i++) //for each row
130     {
131 //      print_dbg("\n\rInput to FFT: \n\r");
132 //      for(j = 0; j < FFT_SIZE; j++)
133 //      {
134 //          Input_R_1D[j] = Signal[Ptr++]; //copy the data across
135 //          print_dbg_ulong(Input_R_1D[j]);
136 //          print_dbg(", ");
137 //      }
138 //      print_dbg("\b\b]");
139 //Do the FFT
140     dsp16_trans_realcomplexfft(Result_C_1D, Input_R_1D, log_2(FFT_SIZE));
141 //Copy data into 2D result TRANSPOSED
142 //      print_dbg("\n\rOutput of FFT:\n\r");
143     for(j = 0; j < FFT_SIZE; j++)
144     {
145         Result_C_2D[i + (j * FFT_SIZE)].imag = Result_C_1D[j].imag * FFT_SIZE;// scale back up
146         Result_C_2D[i + (j * FFT_SIZE)].real = Result_C_1D[j].real * FFT_SIZE;
147 //        print_dbg_ulong(Result_C_2D[i + (j * FFT_SIZE)].real);

```

```

148 //      print_dbg(" + j");
149 //      print_dbg_ulong(Result_C_2D[i + (j * FFT_SIZE)].imag);
150 //      print_dbg(" , ");
151 }
152 //      print_dbg("\b\b]");
153 }
154 //Stage 2 - FFT Complex Values from Result_2D, put back into Rows

156     for(i = 0; i < FFT_SIZE; i++)//for each row
157     {
158 //      print_dbg("\n\rInput to FFT: \n\r[");
159         for(j = 0; j < FFT_SIZE; j++)//copy the data across
160         {
161             Input_C_1D[j].imag = Result_C_2D[j + i * FFT_SIZE].imag;
162             Input_C_1D[j].real = Result_C_2D[j + i * FFT_SIZE].real;
163 //             print_dbg_ulong(Input_C_1D[j].real);
164 //             print_dbg(" + j");
165 //             print_dbg_ulong(Input_C_1D[j].imag);
166 //             print_dbg(" , ");
167         }
168 //         print_dbg("\b\b]");
169 //Do Fourier
170 dsp16_trans_complexfft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
171 //Copy back

173 //      print_dbg("\n\rOutput to FFT: \n\r[");
174 //      for(j = 0; j < FFT_SIZE; j++)//copy the data across
175 //      {
176 //          print_dbg_ulong(Result_C_1D[j].real);
177 //          print_dbg(" + j");
178 //          print_dbg_ulong(Result_C_1D[j].imag);
179 //          print_dbg(" , ");
180 //      }
181 //      print_dbg("\b\b]");
182 //Calculate Abs and put back into Signal TRANSPOSED
183 dsp16_vect_complex_abs(Input_R_1D, Result_C_1D, FFT_SIZE);

185     for(j = 0; j < FFT_SIZE; j++)
186     {
187         Signal[i + (j*FFT_SIZE)] = Input_R_1D[j] * FFT_SIZE;
188     }
189 }
190 return Signal;
191 }

196 void PrepareImage(Image_t *Image)
197 {
198     int row, col;
199     uint16_t *PreparedImage;
200 //Allocate some memory in the RAM
201 PreparedImage = mspace_malloc(sdram_msp, 256*256 );

203 //print_dbg("\n\rPrepared Image Pointer = ");
204 //print_dbg_ulong(PreparedImage);
205 for(row = 0; row < 256; row++)

```

```

206 {
207     for(col = 0; col < 256; col++)
208     {
209         if(row < 240)
210             PreparedImage[row*256 + col] = Image->ImagePtr[row * 256 + col];
211         else
212             PreparedImage[row * 256 + col] = 0;//Image->ImagePtr[(row - 240) * 256
213             + col + 32];
214     }
215 }

216 mspace_free(sdram_msp, Image->ImagePtr); //free up the old image
217 Image->ImagePtr = PreparedImage; //move the pointer to the prepared image
218 Image->Height = 256;
219 Image->Width = 256;
220 //SaveBitmap(PreparedImage, 256, 256, "PreparedImage.bmp");
221 //mspace_free(sdram_msp, PreparedImage);
222 //return PreparedImage;
223 }

224

225 //*****
226 // Method: IFFT2D
227 // FullName: IFFT2D
228 // Access: public
229 // Returns: void
230 // Qualifier:
231 // Parameter: dsp16_complex_t * Signal
232 // *****
233 void IFFT2D (dsp16_complex_t *Signal) //Need to test this!
234 {
235     int i, j = 0;
236     int Ptr;
237     Ptr = 0;
238     A_ALIGNED dsp16_complex_t Input_C_1D[FFT_SIZE];
239     A_ALIGNED dsp16_complex_t Result_C_1D[FFT_SIZE];
240     A_ALIGNED dsp16_complex_t Result_C_2D[FFT_SIZE*FFT_SIZE];
241     A_ALIGNED dsp16_t Input_R_1D[FFT_SIZE];

242

243     //Stage 1 - FFT Real values from Signal. Store VERTICALLY in Result_2D
244     for(i = 0; i < FFT_SIZE; i++) //for each row
245     {
246         for(j = 0; j < FFT_SIZE; j++)
247         {
248             Input_C_1D[j].real = Signal[Ptr].real; //copy the data across
249             Input_C_1D[j].imag = Signal[Ptr].imag;
250         }

251         //Do the FFT
252         dsp16_trans_complexifft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
253         //Copy data into 2D result TRANSPOSED

254         for(j = 0; j < FFT_SIZE; j++)
255         {
256             Result_C_2D[i + (j * FFT_SIZE)].imag = Result_C_1D[j].imag * FFT_SIZE;///
257             scale back up
258             Result_C_2D[i + (j * FFT_SIZE)].real = Result_C_1D[j].real * FFT_SIZE;
259         }
260     }
261 }

```

```

262     }
264 }
//Stage 2 - FFT Complex Values from Result_2D, put back into Rows
265
268 for(i = 0; i < FFT_SIZE; i++)//for each row
269 {
271     for(j = 0; j < FFT_SIZE; j++)//copy the data across
272     {
273         Input_C_1D[j].imag = Result_C_2D[j + i * FFT_SIZE].imag;
274         Input_C_1D[j].real = Result_C_2D[j + i * FFT_SIZE].real;
275     }
278
279 //Do Fourier
280 dsp16_trans_complexifft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
281 //Copy back
282
283 //Put back into Signal TRANSPOSED
284 //dsp16_vect_complex_abs(Input_R_1D, Result_C_1D, FFT_SIZE);
285
286 for(j = 0; j < FFT_SIZE; j++)
287 {
288     Signal[i + j * FFT_SIZE].imag = Result_C_1D[j].imag;
289     Signal[i + j * FFT_SIZE].real = Result_C_1D[j].real;
290     //Signal[i + (j*FFT_SIZE)] = Input_R_1D[j] * FFT_SIZE;
291 }
292
293 //return Signal;
294 }
295
297 void ComplexMultiply(dsp16_complex_t *Result_Input1, dsp16_complex_t *Input2,
298 int size)
299 {
300     int i = 0;
301     dsp16_complex_t c;
302     for(i = 0; i < size; i++)
303     {
304         //((a+jb).(c+jd) = (ac - bd) + j(ad + bc)
305         c.real = (Result_Input1[i].real * Input2[i].real) - (Result_Input1[i].imag
306             * Input2[i].imag);
307         c.imag = (Result_Input1[i].real * Input2[i].imag) + (Result_Input1[i].imag
308             * Input2[i].real);
309         Result_Input1[i].imag = c.imag;
310         Result_Input1[i].real = c.real;
311     }
312 }
```

G.1.1.6 MotorDriver.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/MotorDriver.h

```
1  /*
2   * MotorDriver.h
3   *
4   * Created: 10/02/2013 18:11:55
5   * Author: hslovett
6   */
7
8
9 #ifndef MOTORDRIVER_H_
10 #define MOTORDRIVER_H_
11 #include <asf.h>
12 //Definitions
13 #define MOTOR_L      ML_PWM_CHANNEL_ID
14 #define MOTOR_R      MR_PWM_CHANNEL_ID
15
16 #define FORWARD      2
17 #define BACKWARD     3
18 #define LEFT_SPOT    4
19 #define RIGHT_SPOT   5
20 #define SPOT_PIVOT   6
21 #define STOP         7
22
23
24 #define ENABLE ACA_INTERRUPT    // {AVR32_ACIFA1.iер = 1; }
25 #define DISABLE ACA_INTERRUPT   // {AVR32_ACIFA1.idр = 1; }
26 #define ENABLE ACB_INTERRUPT    // {AVR32_ACIFA1.iер = 2; }
27 #define DISABLE ACB_INTERRUPT   // {AVR32_ACIFA1.idр = 2; }
28 #define INTERRUPTS_PER_REVOLUTION 5 // Interrupts caused per full rotation of a
29 //wheel
30 #define CIRCUMFERENCE_WHEEL_MM    116 //in millimeters
31 #define CIRCUMFERENCE_WHEEL_CM    12 //in centimeters
32 #define MIN_RESOLUTION           CIRCUMFERENCE_WHEEL_CM /
33 //INTERERRUPTS_PER_REVOLUTION
34 #define C_ROT_MM                 276
35 #define ROTATION_CONST          (INTERRUPTS_PER_REVOLUTION * C_ROT_MM) / (
36     CIRCUMFERENCE_WHEEL_MM * 360)
37
38 //Type Defs
39 typedef struct {
40     int Left_State;
41     int Right_State;
42     int Left_Count;
43     int Right_Count;
44 } Motor_Control_t;
45
46
47 //Globals
48 pwm_opt_t pwm_opt;                      // PWM option config.
49 avr32_pwm_channel_t pwm_channel;
50 Motor_Control_t Motor_Control;
51
52 void Motor_Init();
53 void Motor_Go();
54 void Analogue_Comparator_Init();
55 void Motor_Start(int Motors);
56 void Motors_Reset(void);
57 void Motor_Stop(int Motors);
58 bool Motors_Moving();
```

```

54 void Motors_Move(int centimetres_fwd)/*Move this amount forward in centimeters
55 */
56 void Motors_Execute();
57 void Motors_Rotate(int angle_degs);
58 /*static void ACInterruptHandler(void);*/
59 #endif /* MOTORDRIVER_H_ */

```

G.1.1.7 MotorDriver.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/MotorDriver.c

```

1 /*
2  * MotorDriver.c
3  *
4  * Created: 10/02/2013 18:12:07
5  * Author: hslovett
6  */
7 #include <asf.h>
8 #include "CustomDevices/CustomDevices.h"
9 #include <delay.h>
10 //Camera
11 /*#include "CustomDevices/OV7670.h"*/
12 //I2C Mux
13 /*#include "CustomDevices/PCA9542A.h"*/
14 //MotorDriver
15 /*#include "CustomDevices/MotorDriver.h"*/
16 //SDCard
17 /*#include "CustomDevices/SD_Card.h"*/
18
19
20
21 static void local_start_highfreq_clock(void)
22 {
23     const scif_pll_opt_t opt = {
24         .osc = SCIF_OSC0,           // Sel Osc0/PLLO or Osc1/PLL1
25         .lockcount = 16,            // lockcount in main clock for the PLL wait
26         .lock,                      // lock
27         .div = 1,                  // DIV=1 in the formula
28         .mul = 6,                  // MUL=7 in the formula
29         .pll_div2 = 1,              // pll_div2 Divide the PLL output frequency
30         .by 2 (this settings does not change the FVCO value)
31         .pll_wbwdisable = 0,        // pll_wbwdisable 1 Disable the Wide-Bandith
32         Mode (Wide-Bandwith mode allow a faster startup time and out-of-lock time
33         ). 0 to enable the Wide-Bandith Mode.
34         .pll_freq = 1,              // Set to 1 for VCO frequency range 80-180
35         MHz, set to 0 for VCO frequency range 160-240Mhz.
36     };
37     // Switch main clock to Osc0.
38     // pcl_switch_to_osc(PCL_OSC0, FOSCO, OSCO_STARTUP);
39
40     /* Setup PLLO on Osc0, mul=7 ,no divisor, lockcount=16, ie. (16Mhz*7)/(div2)
41      = 56MHz output */
42     scif_pll_setup(SCIF_PLLO, &opt); // lockcount in main clock for the PLL wait
43     lock

```

```
38     /* Enable PLL0 */
39     scif_pll_enable(SCIF_PLL0);

41     /* Wait for PLL0 locked */
42     scif_wait_for_pll_locked(SCIF_PLL0) ;
43 }
44 static void pwm_start_gc(void)
45 {
46     scif_gc_setup(AVR32_SCIF_GCLK_PWM ,
47                   SCIF_GCCTRL_PLL0 ,
48                   AVR32_SCIF_GC_NO_DIV_CLOCK ,
49                   0);
50 //    scif_gc_setup( AVR32_SCIF_GCLK_PWM ,
51 //                   SCIF_GCCTRL_OSC0 ,
52 //                   AVR32_SCIF_GC_NO_DIV_CLOCK ,
53 //                   0);
54     // Now enable the generic clock
55     scif_gc_enable(AVR32_SCIF_GCLK_PWM);
56 }
57 // # define EXAMPLE_PWM_L_PIN           AVR32_PWM_PWML_0_1_PIN
58 // # define EXAMPLE_PWM_L_FUNCTION      AVR32_PWM_PWML_0_1_FUNCTION
59 // # define EXAMPLE_PWM_H_PIN           AVR32_PWM_PWMH_0_1_PIN
60 // # define EXAMPLE_PWM_H_FUNCTION      AVR32_PWM_PWMH_0_1_FUNCTION
61 // # define EXAMPLE_PWM_CHANNEL_ID      0
62 void Motor_Init()
63 {
64     //Turn boths motors off
65     ML_STANDBY;
66     MR_STANDBY;

68     ML_IN1_CLR;
69     ML_IN2_CLR;

71     MR_IN1_CLR;
72     MR_IN2_CLR;

74     Motor_Control.Left_Count = 0;
75     Motor_Control.Right_Count = 0;
76     Motor_Control.Left_State = STOP;
77     Motor_Control.Right_State = STOP;

79     avr32_pwm_channel_t pwm_channel = {{0}, // cmr
80                                         {0}, // cdtv
81                                         {0}, // cdtvupd
82                                         {0}, // cpred
83                                         {0}, // cpredupd
84                                         {0}, // ccnt
85                                         {0}, // dt
86                                         {0}}; // dtupd ; One channel config.
87 /* unsigned int channel_id; */

89     // Start PLL for PWM
90     local_start_highfreq_clock();
91     // Start Enable Generic Clock with PLL as source clock
92     pwm_start_gc();
```

```

95 //  gpio_enable_module_pin(EXAMPLE_PWM_L_PIN, EXAMPLE_PWM_L_FUNCTION);
96 //  gpio_enable_module_pin(EXAMPLE_PWM_H_PIN, EXAMPLE_PWM_H_FUNCTION);
97 //  gpio_enable_module_pin(M0_PWM_H_PIN, M0_PWM_H_FUNCTION);
98 //  gpio_enable_module_pin( AVR32_PIN_PB10, AVR32_PWM_PWMH_1_1_FUNCTION); // 
99   PWM1 Low
100 gpio_enable_module_pin(ML_PWM_H_PIN, ML_PWM_H_FUNCTION);
101 gpio_enable_module_pin(MR_PWM_H_PIN, MR_PWM_H_FUNCTION); //PWM1 Low
102 //gpio_enable_module_pin(M1_PWM_H_PIN, M1_PWM_H_FUNCTION);
103 //  PWM controller configuration.
104 pwm_opt.diva = AVR32_PWM_DIVA_CLK_OFF;
105 pwm_opt.divb = AVR32_PWM_DIVB_CLK_OFF;
106 pwm_opt.prea = AVR32_PWM_PREA_CCK;
107 pwm_opt.preb = AVR32_PWM_PREB_CCK;

108 pwm_opt.fault_detection_activated = false;
109 pwm_opt.sync_channel_activated = true;
110 pwm_opt.sync_update_channel_mode =
111   PWM_SYNC_UPDATE_MANUAL_WRITE_MANUAL_UPDATE;
112 pwm_opt.sync_channel_select[0] = false;
113 pwm_opt.sync_channel_select[1] = false;
114 pwm_opt.sync_channel_select[2] = false;
115 pwm_opt.sync_channel_select[3] = false;
116 pwm_opt.cksel = PWM_CKSEL_GCLK;
117 pwm_init(&pwm_opt);

118 // Update the period
119 pwm_update_period_value(10);

120 // Channel configuration
121 pwm_channel.CMR.dte = 0;           // Enable Deadtime for complementary Mode
122 pwm_channel.CMR.dthi = 0;          // Deadtime Inverted on PWMH
123 pwm_channel.CMR.dtli = 0;          // Deadtime Not Inverted on PWML
124 pwm_channel.CMR.ces = 0;           // 0/1 Channel Event at the End of PWM
125   Period
126 pwm_channel.CMR.calg = PWM_MODE_LEFT_ALIGNED;      // Channel mode.
127 pwm_channel.CMR.cpol = PWM_POLARITY_HIGH;           // Channel polarity.
128 pwm_channel.CMR.cpre = AVR32_PWM_CPRE_CCK;         // Channel prescaler.
129 pwm_channel.cdtv = 50;                // Channel duty cycle, should be < CPRD.
130 pwm_channel.cprd = 200;               // Channel period.

131 /* channel_id = M0_PWM_CHANNEL_ID;*/
132 pwm_channel_init(ML_PWM_CHANNEL_ID, &pwm_channel); // Set channel
133   configuration to channel 0
134 //pwm_start_channels((1 << channel_id)); // Start channel 0 & 1.
135 /* channel_id = M1_PWM_CHANNEL_ID; */
136 pwm_channel_init(MR_PWM_CHANNEL_ID, &pwm_channel); // Set channel
137   configuration to channel 0
138 //pwm_start_channels((1 << channel_id)); // Start channel 0 & 1.
139 Analogue_Comparator_Init();
140 }
141 __attribute__((__interrupt__)) static void ACInterruptHandler(void)
142 {
143   //print_dbg("\n\rACIFA Interrupt Entered.");
144   acifa_clear_flags(&AVR32_ACIFA1, 3);

145   if (acifa_is_acb_inp_higher(&AVR32_ACIFA1)) //LEFT MOTOR
146   {
147     LED5_CLR; //wheel not on white tab

```

```
148     }
149     else
150     {
151         LED5_SET;
152         Motor_Control.Left_Count--;
153         print_dbg("\n\rLeft Wheel Interrupt");
154         DISABLE_ACB_INTERRUPT;
155         //delay_ms(100);
156     }

158     if (acifa_is_aca_inp_higher(&AVR32_ACIFA1))
159     {

161         LED6_CLR;

163     }
164     else
165     {
166         LED6_SET;
167         Motor_Control.Right_Count--;
168         print_dbg("\n\rRight Wheel Interrupt");
169         //delay_ms(100);
170         DISABLE ACA_INTERRUPT;
171     }

173     int temp = 0;
174     if(Motor_Control.Left_Count <= 0) //if we have reached the end of the
175         movement on left wheel
176         temp |= MOTOR_L;

177     if(Motor_Control.Right_Count <= 0)
178         temp |= MOTOR_R;
179     if(temp != 0)
180         Motor_Stop(temp); //Stop the Motor
181     //delay_ms(100);

183 }
184 void Analogue_Comparator_Init()
185 {
186     static const gpio_map_t ACIFA_GPIO_MAP =
187     {
188     {POTO_AC1AP1_PIN, POTO_AC1AP1_FUNCTION},
189     {POT1_AC1BP1_PIN, POT1_AC1BP1_FUNCTION},
190     {SENSEO_AC1AN1_PIN, SENSEO_AC1AN1_FUNCTION},
191     {SENSE1_AC1BN1_PIN, SENSE1_AC1BN1_FUNCTION},
192     };

194     gpio_enable_module(ACIFA_GPIO_MAP, sizeof(ACIFA_GPIO_MAP) / sizeof(
195         ACIFA_GPIO_MAP[0]));
196     //Make it an interrupt
197     Disable_global_interrupt();

198     //INTC_init_interrupts();
199     acifa_configure_hysteresis(&AVR32_ACIFA1, ACIFA_COMP_SELA, 2);
200     acifa_configure(&AVR32_ACIFA1,
201     ACIFA_COMP_SELA,
202     POTO_AC1AP1_INPUT,
203     SENSEO_AC1AN1_INPUT,
```

```

204     FOSCO);

206     acifa_configure_hysteresis(&AVR32_ACIFA1, ACIFA_COMP_SELB, 2);
207     acifa_configure(&AVR32_ACIFA1,
208                     ACIFA_COMP_SELB,
209                     POT1_AC1BP1_INPUT,
210                     SENSE1_AC1BN1_INPUT,
211                     FOSCO);

213     //    //Reset Wheels
214     /*      Motor_Go(FORWARD); */
215     //MO_IN1_CLR;
216     //    M1_IN1_CLR;
217     //    while(acifa_is_aca_inp_higher(&AVR32_ACIFA1) == false)
218     //    ;
219     //    MO_IN1_CLR;
220     //
221     //    M1_IN1_SET;
222     //    while(!acifa_is_acb_inp_higher(&AVR32_ACIFA1))
223     //    ;
224     //    M1_IN1_CLR;

227     //Motor_Go(S)
228     //acifa_enable_interrupt(&AVR32_ACIFA1, (1 << AVR32_ACIFA_ACBINT )| (1 <<
229     //                                AVR32_ACIFA_ACAINT));//Enable ACBINT and ACAINT
230     ENABLE_AC_A_INTERRUPT;
231     ENABLE_AC_B_INTERRUPT;
232     AVR32_ACIFA1.iер = 3; //enable interrupts
233     //acifa_enable_interrupt_toggle(&AVR32_ACIFA1, ACIFA_COMP_SELA);
234     //acifa_enable_interrupt_toggle(&AVR32_ACIFA1, ACIFA_COMP_SELB);
235     acifa_enable_interrupt_inp_lower(&AVR32_ACIFA1, ACIFA_COMP_SELA);
236     acifa_enable_interrupt_inp_lower(&AVR32_ACIFA1, ACIFA_COMP_SELB);
237     acifa_start(&AVR32_ACIFA1, (ACIFA_COMP_SELA|ACIFA_COMP_SELB));

241     INTC_register_interrupt(&ACIInterruptHandler, AVR32_ACIFA1_IRQ , AVR32_INTC_INTO);

243     Enable_global_interrupt();
244 }
245 void Motor_Start(int Motors)
246 {
247     if(Motors & MOTOR_L)
248     {
249         if(Motor_Control.Left_State == FORWARD)
250         {
251             ML_IN1_SET;
252             ML_IN2_CLR;
253         }
254         else if (Motor_Control.Left_State == BACKWARD)
255         {
256             ML_IN1_CLR;
257             ML_IN2_SET;
258         }
259         else //Somethings gone wrong

```

```
260     {
261         ML_IN1_CLR;
262         ML_IN2_CLR;
263         return; //don't start any pwm channel
264     }
265     ML_GO;
266     pwm_start_channels((1 << MOTOR_L)); //Start PWM Channel on M0 line
267 }
268
269 if(Motors & MOTOR_R)
270 {
271     if(Motor_Control.Right_State == FORWARD)
272     {
273         MR_IN1_SET;
274         MR_IN2_CLR;
275     }
276     else if (Motor_Control.Right_State == BACKWARD)
277     {
278         MR_IN1_CLR;
279         MR_IN2_SET;
280     }
281     else //Somethings gone wrong
282     {
283         MR_IN1_CLR;
284         MR_IN2_CLR;
285         return; //don't start any pwm channel
286     }
287     MR_GO;
288     pwm_start_channels((1 << MOTOR_R));
289 }
290
291 void Motors_Execute()
292 {
293     while(Motors_Moving())
294     {
295         ENABLE ACA_INTERRUPT;
296         ENABLE ACB_INTERRUPT;
297         for(int i = 0; i < 750; i++)
298         {
299             delay_ms(1);
300         }
301     }
302 }
303 void Motor_Stop(int Motors)
304 {
305     if(Motors & MOTOR_L)
306     {
307         ML_STANDBY;
308         Motor_Control.Left_State = STOP;
309         pwm_stop_channels((1 << MOTOR_L)); //Start PWM Channel on M0 line
310     }
311
312     if(Motors & MOTOR_R)
313     {
314         MR_STANDBY;
315         Motor_Control.Right_State = STOP;
316         pwm_stop_channels((1 << MOTOR_R));
317     }
```

```
318 }
319 void Motors_Move(int centimetres_fwd)//Move this amount forward in centimeters
320 {
321     //Calculate number of interrupts of each wheel
322     int number_interrupts;
323     if(centimetres_fwd > 0)
324     {
325         Motor_Control.Left_State = FORWARD;
326         Motor_Control.Right_State = FORWARD;
327     }
328     else
329     {
330         centimetres_fwd = Abs(centimetres_fwd);
331         Motor_Control.Left_State = BACKWARD;
332         Motor_Control.Right_State = BACKWARD;
333     }
334     number_interrupts = (centimetres_fwd * (int)INTERRUPTS_PER_REVOLUTION) / (
335         int)CIRCUMFERENCE_WHEEL_CM;
336     print_dbg("\n\rNumber of interrupts to move = ");
337     print_dbg_ulong(number_interrupts);

338     Motor_Control.Left_Count = number_interrupts;
339     Motor_Control.Right_Count = number_interrupts;
340     Motor_Start(MOTOR_L | MOTOR_R);
341     Motors_Execute();
342 }

343 void Motors_Reset(void)
344 {
345     Motor_Control.Left_State = FORWARD;
346     Motor_Control.Left_Count = 1;
347     Motor_Control.Right_State = FORWARD;
348     Motor_Control.Right_Count = 1;
349     Motor_Start(MOTOR_L | MOTOR_R);
350 }
351 }

352 bool Motors_Moving()
353 {
354     // if(Motor_Control.Left_State != STOP)
355     // {
356     //     if(Motor_Control.Right_State != STOP)
357     //     {
358     //         return true;
359     //     }
360     //     else
361     //         return false;
362     // }
363     // else
364     // {
365     //     return false;
366     // }
367     if(Motor_Control.Left_State != STOP) //Left is moving
368     {
369         return true;
370     }
371     else if (Motor_Control.Right_State != STOP) //Right is moving
372     {
373         return true;
374 }
```

```
375     }
376     else
377     {
378         return false;
379     }
380 }

383 void Motors_Rotate(int angle_degs)
384 {
385     int interrupts_to_move = 0;
386     //calculate interrupts to move
387     interrupts_to_move = angle_degs * ROTATION_CONST;
388 //    if(Pivot_Type == LEFT_SPOT)
389 //    {
390 //        //Right wheel moves
391 //        Motor_Control.Left_Count = 0;
392 //        Motor_Control.Left_State = STOP;
393 //        if(interrupts_to_move > 0)
394 //        {
395 //            Motor_Control.Right_State = FORWARD;
396 //        }
397 //        else
398 //        {
399 //            Motor_Control.Right_State = BACKWARD;
400 //        }
401 //        Motor_Control.Right_Count = Abs(interrupts_to_move);
402 //    }
403 //    else if (Pivot_Type == RIGHT_SPOT)
404 //    {
405 //        //Left Wheel Moves
406 //        Motor_Control.Right_Count = 0;
407 //        Motor_Control.Right_State = STOP;
408 //        if(interrupts_to_move > 0)
409 //        {
410 //            Motor_Control.Left_State = FORWARD;
411 //        }
412 //        else
413 //        {
414 //            Motor_Control.Left_State = BACKWARD;
415 //        }
416 //        Motor_Control.Left_Count = Abs(interrupts_to_move);
417 //    }
418 //    else if (Pivot_Type == SPOT_PIVOT)
419 //    {
420 //        //Both Wheels Move
421 //        if(interrupts_to_move > 0)
422 //        {
423 //            Motor_Control.Left_State = FORWARD;
424 //            Motor_Control.Right_State = BACKWARD;
425 //        }
426 //        else
427 //        {
428 //            Motor_Control.Right_State = FORWARD;
429 //            Motor_Control.Left_State = BACKWARD;
430 //        }
431 //        Motor_Control.Left_Count = Abs(interrupts_to_move);
432 //        Motor_Control.Right_Count = Abs(interrupts_to_move);
```

```

433     Motor_Start(MOTOR_L | MOTOR_R);
434 // }
435 }
```

G.1.1.8 OV7670.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/OV7670.h

```

1  /*
2   * OV7670.h
3   *
4   * Created: 15/02/2013 13:12:00
5   * Author: hslovett
6   */
7
8
9 #ifndef OV7670_H_
10 #define OV7670_H_
11 #include <asf.h>
12 ///////////////////////////////////////////////////////////////////
13 // Constants
14 ///////////////////////////////////////////////////////////////////
15 #define HEIGHT          240
16 #define WIDTH           320
17 #define PIXELSIZE       2
18 #define SETTINGS_LENGTH 167
19 #define OV7670_ADDR      0x21
20
21 #define CAMERA_LEFT      1
22 #define CAMERA_RIGHT     2
23
24 #define CAMERA_LEFT_ERR  0x10
25 #define CAMERA_RIGHT_ERR 0x20
26
27 #define BMPHEADERSIZE   14
28 #define DIBHEADERSIZE   124 //v5
29 #define FILESIZE        153738
30 ///////////////////////////////////////////////////////////////////
31 // Globals
32 ///////////////////////////////////////////////////////////////////
33 const char default_settings[SETTINGS_LENGTH][2];
34 const uint8_t DIBHead[DIBHEADERSIZE];
35 const uint8_t BMPHeader[BMPHEADERSIZE];
36 typedef struct {
37     uint8_t Status;
38     bool Camera_0_Found;
39     bool Camera_1_Found;
40     bool Camera_0_Error;
41     bool Camera_1_Error;
42     uint8_t VSYNC0_State;
43     uint8_t VSYNC1_State;
44 } OV7670_t ;
45
46 OV7670_t OV7670_Status;
```

```

48 #define IDLE 0
49 #define TAKE_PHOTO 1
50 #define TAKING_PHOTO 2
51 #define TAKEN_PHOTO 3
52 #define CAMERAS_BUSY 4

54 #define Image0Name "Image_L_%d.bmp"
55 #define Image1Name "Image_R_%d.bmp"
56 ///////////////////////////////////////////////////////////////////
57 // Methods
58 ///////////////////////////////////////////////////////////////////
59 void OV7670_Init(void); //Initialises Camera
60 void FIFO_Init();
61 int TakePhoto(uint8_t Cameras);
62 bool Photos_Ready(void);
63 void Store_Image_0();
64 void Store_Image_1();
65 void FIFO_Reset(uint8_t CameraID);
66 bool Store_Both_Images();
67 //void FIFO_Reset(uint8_t CameraID);
68 ///////////////////////////////////////////////////////////////////
69 // Pins & Macros
70 ///////////////////////////////////////////////////////////////////
71 #define FIFO_0_RCLK AVR32_PIN_PA19
72 #define FIFO_0_nRRST AVR32_PIN_PA15
73 #define FIFO_0_WEN AVR32_PIN_PA20
74 #define FIFO_0_WRST AVR32_PIN_PA21
75 #define FIFO_0_nOE AVR32_PIN_PA28
76 #define FIFO_0_VSYNC AVR32_PIN_PA29

78 #define FIFO_1_RCLK AVR32_PIN_PA23
79 #define FIFO_1_nRRST AVR32_PIN_PA22
80 #define FIFO_1_WEN AVR32_PIN_PA24
81 #define FIFO_1_WRST AVR32_PIN_PA25
82 #define FIFO_1_nOE AVR32_PIN_PA27

84 #define VSYNC_1_PIN AVR32_EIC_EXTINT_1_2_PIN
85 #define VSYNC_1_FUNCTION AVR32_EIC_EXTINT_1_2_FUNCTION
86 #define VSYNC_1_LINE 1
87 #define VSYNC_1_ENABLE_INTERRUPT {eic_enable_interrupt_line(&AVR32_EIC,
     VSYNC_1_LINE);}
88 #define VSYNC_1_DISABLE_INTERRUPT {eic_disable_interrupt_line(&AVR32_EIC,
     VSYNC_1_LINE);}

90 #define VSYNC_0_PIN AVR32_EIC_EXTINT_4_0_PIN
91 #define VSYNC_0_FUNCTION AVR32_EIC_EXTINT_4_0_FUNCTION
92 #define VSYNC_0_LINE 4
93 #define VSYNC_0_ENABLE_INTERRUPT {eic_enable_interrupt_line(&AVR32_EIC,
     VSYNC_0_LINE);}
94 #define VSYNC_0_DISABLE_INTERRUPT {eic_disable_interrupt_line(&AVR32_EIC,
     VSYNC_0_LINE);}

97 #define FIFO_0_RCLK_SET {gpio_set_gpio_pin(FIFO_0_RCLK);}
98 #define FIFO_0_nRRST_SET {gpio_set_gpio_pin(FIFO_0_nRRST);}
99 #define FIFO_0_WEN_SET {gpio_set_gpio_pin(FIFO_0_WEN);}
100 #define FIFO_0_WRST_SET {gpio_set_gpio_pin(FIFO_0_WRST);}

```

```

101 #define FIFO_0_nOE_SET    {gpio_set_gpio_pin(FIFO_0_nOE);}
103 #define FIFO_0_RCLK_CLR   {gpio_clr_gpio_pin(FIFO_0_RCLK);}
104 #define FIFO_0_nRRST_CLR  {gpio_clr_gpio_pin(FIFO_0_nRRST);}
105 #define FIFO_0_WEN_CLR    {gpio_clr_gpio_pin(FIFO_0_WEN);}
106 #define FIFO_0_WRST_CLR   {gpio_clr_gpio_pin(FIFO_0_WRST);}
107 #define FIFO_0_nOE_CLR    {gpio_clr_gpio_pin(FIFO_0_nOE);}

111 #define FIFO_1_RCLK_SET   {gpio_set_gpio_pin(FIFO_1_RCLK);}
112 #define FIFO_1_nRRST_SET  {gpio_set_gpio_pin(FIFO_1_nRRST);}
113 #define FIFO_1_WEN_SET    {gpio_set_gpio_pin(FIFO_1_WEN);}
114 #define FIFO_1_WRST_SET   {gpio_set_gpio_pin(FIFO_1_WRST);}
115 #define FIFO_1_nOE_SET    {gpio_set_gpio_pin(FIFO_1_nOE);}

117 #define FIFO_1_RCLK_CLR   {gpio_clr_gpio_pin(FIFO_1_RCLK);}
118 #define FIFO_1_nRRST_CLR  {gpio_clr_gpio_pin(FIFO_1_nRRST);}
119 #define FIFO_1_WEN_CLR    {gpio_clr_gpio_pin(FIFO_1_WEN);}
120 #define FIFO_1_WRST_CLR   {gpio_clr_gpio_pin(FIFO_1_WRST);}
121 #define FIFO_1_nOE_CLR    {gpio_clr_gpio_pin(FIFO_1_nOE);}

124 #define CAMERA_INPUT  {(uint8_t)((AVR32_GPIO.port[1].pvr) & 0xFF);}
125 //////////////////////////////////////////////////////////////////
126 //Camera Register Address definitions
127 //////////////////////////////////////////////////////////////////
128 #define OV_GAIN      0x00 //Gain Control Setting - ACG[7:0]
129 #define OV_BLUE      0x01 //Blue Channel Gain
130 #define OV_RED       0x02 //Red Channel Gain
131 #define OV_VREF      0x03 //Vertical Frame Control & ACG[9:8]
132 #define OV_COM1      0x04 //CCIR656 enable, AEC low bits (AECHH, AECH)
133 #define OV_BAVE      0x05 //U/B Average level - AUTO UPDATED
134 #define OV_GbAVE     0x06 //Y/Gb Average Level - AUTO UPDATED
135 #define OV_AECHH     0x07 //Exposure value [15:10] (AECH, COM1)
136 #define OV_RAVE      0x08 //V/R Average level - AUTO UPDATED
137 #define OV_COM2      0x09 //Soft Sleep, Output drive capability
138 #define OV_PID       0x0A //Product ID MSB Read only
139 #define OV_VER       0x0B //Product ID LSB Read Only
140 #define OV_COM3      0x0C //Output data MSB/LSB swap + other stuff
141 #define OV_COM4      0x0D //Average values - MUST BE SAME AS COM17
142 #define OV_COM5      0x0E //RESERVED
143 #define OV_COM6      0x0F //COM6
144 #define OV_AECH      0x10 //Exposure value [9:2] (see AECHH, COM1)
145 #define OV_CLKRC     0x11 //Internal Clock options
146 #define OV_COM7      0x12 //RESET, Output format
147 #define OV_COM8      0x13 //Common control 8
148 #define OV_COM9      0x14 //Automatic Gain Ceiling
149 #define OV_COM10     0x15 //PCLK, HREF and VSYNC options
150 #define OV_RSVD      0x16 //RESERVED
151 #define OV_HSTART    0x17 //Output format Horizontal Frame start
152 #define OV_HSTOP     0x18 //Output format Horizontal Frame end
153 #define OV_VSTRT     0x19 //Output format Vertical Frame start
154 #define OV_VSTOP     0x1A //Output format Vertical Frame Stop
155 #define OV_PSHFT     0x1B //Pixel Delay Select
156 #define OV_MIDH      0x1C //Manufacturer ID MSB - READ ONLY
157 #define OV_MIDL      0x1D //Manufacturer ID LSB - READ ONLY
158 #define OV_MVFP      0x1E //Mirror / VFlip Enable

```

```

159 #define OV_LAEC      0x1F //RESERVED
160 #define OV_ADCCTR0    0x20 //ADC Control
161 #define OV_ADCCTR1    0x21 //RESERVED
162 #define OV_ADCCTR2    0x22 //RESERVED
163 #define OV_ADCCTR3    0x23 //RESERVED
164 #define OV_AEW        0x24 //ACG/AEC Stable Operating Region Upper Limit
165 #define OV_AEB        0x25 //ACG/AEC Stable Operation Region Lower Limit
166 #define OV_VPT        0x26 //ACG/AEC Fast Mode Operation Region
167 #define OV_BBIAS       0x27 //B Channel Signal Output Bias
168 #define OV_GbBIAS      0x28 //Gb Channel Output Bias
169 #define OV_RSVD1       0x29 //RESERVED
170 #define OV_EXHCH       0x2A //Dummy Pixel Insert MSB
171 #define OV_EXHCL       0x2B //Dummy Pixel Insert LSB
172 #define OV_RBIAS       0x2C //R Channel Signal Output Bias
173 #define OV_ADVFL       0x2D //LSB of insert dummy line in vertical direction
174 #define OV_AdVFH       0x2E //MSB of insert dummy line in vertical direction
175 #define OV_YAVE        0x2F //Y/G Channel Average Value
176 #define OV_HSYST       0x30 //HSYNC Rising Edge Delay (low 8 bits)
177 #define OV_HSYEN       0x31 //HSYNCE Falling Edge Delay (low 8 bits)
178 #define OV_HREF        0x32 //HREF Control
179 #define OV_CHLF        0x33 //Array Current Control - RESERVED
180 #define OV_ARBLM       0x34 //Array Reference Control - RESERVED
181 #define OV_RSVD2       0x35 //RESERVED
182 #define OV_RSVD3       0x36 //RESERVED
183 #define OV_ADCCTRL     0x37 //ADC Control - RESERVED
184 #define OV_ACOM        0x38 //ADC and Analog Common Mode Control - RESERVED
185 #define OV_OFON        0x39 //ADC Offset Control
186 #define OV_TSLB        0x3A //Line Buffer Test Option
187 #define OV_COM11       0x3B //COM11
188 #define OV_COM12       0x3C //COM12
189 #define OV_COM13       0x3D //COM13
190 #define OV_COM14       0x3E //COM14
191 #define OV_EDGE         0x3F //Edge Detection Adjustment
192 #define OV_COM15       0x40 //COM15
193 #define OV_COM16       0x41 //COM16
194 #define OV_COM17       0x42 //COM17
195 #define OV_AWBC1       0x43
196 #define OV_AWBC2       0x44
197 #define OV_AWBC3       0x45
198 #define OV_AWBC4       0x46
199 #define OV_AWBC5       0x47
200 #define OV_AWBC6       0x48
201 #define OV_RSVD4       0x49
202 #define OV_RSVD5       0x40
203 #define OV_RSVD6       0x4A
204 #define OV_REG4B       0x4B
205 #define OV_DNSTH       0x4C
206 #define OV_RSVD7       0x4D
207 #define OV_RSVD8       0x4E
208 #define OV_MTX1        0x4F
209 #define OV_MTX2        0x50
210 #define OV_MTX3        0x51
211 #define OV_MTX4        0x52
212 #define OV_MTX5        0x53
213 #define OV_MTX6        0x54
214 #define OV_BRIGHT       0x55
215 #define OV_CONTRAS      0x56
216 #define OV_CONTRASCNTR 0x57

```

```
217 #define OV_MTXS      0x58
218 #define OV_RSVD9      0x59
219 #define OV_RSVD9_1    0x5A
220 #define OV_RSVD9_2    0x5B
221 #define OV_RSVD9_3    0x5C
222 #define OV_RSVD9_4    0x5D
223 #define OV_RSVD9_5    0x5E
224 #define OV_RSVD9_6    0x5F
225 #define OV_RSVD10     0x60
226 #define OV_RSVD11     0x61
227 #define OV_LCC1       0x62
228 #define OV_LCC2       0x63
229 #define OV_LCC3       0x64
230 #define OV_LCC4       0x65
231 #define OV_LCC5       0x66
232 #define OV_MANU      0x67
233 #define OV_MANV      0x68
234 #define OV_GFIX       0x69
235 #define OV_GGAIN      0x6A
236 #define OV_DBLV       0x6B
237 #define OV_AWBCTR3    0x6C
238 #define OV_AWBCTR2    0x6D
239 #define OV_AWBCTR1    0x6E
240 #define OV_AWBCTR0    0x6F
241 #define OV_SCALING_XSC 0x70
242 #define OV_SCALING_YSC 0x71
243 #define OV_SCALING_DCWCTR 0x72
244 #define OV_SCALING_PCLK_DIV 0x73
245 #define OV_REG74       0x74
246 #define OV_REG75       0x75
247 #define OV_REG76       0x76
248 #define OV_REG77       0x77
249 #define OV_RSVD12     0x78
250 #define OV_RSVD13     0x79
251 #define OV_GAM1        0x7A
252 #define OV_GAM2        0x7B
253 #define OV_GAM3        0x7C
254 #define OV_GAM4        0x7D
255 #define OV_GAM5        0x7E
256 #define OV_GAM6        0x7F
257 #define OV_GAM7        0x80
258 #define OV_GAM8        0x81
259 #define OV_GAM9        0x82
260 #define OV_GAM10       0x83
261 #define OV_GAM11       0x84
262 #define OV_GAM12       0x85
263 #define OV_GAM13       0x86
264 #define OV_GAM14       0x87
265 #define OV_GAM15       0x88
266 #define OV_GAM16       0x89
267 #define OV_RSVD14     0x8A
268 #define OV_RSVD15     0x8B
269 #define OV_RSVD16     0x8C
270 #define OV_RSVD17     0x8D
271 #define OV_RSVD18     0x8E
272 #define OV_RSVD19     0x8F
273 #define OV_RSVD20     0x90
274 #define OV_RSVD21     0x91
```

```
275 #define OV_DM_LNL    0x92
276 #define OV_DM_LNH    0x93
277 #define OV_LCC6      0x94
278 #define OV_LCC7      0x95
279 #define OV_RSVD22    0x96
280 #define OV_RSVD23    0x97
281 #define OV_RSVD24    0x98
282 #define OV_RSVD25    0x99
283 #define OV_RSVD26    0x9A
284 #define OV_RSVD27    0x9B
285 #define OV_RSVD28    0x9C
286 #define OV_BD50ST    0x9D
287 #define OV_BD60ST    0x9E
288 #define OV_HIST0     0x9F
289 #define OV_HIST1     0xA0
290 #define OV_HIST2     0xA1
291 #define OV_HIST3     0xA2
292 #define OV_HIST4     0xA3
293 #define OV_HIST5     0xA4
294 #define OV_HIST6     0xA5
295 #define OV_HIST7     0xA6
296 #define OV_HIST8     0xA7
297 #define OV_HIST9     0xA8
298 #define OV_HIST10    0xA9
299 #define OV_HIST11    0xAA
300 #define OV_HIST12    0xAB
301 #define OV_STR_OPT   0xAC
302 #define OV_STR_R     0xAD
303 #define OV_STR_G     0xAE
304 #define OV_STR_B     0xAF
305 #define OV_RSVD28_1   0xB0
306 #define OV_RSVD29    0xB1
307 #define OV_RSVD30    0xB2
308 #define OV_THL_ST    0xB3
309 #define OV_RSVD31    0xB4
310 #define OV_THL_DLT   0xB5
311 #define OV_RSVD32    0xB6
312 #define OV_RSVD33    0xB7
313 #define OV_RSVD34    0xB8
314 #define OV_RSVD35    0xB9
315 #define OV_RSVD36    0xBA
316 #define OV_RSVD37    0xBB
317 #define OV_RSVD38    0xBC
318 #define OV_RSVD39    0xBD
319 #define OV_AD_CHB    0xBE
320 #define OV_AD_CHR    0xBF
321 #define OV_AD_CHGb   0xC0
322 #define OV_AD_CHGr   0xC1
323 #define OV_RSVD40    0xC2
324 #define OV_RSVD41    0xC3
325 #define OV_RSVD42    0xC4
326 #define OV_RSVD43    0xC5
327 #define OV_RSVD44    0xC6
328 #define OV_RSVD45    0xC7
329 #define OV_RSVD46    0xC8
330 #define OV_SATCTR   0xC9
```

```
334 #endif /* OV7670_H */
```

G.1.1.9 OV7670.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/OV7670.c

```

1  /*
2   *  OV7670.c
3   *
4   *  Created: 15/02/2013 13:12:12
5   *  Author: hslovett
6   */
7
8
9 #include <asf.h>
10 #include "CustomDevices/CustomDevices.h"
11 #include "stdio.h"
12 #include "delay.h"
13 // Camera
14 // #include "CustomDevices/OV7670.h"
15 // I2C Mux
16 // #include "CustomDevices/PCA9542A.h"
17 // MotorDriver
18 // /*#include "CustomDevices/MotorDriver.h"*/
19 // SDCard
20 // #include "CustomDevices/SD_Card.h"
21
22 __attribute__((__interrupt__)) static void VSYNC0_Handler (void)
23 {
24     //print_dbg("\n\rVSYNC0 Detected!");
25     eic_clear_interrupt_line(&AVR32_EIC, VSYNC_0_LINE);
26     //VSYNC_0_DISABLE_INTERRUPT;
27     switch(OV7670_Status.VSYNC0_State)
28     {
29         case(TAKE_PHOTO):
30             FIFO_0_WEN_SET;
31             OV7670_Status.VSYNC0_State = TAKING_PHOTO;
32             break;
33
34         case(TAKING_PHOTO):
35             FIFO_0_WEN_CLR;
36             OV7670_Status.VSYNC0_State = TAKEN_PHOTO;
37             break;
38
39         case (TAKEN_PHOTO):
40             FIFO_0_WEN_CLR;
41             break;
42
43         case(IDLE):
44         default:
45             VSYNC_0_DISABLE_INTERRUPT;
46             FIFO_0_WEN_CLR;
47             OV7670_Status.VSYNC0_State = IDLE;
48 }
```

```
48         break;
49     }
50 }

52 __attribute__((__interrupt__)) static void VSYNC1_Handler (void)
53 {
54     //print_dbg("\n\rVSYNC1 Detected!");
55     eic_clear_interrupt_line(&AVR32_EIC, VSYNC_1_LINE);
56     //VSYNC_1_DISABLE_INTERRUPT;
57     switch(OV7670_Status.VSYNC1_State)
58     {
59         case(TAKE_PHOTO):
60             FIFO_1_WEN_SET;
61             OV7670_Status.VSYNC1_State = TAKING_PHOTO;
62             //print_dbg("\n\rCase: Take Photo;");
63             break;
64
65         case(TAKING_PHOTO):
66             FIFO_1_WEN_CLR;
67             OV7670_Status.VSYNC1_State = TAKEN_PHOTO;
68             //print_dbg("\n\rCase: Taking Photo;");
69             break;
70
71         case(TAKEN_PHOTO):
72             FIFO_1_WEN_CLR;
73             //print_dbg("\n\rCase: Taken Photo;");
74             break;
75
76         case(IDLE):
77             default:
78                 VSYNC_1_DISABLE_INTERRUPT;
79                 FIFO_1_WEN_CLR;
80                 OV7670_Status.VSYNC1_State = IDLE;
81                 //print_dbg("\n\rCase: Idle;");
82                 break;
83     }
84 }
85 unsigned char Write_Reg(unsigned char Register, unsigned char Data)
86 {
87     /* I2C Traffic Generated:
88      * S | OV_7670 + W | A | RegID | A | Data | A | P |
89      */
90     uint8_t Buff[2] = {Register, Data};
91     int status = twim_write(&AVR32_TWIMO, &Buff, 2, OV7670_ADDR, false);
92     return status;
93 }
94 unsigned char Read_Reg(unsigned char Register, unsigned char *Data)
95 {
96     /* I2C Traffic Generated:
97      * S | OV_ADDR + W | A | RegID | A | P |
98      * S | OV_ADDR + R | A | Data | ~A | P |
99      */
100    unsigned char Buff[2] = {Register, 0};
101    int status = twim_write(&AVR32_TWIMO, &Buff, 1, OV7670_ADDR, false);
102    if(status != STATUS_OK)
103        return status;
104
105    status = twim_read(&AVR32_TWIMO, &Buff, 1, OV7670_ADDR, false);
```

```
106     *Data = Buff[0];
108
109     return status;
110 }
111 void OV7670_Init()
112 {
113
114     //Check Cameras Exist
115     PCA9542A_Chан_Sel(I2C_CHANNEL_0);
116     if (twim_probe(&AVR32_TWIMO, OV7670_ADDR) == STATUS_OK)
117         OV7670_Status.Camera_0_Found = true;
118     else
119         OV7670_Status.Camera_0_Found = false;
120
121     PCA9542A_Chан_Sel(I2C_CHANNEL_1);
122     if (twim_probe(&AVR32_TWIMO, OV7670_ADDR) == STATUS_OK)
123         OV7670_Status.Camera_1_Found = true;
124     else
125         OV7670_Status.Camera_1_Found = false;
126
127
128     //Initialise Cameras
129     if(OV7670_Status.Camera_0_Found)
130     {
131         PCA9542A_Chан_Sel(I2C_CHANNEL_0);
132         //Reset Camera
133         if(STATUS_OK != Write_Reg(OV_COM7, 0x80))
134         {
135             print_dbg("\n\rCamera Reset Fail");
136             OV7670_Status.Camera_0_Error = true;
137             OV7670_Status.Status = ERR_DEVICE;
138             //return FAIL;
139         }
140         delay_ms(10); //wait for Camera to reset
141         for (int i = 0; i < SETTINGS_LENGTH; i++)
142         {
143             if(STATUS_OK != Write_Reg(default_settings[i][0], default_settings[i][1]))
144             {
145                 print_dbg("\n\rCamera Initialise Fail");
146                 //return FAIL;
147                 OV7670_Status.Camera_0_Error = true;
148                 OV7670_Status.Status = ERR_DEVICE;
149                 break;
150             }
151             delay_ms(1);
152         }
153     }
154     if(OV7670_Status.Camera_1_Found)
155     {
156         PCA9542A_Chан_Sel(I2C_CHANNEL_1);
157
158         //Reset Camera
159         if(STATUS_OK != Write_Reg(OV_COM7, 0x80))
160         {
161             print_dbg("\n\rCamera Reset Fail");
162             OV7670_Status.Camera_1_Error = true;
```

```
163     OV7670_Status.Status = ERR_DEVICE;
164     //return FAIL;
165 }
166 delay_ms(10); //wait for Camera to reset
167 for (int i = 0; i < SETTINGS_LENGTH; i++)
168 {
169     if(STATUS_OK != Write_Reg(default_settings[i][0], default_settings[i]
170 ] [1]))
171     {
172         print_dbg("\n\rCamera Initialise Fail");
173         //return FAIL;
174         OV7670_Status.Camera_1_Error = true;
175         OV7670_Status.Status = ERR_DEVICE;
176         break;
177     }
178     delay_ms(1);
179 }
180 PCA9542A_Chан_Sel(NO_SELECT);

182 //Initialise VSYNC Interrupts
183 eic_options_t eic_options;
184 eic_options.eic_mode = EIC_MODE_EDGE_TRIGGERED;
185 eic_options.eic_edge = EIC_EDGE_FALLING_EDGE;
186 eic_options.eic_async = EIC_SYNCH_MODE;
187 eic_options.eic_line = VSYNC_1_LINE;
188 //eic_options.eic_line = VSYNC_0_LINE;

190 Disable_global_interrupt();
191 gpio_enable_module_pin(VSYNC_1_PIN, VSYNC_1_FUNCTION);
192 gpio_enable_module_pin(VSYNC_0_PIN, VSYNC_0_FUNCTION);

194 gpio_enable_pin_pull_up(VSYNC_1_PIN); //Enable pull up as it is a low level
195     interrupt
196 gpio_enable_pin_pull_up(VSYNC_0_PIN);
197 //Initialise EIC
198 eic_init(&AVR32_EIC, &eic_options, 1);
199 eic_options.eic_line = VSYNC_0_LINE;
200 eic_init(&AVR32_EIC, &eic_options, 1);

201 INTC_register_interrupt(&VSYNC1_Handler, AVR32_EIC_IRQ_1, AVR32_INTC_INT0);
202 INTC_register_interrupt(&VSYNC0_Handler, AVR32_EIC_IRQ_4, AVR32_INTC_INT0);
203 //Enable interrupt on VSYNC1
204 eic_enable_line(&AVR32_EIC, VSYNC_1_LINE);
205 eic_enable_line(&AVR32_EIC, (VSYNC_0_LINE));
206 VSYNC_1_ENABLE_INTERRUPT;
207 VSYNC_0_ENABLE_INTERRUPT;

209 FIFO_Init();
210 Enable_global_interrupt();

212 }
213 void FIFO_Init()
214 {
215     //Disable both outputs
216     FIFO_0_noE_SET
217     FIFO_1_noE_SET
```

```
219 //Reset Buffer 0
220 FIFO_0_WRST_CLR;
221 FIFO_0_RCLK_CLR;
222 FIFO_0_nRRST_SET;
223 FIFO_0_WEN_CLR;
224 delay_us(10);
225 FIFO_0_RCLK_SET;
226 delay_us(10);
227 FIFO_0_RCLK_CLR;
228 FIFO_0_nRRST_CLR;
229 delay_us(10);
230 FIFO_0_RCLK_SET;
231 delay_us(10);
232 FIFO_0_RCLK_CLR;
233 FIFO_0_nRRST_SET;
234 delay_us(10);
235 FIFO_0_WRST_SET;

237 //Reset Buffer 1
238 FIFO_1_WRST_CLR;
239 FIFO_1_RCLK_CLR;
240 FIFO_1_nRRST_SET;
241 FIFO_1_WEN_CLR;
242 delay_us(10);
243 FIFO_1_RCLK_SET;
244 delay_us(10);
245 FIFO_0_RCLK_CLR;
246 FIFO_1_nRRST_CLR;
247 delay_us(10);
248 FIFO_1_RCLK_SET;
249 delay_us(10);
250 FIFO_1_RCLK_CLR;
251 FIFO_1_nRRST_SET;
252 delay_us(10);
253 FIFO_1_WRST_SET;
254 }

256 void FIFO_Reset(uint8_t CameraID)
257 {
258     FIFO_0_nOE_SET;
259     FIFO_1_nOE_SET;
260     if(CameraID & CAMERA_LEFT)
261     {
262         FIFO_0_WRST_CLR;
263         FIFO_0_nRRST_CLR;
264         FIFO_0_RCLK_SET;
265         delay_us(10);
266         FIFO_0_RCLK_CLR;
267         FIFO_0_nRRST_SET;
268         FIFO_0_WRST_SET;
269     }
270     if(CameraID & CAMERA_RIGHT)
271     {
272         FIFO_1_WRST_CLR;
273         FIFO_1_nRRST_CLR;
274         FIFO_1_RCLK_SET;
275         delay_us(10);
276         FIFO_1_RCLK_CLR;
```

```
277     FIFO_1_nRRST_SET;
278     FIFO_1_WRST_SET;
279 }
280 }
281
282 int TakePhoto(uint8_t Cameras)
283 {
284
285     //Only want to take pictures on cameras found
286     if(((OV7670_Status.VSYNC0_State != IDLE) || !OV7670_Status.Camera_0_Found)
287         && ((OV7670_Status.VSYNC1_State != IDLE) || !OV7670_Status.Camera_1_Found)
288         )
289     return CAMERAS_BUSY; //wait for cameras to be idle if they are found
290
291     if(Cameras & CAMERA_LEFT)
292         OV7670_Status.VSYNC0_State = TAKE_PHOTO;
293
294     if(Cameras & CAMERA_RIGHT)
295         OV7670_Status.VSYNC1_State = TAKE_PHOTO;
296     eic_clear_interrupt_line(&AVR32_EIC, VSYNC_1_LINE);
297     eic_clear_interrupt_line(&AVR32_EIC, VSYNC_0_LINE);
298     VSYNC_0_ENABLE_INTERRUPT;
299     VSYNC_1_ENABLE_INTERRUPT;
300
301     return TAKING_PHOTO;
302 }
303
304 bool Photos_Ready(void)
305 {
306     int status = 0;
307     if(OV7670_Status.Camera_0_Found == true) //If camera is there
308     {
309         if(OV7670_Status.Camera_0_Error == false)//and has no errors
310         {
311             if(OV7670_Status.VSYNC0_State == TAKEN_PHOTO)
312             {
313                 status |= 1; //camera0 has taken photo
314             }
315         }
316         else
317             status |= 1;
318     }
319     else
320         status |= 1;
321
322     if(OV7670_Status.Camera_1_Found == true) //If camera is there
323     {
324         if(OV7670_Status.Camera_1_Error == false)//and has no errors
325         {
326             if(OV7670_Status.VSYNC1_State == TAKEN_PHOTO)
327             {
328                 status |= 1; //camera0 has taken photo
329             }
330         }
331         else
332             status |= 1;
```

```
333     }
334     else
335         status |= 1;
336
337     if(status)
338         return true;
339     else
340         return false;
341 }

342
343
344 bool Store_Both_Images()
345 {
346     if(Photos_Ready() == false)
347         return false;
348
349     Store_Image_1();
350     FIFO_Reset(CAMERA_RIGHT);
351
352     Store_Image_0();
353     FIFO_Reset(CAMERA_LEFT);
354
355     OV7670_Status.VSYNC0_State = IDLE;
356     OV7670_Status.VSYNC1_State = IDLE;
357
358     return true;
359 }
360 // void Store_Image_0()
361 // {
362 //     int i,j;
363 //     //Image0
364 //     //make file
365 //     //delete file if it exists already
366 //     char Filename_buff[15];
367 //     i = 0;
368 //     while(1)
369 //     {
370 //         nav_filelist_reset();
371 //         sprintf(&Filename_buff, Image0Name, i++);
372 //         if(nav_filelist_findname((FS_STRING)Filename_buff, false))
373 //         {
374 //             //nav_setcwd((FS_STRING)Image0Name, true, false);
375 //             // print_dbg("\n\r File Exists");
376 //             // print_dbg(&Filename_buff);
377 //             //nav_file_del(false);
378 //         }
379 //         else
380 //         {
381 //             break;
382 //         }
383 //     }
384 //     nav_file_create((FS_STRING)Filename_buff); //create file
385 //
386 //     file_open(FOPEN_MODE_W);
387 //     //write bitmap headers
388 //     file_write_buf(BMPHeader, BMPHEADERSIZE);
389 //     file_write_buf(DIBHead, DIBHEADERSIZE);
390 // }
```

```
391 // //read and write image data
392 // //Image0
393 // //reset read pointer
394 // FIFO_0_nRRST_CLR;
395 // FIFO_0_RCLK_SET;
396 //
397 // FIFO_0_RCLK_CLR;
398 // FIFO_0_nRRST_SET;
399 // delay_us(10);
400 // //enable output
401 // FIFO_0_nOE_CLR;
402 // uint8_t buffer[WIDTH * 2];
403 //
404 // for(j = 0; j < HEIGHT; j++)
405 //{
406 //     for(i = 0; i < WIDTH*2; i+=2)
407 //     {
408 //         FIFO_0_RCLK_SET;
409 //         delay_us(10);
410 //         buffer[i+1] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
411 //         delay_us(10);
412 //         FIFO_0_RCLK_CLR;
413 //         delay_us(10);
414 //         FIFO_0_RCLK_SET;
415 //         delay_us(10);
416 //         buffer[i] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
417 //         delay_us(10);
418 //         FIFO_0_RCLK_CLR;
419 //         delay_us(10);
420 //     }
421 //     file_write_buf(&buffer, WIDTH * 2);
422 //}
423 // FIFO_0_nOE_SET;
424 // file_close();
425 //
426 //
427 //}

428 // void Store_Image_1()
429 //{
430 //     int i, j;
431 //     uint8_t buffer[WIDTH * 2];
432 //     char Filename_buff[15];
433 //     //uint8_t *Buffer_ram;
434 //     //Buffer_ram = mspace_malloc(sdram_msp, WIDTH * 2);
435 //     //if(Buffer_ram == NULL)
436 //     //{
437 //         print_dbg("\n\rBuffer allocation fail.\n\r");
438 //         return;
439 //     }
440 //     i = 0;
441 //     //make file
442 //     //delete file if it exits already
443 //     nav_filelist_reset();
444 //     while(1)
445 //     {
446 //         sprintf(&Filename_buff, Image1Name, i++);
447 //         if(nav_filelist_findname((FS_STRING)Filename_buff, false))
```

```
449 //      {
450 //          //nav_setcwd((FS_STRING)Image1Name, true, false);
451 //          //print_dbg("\n\rImage1.bmp File Exists");
452 //          //nav_file_del(false);
453 //      }
454 //      else
455 //      {
456 //          break;
457 //      }
458 //  }
459 //  nav_file_create((FS_STRING)Filename_buff); //create file
460 //  file_open(FOPEN_MODE_W);
461 //  //write bitmap headers
462 //  file_write_buf(BMPHeader, BMPHEADERSIZE);
463 //  file_write_buf(DIBHead, DIBHEADERSIZE);
464 //  //Image1
465 //  //reset read pointer
466 //  FIFO_1_nRRST_CLR;
467 //
468 //  FIFO_1_RCLK_SET;
469 //  delay_us(10);
470 //  FIFO_1_RCLK_CLR;
471 //  FIFO_1_nRRST_SET;
472 //
473 //  //enable output
474 //  FIFO_1_nOE_CLR;
475 //  // uint8_t buffer[WIDTH * 2];
476 //
477 //  for(j = 0; j < HEIGHT; j++)
478 //  {
479 //      for(i = 0; i < WIDTH*2; i+=2)
480 //      {
481 //          FIFO_1_RCLK_SET;
482 //          delay_us(10);
483 //          buffer[i+1] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
484 //          delay_us(10);
485 //          FIFO_1_RCLK_CLR;
486 //          delay_us(10);
487 //          FIFO_1_RCLK_SET;
488 //          delay_us(10);
489 //          buffer[i] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
490 //          delay_us(10);
491 //          FIFO_1_RCLK_CLR;
492 //          delay_us(10);
493 //      }
494 //      file_write_buf(&buffer, WIDTH * 2);
495 //  }
496 //
497 //  FIFO_1_nOE_SET; //disable output
498 //  file_close();
499 //  //mspace_free(sDRAM_msp, Buffer_ram);
500 //  /* mspace_free(sDRAM_msp, Buffer_ram); */
501 // }

503 void Store_Image_1()
504 {
505     int i, j;
506     //uint8_t buffer[WIDTH * 2];
```

```
507     char Filename_buff[15];
508     uint8_t *Buffer_ram;
509     Buffer_ram = mspace_malloc(sdram_msp, HEIGHT * WIDTH * 2);
510     i = 0;
511     //make file
512     //delete file if it exists already
513     nav_filelist_reset();
514     while(1)
515     {
516         sprintf(&Filename_buff, Image1Name, i++);
517         if(nav_filelist_findname((FS_STRING)Filename_buff, false))
518         {
519             ;
520         }
521         else
522         {
523             break;
524         }
525     }

527     //Image1
528     //reset read pointer
529     FIFO_1_nRRST_CLR;

531     FIFO_1_RCLK_SET;
532     delay_us(10);
533     FIFO_1_RCLK_CLR;
534     FIFO_1_nRRST_SET;

536     //enable output
537     FIFO_1_nOE_CLR;
538     //  uint8_t buffer[WIDTH * 2];

540     for(j = 0; j < HEIGHT * WIDTH * 2; j+= 2)
541     {
542         FIFO_1_RCLK_SET;
543         delay_us(10);
544         Buffer_ram[j+1] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
545         delay_us(10);
546         FIFO_1_RCLK_CLR;
547         delay_us(10);
548         FIFO_1_RCLK_SET;
549         delay_us(10);
550         Buffer_ram[j] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
551         delay_us(10);
552         FIFO_1_RCLK_CLR;
553         delay_us(10);
554     }

556     FIFO_1_nOE_SET; //disable output
557 /*   file_close(); */
558     SaveBitmap(Buffer_ram, WIDTH, HEIGHT, Filename_buff);
559     mspace_free(sdram_msp, Buffer_ram);
560 }

562 void Store_Image_0()
563 {
564     int i, j;
```

```
565 //uint8_t buffer[WIDTH * 2];
566 char Filename_buff[15];
567 uint16_t *Buffer_ram;
568 Buffer_ram = mspace_malloc(sdram_msp, HEIGHT * WIDTH );
569 i = 0;
570 //make file
571 //delete file if it exists already
572 nav_filelist_reset();
573 while(1)
574 {
575     sprintf(&Filename_buff, ImageOName, i++);
576     if(nav_filelist_findname((FS_STRING)Filename_buff, false))
577     {
578         ;
579     }
580     else
581     {
582         break;
583     }
584 }

585 //Image1
586 //reset read pointer
587 FIFO_O_nRRST_CLR;

588 FIFO_O_RCLK_SET;
589 delay_us(10);
590 FIFO_O_RCLK_CLR;
591 FIFO_O_nRRST_SET;

592 //enable output
593 FIFO_O_nOE_CLR;
594 // uint8_t buffer[WIDTH * 2];

595 for(j = 0; j < HEIGHT * WIDTH; j++)
596 {
597     FIFO_O_RCLK_SET;
598     delay_us(10);
599     Buffer_ram[j] = ((AVR32_GPIO.port[1].pvr) & 0xFF); //CAMERA_INPUT;
600     delay_us(10);
601     FIFO_O_RCLK_CLR;
602     delay_us(10);
603     FIFO_O_RCLK_SET;
604     delay_us(10);
605     Buffer_ram[j] |= (((AVR32_GPIO.port[1].pvr) & 0xFF) << 8); //CAMERA_INPUT;
606     delay_us(10);
607     FIFO_O_RCLK_CLR;
608     delay_us(10);
609 }

610 FIFO_O_nOE_SET;//disable output
611 /* file_close(); */
612 SaveBitmap(Buffer_ram, WIDTH, HEIGHT, Filename_buff);
613 mspace_free(sdram_msp, Buffer_ram);
614 }
```

G.1.1.10 OV7670.c

./Code/The_Columbus/ColumbusTest/src/CustomDevices/OV7670_Setup.c

```
1  /*
2   * OV7670_Setup.c
3   *
4   * Created: 15/02/2013 13:14:09
5   * Author: hslovett
6   */
7
8 #include "CustomDevices/CustomDevices.h"
9
10 const char default_settings[SETTINGS_LENGTH][2]=
11 {
12 {OV_TSLB, 0x04},
13 {OV_COM15, 0xd0}, //RGB565 / RGB555
14 {OV_COM7, 0x14},
15 {OV_HREF, 0x80},
16 {OV_HSTART, 0x16},
17 {OV_HSTOP, 0x04},
18 {OV_VSTART, 0x02},
19 {OV_VSTOP, 0x7b}, //0x7a,
20 {OV_VREF, 0x06}, //0x0a,
21 {OV_COM3, 0x00}, //MSB and LSB swapped
22 {OV_COM14, 0x00}, //
23 {OV_SCALING_XSC, 0x00},
24 {OV_SCALING_YSC, 0x00},
25 {OV_SCALING_DCWCTR, 0x11},
26 {OV_SCALING_PCLK_DIV, 0x00}, //
27 {0xa2, 0x02},
28 {OV_CLKRC, 0x01},
29 {OV_GAM1, 0x20},
30 {OV_GAM2, 0x1c},
31 {OV_GAM3, 0x28},
32 {OV_GAM4, 0x3c},
33 {OV_GAM5, 0x55},
34 {OV_GAM6, 0x68},
35 {OV_GAM7, 0x76},
36 {OV_GAM8, 0x80},
37 {OV_GAM9, 0x88},
38 {OV_GAM10, 0x8f},
39 {OV_GAM11, 0x96},
40 {OV_GAM12, 0xa3},
41 {OV_GAM13, 0xaf},
42 {OV_GAM14, 0xc4},
43 {OV_GAM15, 0xd7},
44 {OV_GAM16, 0xe8},
45 {OV_COM8, 0xe0},
46 {OV_GAIN, 0x00}, //AGC
47 {OV_AECH, 0x00},
48 {OV_COM4, 0x00},
49 {OV_COM9, 0x20}, //0x38, limit the max gain
50 {OV_HIST6, 0x05},
51 {OV_HIST12, 0x07},
52 {OV_AEW, 0x75},
53 {OV_AEB, 0x63},
```

```
54 {OV_VPT, 0xA5},
55 {OV_HIST0, 0x78},
56 {OV_HIST1, 0x68},
57 {OV_HIST2, 0x03}, //0x0b,
58 {OV_HIST7, 0xdf}, //0xd8,
59 {OV_HIST8, 0xdf}, //0xd8,
60 {OV_HIST9, 0xf0},
61 {OV_HIST10, 0x90},
62 {OV_HIST11, 0x94},
63 {OV_COM8, 0xe5},
64 {OV_COM5, 0x61},
65 {OV_COM6, 0x4b},
66 {0x16, 0x02},
67 {OV_MVFP, 0x27}, //0x37,
68 {0x21, 0x02},
69 {0x22, 0x91},
70 {0x29, 0x07},
71 {0x33, 0x0b},
72 {0x35, 0x0b},
73 {0x37, 0x1d},
74 {0x38, 0x71},
75 {OV_OFON, 0x2a}, //
76 {OV_COM12, 0x78},
77 {0x4d, 0x40},
78 {0x4e, 0x20},
79 {OV_GFIX, 0x0c}, ///////////////////////////////
80 {OV_DBLV, 0x60}, //PLL
81 {OV_REG74, 0x19},
82 {0x8d, 0x4f},
83 {0x8e, 0x00},
84 {0x8f, 0x00},
85 {0x90, 0x00},
86 {0x91, 0x00},
87 {OV_DM_LNL, 0x00}, //0x19, //0x66
88 {0x96, 0x00},
89 {0x9a, 0x80},
90 {0xb0, 0x84},
91 {0xb1, 0x0c},
92 {0xb2, 0x0e},
93 {OV_THL_ST, 0x82},
94 {0xb8, 0xa},
95 {OV_AWBC1, 0x14},
96 {OV_AWBC2, 0xf0},
97 {OV_AWBC3, 0x34},
98 {OV_AWBC4, 0x58},
99 {OV_AWBC5, 0x28},
100 {OV_AWBC6, 0x3a},
101 {0x59, 0x88},
102 {0x5a, 0x88},
103 {0x5b, 0x44},
104 {0x5c, 0x67},
105 {0x5d, 0x49},
106 {0x5e, 0x0e},
107 {OV_LCC3, 0x04},
108 {OV_LCC4, 0x20},
109 {OV_LCC5, 0x05},
110 {OV_LCC6, 0x04},
111 {OV_LCC7, 0x08},
```

```
112 {OV_AWBCTR3, 0x0a},
113 {OV_AWBCTR2, 0x55},
114 {OV_AWBCTR1, 0x11},
115 {OV_AWBCTR0, 0x9f}, //0x9e for advance AWB
116 {OV_GGAIN, 0x40},
117 {OV_BLUE, 0x40},
118 {OV_RED, 0x40},
119 {OV_COM8, 0xe7},
120 {OV_COM10, 0x02}, //VSYNC negative
121 {OV_MTX1, 0x80},
122 {OV_MTX2, 0x80},
123 {OV_MTX3, 0x00},
124 {OV_MTX4, 0x22},
125 {OV_MTX5, 0x5e},
126 {OV_MTX6, 0x80},
127 {OV_MT XS, 0x9e},
128 {OV_COM16, 0x08},
129 {OV_EDGE, 0x00},
130 {OV_REG75, 0x05},
131 {OV_REG76, 0xe1},
132 {OV_DNSTH, 0x00},
133 {OV_REG77, 0x01},
134 {OV_COM13, 0xc2}, //0xc0,
135 {OV_REG4B, 0x09},
136 {OV_SATCTR, 0x60},
137 {OV_COM16, 0x38},
138 {OV CONTRAS, 0x40},
139 {0x34, 0x11},
140 {OV_COM11, 0x02}, //0x00, //0x02,
141 {OV_HIST5, 0x89}, //0x88,
142 {0x96, 0x00},
143 {0x97, 0x30},
144 {0x98, 0x20},
145 {0x99, 0x30},
146 {0x9a, 0x84},
147 {0x9b, 0x29},
148 {0x9c, 0x03},
149 {OV_BD50ST, 0x4c},
150 {OV_BD60ST, 0x3f},
151 {0x78, 0x04},
152 {0x79, 0x01}, //Some weird thing with reserved registers.
153 {0xc8, 0xf0},
154 {0x79, 0x0f},
155 {0xc8, 0x00},
156 {0x79, 0x10},
157 {0xc8, 0x7e},
158 {0x79, 0x0a},
159 {0xc8, 0x80},
160 {0x79, 0x0b},
161 {0xc8, 0x01},
162 {0x79, 0x0c},
163 {0xc8, 0x0f},
164 {0x79, 0x0d},
165 {0xc8, 0x20},
166 {0x79, 0x09},
167 {0xc8, 0x80},
168 {0x79, 0x02},
169 {0xc8, 0xc0},
```

```

170 {0x79, 0x03},
171 {0xc8, 0x40},
172 {0x79, 0x05},
173 {0xc8, 0x30},
174 {0x79, 0x26},
175 {OV_COM2, 0x03},
176 {OV_BRIGHT, 0x00},
177 {OV_CONTRAS, 0x40},
178 {OV_COM11, 0x42}, //0x82, //0xc0, //0xc2, //night mode
179
180 };

```

G.1.1.11 PCA9542A.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/PCA9542A.h

```

/*
 * PCA9542A.h
 *
 * Created: 15/02/2013 12:21:46
 * Author: hslovett
 */

#ifndef PCA9542A_H_
#define PCA9542A_H_

#define A0 0
#define A1 0
#define A2 1
#define PCA9542A_ADDR (0x70 | (A2 << 2) | (A1 << 1) | A0)

#define NO_SELECT 0x00
//#define ERROR 0x01
#define I2C_CHANNEL_0 0x04
#define I2C_CHANNEL_1 0x05

//Status Codes
#define SUCCESS 0
#define DEVICE_NOT_FOUND 2

typedef struct {
    uint8_t Status;
    uint8_t ChannelSelected;
} PCA9542A_t;

PCA9542A_t PCA9542A;
int PCA9542A_Init();
//void PCA9542A_Channel_Select(uint8_t Channel);
void PCA9542A_Chain_Sel(unsigned char Channel);
#endif /* PCA9542A_H_ */

```

G.1.1.12 PCA9542A.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/PCA9542A.c

```

1  /*
2   *  PCA9542A.c
3   *
4   *  Created: 15/02/2013 12:21:36
5   *  Author: hslovett
6   */
7
8 #include <asf.h>
9 #include "CustomDevices/CustomDevices.h"
10 //Camera
11 /*#include "CustomDevices/OV7670.h"*/
12 //I2C Mux
13 /*#include "CustomDevices/PCA9542A.h"*/
14 //MotorDriver
15 /*#include "CustomDevices/MotorDriver.h"*/
16 //SDCard
17 /*#include "CustomDevices/SD_Card.h"*/
18
19 int PCA9542A_Init()
20 {
21     int status = twim_probe(&AVR32_TWIMO, PCA9542A_ADDR);
22     if (status != STATUS_OK)
23     {
24         PCA9542A.Status = DEVICE_NOT_FOUND;
25         return DEVICE_NOT_FOUND;
26     }
27     char buff[2] = {NO_SELECT, 0};
28     status = twim_write(&AVR32_TWIMO, &buff, 1, PCA9542A_ADDR, false);
29     PCA9542A.Status = STATUS_OK;
30     PCA9542A.ChannelSelected = NO_SELECT;
31     return status;
32 }
33
34 void PCA9542A_Change_Status(unsigned char Channel)
35 {
36     int status = 0;
37     char buff[2] = {Channel, 0};
38     status = twim_write(&AVR32_TWIMO, &buff, 1, PCA9542A_ADDR, false);
39     if(status == STATUS_OK)
40     {
41         PCA9542A.ChannelSelected = Channel;
42     }
43     else
44     {
45         PCA9542A.Status = ERR_PROTOCOL;
46     }
47 }
48

```

G.1.1.13 SD_Card.h

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/SD_Card.h

```

1  /*
2   * SD_Card.h
3   *
4   * Created: 10/02/2013 17:11:51
5   * Author: hslovett
6   */
7
8
9 #ifndef SD_CARD_H_
10 #define SD_CARD_H_
11 #include "ImageProcessor.h"
12 #define SIGNAL_FILE "signal.bin"
13 #define TWOD_SIGNAL_FILE "signal2d.bin"
14
15 typedef struct {
16     uint8_t Status;
17     uint32_t Memory_size;
18 } SD_Status_t;
19 SD_Status_t SD_Status;
20
21 void local_pdca_init(void);
22 void sd_mmc_resources_init(void);
23 static void pdca_int_handler(void);
24 void wait();
25 void Log_Write_ulong(unsigned long n);
26 void Log_Write(char *buff, int length);
27 void SaveBuff( int * WorkingBuffer , int size);
28 int Read2DSignal( int * WorkingBuffer );
29 int ReadSignal( int * WorkingBuffer );
30 void SaveBitmap(uint16_t *Image , int width, int height, char *FileName);
31 //void ReadBitmap(char *filename);
32 void ReadBitmap(char *Filename, Image_t *image);
33 void SaveBuff_CSV(char *Filename, int *WorkingBuffer, int size);
34 void SaveCBuff_CSV(char *Filename, dsp16_complex_t *ComplexBuffer, int size);
35 void Read_CSV(char *Filename, int *WorkingBuffer, int size);
36#endif /* SD_CARD_H_ */

```

G.1.1.14 SD_Card.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/SD_Card.c

```

1 /*
2  * SD_Card.c
3  *
4  * Created: 10/02/2013 17:11:58
5  * Author: hslovett
6  */
7 //Camera
8 /*#include "CustomDevices/0V7670.h"*/
9 //I2C Mux
10 /*#include "CustomDevices/PCA9542A.h"*/
11 //MotorDriver

```

```
12  /*#include "CustomDevices/MotorDriver.h"*/
13  //SDCard
14  /*#include "CustomDevices/SD_Card.h"*/
15  #include "CustomDevices/CustomDevices.h"
16  #include "conf_sd_mmc_spi.h"
17  #include <asf.h>
18  #include "stdlib.h"
19  #include "stdio.h"
20  // Dummy char table
21  const char dummy_data[] =
22  #include "dummy.h"
23  ;

26  // PDCA Channel pointer
27  volatile avr32_pdca_channel_t* pdca_channelrx ;
28  volatile avr32_pdca_channel_t* pdca_channeltx ;
29  // Used to indicate the end of PDCA transfer
30  volatile bool end_of_transfer;
31  // Local RAM buffer for the example to store data received from the SD/MMC
32  // card
33  volatile char ram_buffer[1000];

35  void wait()
36  {
37      volatile int i;
38      for(i = 0 ; i < 5000; i++);
39  }
40  /* interrupt handler to notify if the Data reception from flash is
41   * over, in this case lunch the Memory(ram_buffer) to USART transfer and
42   * disable interrupt*/
43
44  static void pdca_int_handler(void)
45  {
46      // Disable all interrupts.
47      Disable_global_interrupt();

48      // Disable interrupt channel.
49      pdca_disable_interrupt_transfer_complete(AVR32_PDCA_CHANNEL_SPI_RX);

50      sd_mmc_spi_read_close_PDCA(); //unselects the SD/MMC memory.
51      wait();
52      // Disable unnecessary channel
53      pdca_disable(AVR32_PDCA_CHANNEL_SPI_TX);
54      pdca_disable(AVR32_PDCA_CHANNEL_SPI_RX);

55      // Enable all interrupts.
56      Enable_global_interrupt();

57
58      end_of_transfer = true;
59  }

60
61  */
62  /*! \brief Initializes SD/MMC resources: GPIO, SPI and SD/MMC.
63  */
64  void sd_mmc_resources_init(void)
65  {
66      // GPIO pins used for SD/MMC interface
```

```

69     static const gpio_map_t SD_MMC_SPI_GPIO_MAP =
70 {
71     {SD_MMC_SPI_SCK_PIN, SD_MMC_SPI_SCK_FUNCTION }, // SPI Clock.
72     {SD_MMC_SPI_MISO_PIN, SD_MMC_SPI_MISO_FUNCTION}, // MISO.
73     {SD_MMC_SPI_MOSI_PIN, SD_MMC_SPI_MOSI_FUNCTION}, // MOSI.
74     {SD_MMC_SPI_NPCS_PIN, SD_MMC_SPI_NPCS_FUNCTION} // Chip Select NPCS.
75 };
76
77 // SPI options.
78 spi_options_t spiOptions =
79 {
80     .reg          = SD_MMC_SPI_NPCS,
81     .baudrate    = SD_MMC_SPI_MASTER_SPEED, // Defined in conf_sd_mmc_spi.h.
82     .bits         = SD_MMC_SPI_BITS,           // Defined in conf_sd_mmc_spi.h.
83     .spck_delay   = 0,
84     .trans_delay  = 0,
85     .stay_act     = 1,
86     .spi_mode     = 0,
87     .modfdis     = 1
88 };
89
90 // Assign I/Os to SPI.
91 gpio_enable_module(SD_MMC_SPI_GPIO_MAP,
92                     sizeof(SD_MMC_SPI_GPIO_MAP) / sizeof(SD_MMC_SPI_GPIO_MAP
93 [0]));
94
95 // Initialize as master.
96 spi_initMaster(SD_MMC_SPI, &spiOptions);
97
98 // Set SPI selection mode: variable_ps, pcs_decode, delay.
99 spi_selectionMode(SD_MMC_SPI, 0, 0, 0);
100
101 // Enable SPI module.
102 spi_enable(SD_MMC_SPI);
103
104 // Initialize SD/MMC driver with SPI clock (PBA).
105 sd_mmc_spi_init(spiOptions, PBA_HZ);
106 }
107
108 /*! \brief Initialize PDCA (Peripheral DMA Controller A) resources for the SPI
109    transfer and start a dummy transfer
110 */
111 void local_pdca_init(void)
112 {
113     // this PDCA channel is used for data reception from the SPI
114     pdca_channel_options_t pdca_options_SPI_RX ={ // pdca channel options
115
116         .addr = ram_buffer,
117         // memory address. We take here the address of the string dummy_data. This
118         // string is located in the file dummy.h
119
120         .size = 512,                                // transfer counter: here the
121         // size of the string
122         .r_addr = NULL,                             // next memory address after 1st
123         // transfer complete
124         .r_size = 0,                               // next transfer counter not
125         // used here

```

```

120     .pid = AVR32_PDCA_CHANNEL_USED_RX,           // select peripheral ID - data
121     are on reception from SPI1 RX line
122     .transfer_size = PDCA_TRANSFER_SIZE_BYTE   // select size of the transfer:
123     8,16,32 bits
124 };
125
126 // this channel is used to activate the clock of the SPI by sending a dummy
127 // variables
128 pdca_channel_options_t pdca_options_SPI_TX ={ // pdca channel options
129
130     .addr = (void *)&dummy_data,                // memory address.
131                                         // We take here the address of
132     the string dummy_data.                     // This string is located in the
133     file dummy.h                            // transfer counter: here the
134     .size = 512,                             // size of the string
135     .r_addr = NULL,                          // next memory address after 1st
136     transfer complete.                      // transfer counter not
137     .r_size = 0,                            // next transfer counter not
138     used here.                           // select peripheral ID - data
139     are on reception from SPI1 RX line
140     .transfer_size = PDCA_TRANSFER_SIZE_BYTE // select size of the transfer:
141     8,16,32 bits
142 };
143
144 // Init PDCA transmission channel
145 pdca_init_channel(AVR32_PDCA_CHANNEL_SPI_TX, &pdca_options_SPI_TX);
146
147 // Init PDCA Reception channel
148 pdca_init_channel(AVR32_PDCA_CHANNEL_SPI_RX, &pdca_options_SPI_RX);
149
150 //!\ brief Enable pdca transfer interrupt when completed
151 INTC_register_interrupt(&pdca_int_handler, AVR32_PDCA_IRQ_0, AVR32_INTC_INT1
152 ); // pdca_channel_spi1_RX = 0
153
154 }
155
156 #define BUFFER_FILENAME    "Buffer.bin"
157 #define BUFFERCSV_FILENAME  "Buffer.csv"
158 void SaveBuff( int * WorkingBuffer , int size)
159 {
160     //If the file exists, delete it
161     if(nav_filelist_findname((FS_STRING)BUFFER_FILENAME, false))
162     {
163         nav_setcwd((FS_STRING)BUFFER_FILENAME, false, false);
164         nav_file_del(false);
165     }
166     nav_file_create((FS_STRING)BUFFER_FILENAME);
167     nav_setcwd((FS_STRING)BUFFER_FILENAME, false, true);
168     file_open(FOPEN_MODE_APPEND);
169     file_write_buf(WorkingBuffer, size * sizeof(WorkingBuffer));
170     file_close();
171 }
172
173 void SaveBuff_CSV(char *Filename, int *WorkingBuffer, int size)
174 {
175     int i, j;

```

```
167     char Buff[16];
168     //If the file exists, delete it
169     nav_filelist_reset();
170     if(nav_filelist_findname((FS_STRING)Filename, false))
171     {
172         nav_setcwd((FS_STRING)Filename, false, false);
173         nav_file_del(false);
174     }
175     nav_file_create((FS_STRING)Filename);
176     nav_setcwd((FS_STRING)Filename, false, true);
177     file_open(FOPEN_MODE_W);
178     for(i = 0; i < size; i++)
179     {
180         sprintf(Buff, "%d,", WorkingBuffer[i]);
181         //itoa(WorkingBuffer[i], Buff, 10);
182         j = 0;
183         while(Buff[j++] != 0); //count the size of data to be written
184         atoi(Buff);
185         file_write_buf(Buff, j-1);
186         //file_write_buf(",", 1);
187     }

188     file_close();
189 }
190 void SaveCBuff_CSV(char *Filename, dsp16_complex_t *ComplexBuffer, int size)
191 {
192     int i, j;
193     char Buff[16];
194     //If the file exists, delete it
195     nav_filelist_reset();
196     if(nav_filelist_findname((FS_STRING)Filename, false))
197     {
198         nav_setcwd((FS_STRING)Filename, false, false);
199         nav_file_del(false);
200     }
201     nav_file_create((FS_STRING)Filename);
202     nav_setcwd((FS_STRING)Filename, false, true);
203     file_open(FOPEN_MODE_W);
204     for(i = 0; i < size; i++)
205     {
206         if(ComplexBuffer[i].imag >= 0)
207             sprintf(Buff, "%d+%dj,", ComplexBuffer[i].real, ComplexBuffer[i].imag);
208         else
209             sprintf(Buff, "%d%dj,", ComplexBuffer[i].real, ComplexBuffer[i].imag);
210         //itoa(WorkingBuffer[i], Buff, 10);
211         j = 0;
212         while(Buff[j++] != 0); //count the size of data to be written
213         atoi(Buff);
214         file_write_buf(Buff, j-1);
215         //file_write_buf(",", 1);
216     }

217     file_close();
218 }
219 void Read_CSV(char *Filename, int *WorkingBuffer, int size)
220 {
221     char Buff[32];
222     int i, j;
```

```
225     char c;
226     nav_filelist_reset();
227     if(WorkingBuffer == NULL){
228         print_dbg("\n\rRead_CSV: Buffer not initialised");
229         return;
230     }
231     //Check file Exists
232     if(nav_filelist_findname((FS_STRING)Filename, false) == false){
233         print_dbg("\n\rRead_CSV : File doesn't exist;");
234         return;
235     }
236     nav_setcwd((FS_STRING)Filename, false, true);
237     file_open(FOPEN_MODE_R);
238     for(i = 0; i < size; i++)
239     {
240         if(file_eof())
241             break;
242         c = 0;
243         //j = 0;
244         for(j = 0; j < 32; j++)
245             Buff[j] = 0; //clear the buffer
246         j = 0;
247         while(c != ',')
248         {
249             if(file_eof())
250                 break;
251             c = file_getc();
252             if(c == ',')
253                 break;
254             Buff[j++] = c; //load string into buffer
255         }
256         WorkingBuffer[i] = atoi(Buff); //Convert to int and put into buffer
257     }
258     file_close();
259     return;
260 }
261 void Log_Write(char *buff, int length)
262 {
263     nav_setcwd((FS_STRING)LOG_FILE, true, false);
264     file_open(FOPEN_MODE_APPEND);
265     if(length == -1)
266         length = sizeof(buff);
267     file_write_buf(buff, length);
268     file_close();
269 }
270 void Log_Write_ulong(unsigned long n)
271 {
272     char tmp[11];
273     int i = sizeof(tmp) - 1;

275     // Convert the given number to an ASCII decimal representation.
276     tmp[i] = '\0';
277     do
278     {
279         tmp[--i] = '0' + n % 10;
280         n /= 10;
281     } while (n);
```

```
283 // Transmit the resulting string with the given USART.  
284 Log_Write(tmp + i, -1);  
285 }  
  
287 int ReadSignal( int * WorkingBuffer )  
288 {  
289     bool status_b;  
290     int Status, temp;  
291     char c = 0;  
292     if(Columbus_Status.SD_Card->Status != STATUS_OK)  
293         return ERR_IO_ERROR;  
294     nav_filelist_reset();  
295     nav_setcwd((FS_STRING)SIGNAL_FILE, false, false);  
296     status_b = file_open(FOPEN_MODE_R);  
297     if(status_b == false)  
298     {  
299         print_dbg("File Open Error");  
300         return ERR_IO_ERROR;  
301     }  
  
304 //Status = file_read_buf(WorkingBuffer, 16);  
305 for(Status = 0; Status < FFT_SIZE; Status++)  
306 {  
307 //    print_dbg("\n\r Read from file: ");  
308     c = 0;  
309     temp = 0;  
310     temp |= file_getc() << 24;  
311     temp |= file_getc() << 16;  
312     temp |= file_getc() << 8;  
313     temp |= file_getc();  
  
315 //    print_dbg_char(c);  
  
317     WorkingBuffer[Status] = temp;  
318 //    print_dbg(" Working Buff = ");  
319 //    print_dbg_char(WorkingBuffer[Status]);  
320 }  
321     file_close();  
322     return STATUS_OK;  
323 }  
  
325 int Read2DSignal( int * WorkingBuffer )  
326 {  
327     bool status_b;  
328     int Status, temp;  
329     char c = 0;  
330     if(Columbus_Status.SD_Card->Status != STATUS_OK)  
331         return ERR_IO_ERROR;  
332     nav_filelist_reset();  
333     nav_setcwd((FS_STRING)TWOD_SIGNAL_FILE, false, false);  
334     status_b = file_open(FOPEN_MODE_R);  
335     if(status_b == false)  
336     {  
337         print_dbg("File Open Error");  
338         return ERR_IO_ERROR;  
339     }
```

```
342 //Status = file_read_buf(WorkingBuffer, 16);
343 for(Status = 0; Status < FFT_SIZE * FFT_SIZE; Status++)
344 {
345     //    print_dbg("\n\r Read from file: ");
346     c = 0;
347     temp = 0;
348     temp |= file_getc() << 24;
349     temp |= file_getc() << 16;
350     temp |= file_getc() << 8;
351     temp |= file_getc();

353     //    print_dbg_char(c);

355     WorkingBuffer[Status] = temp;
356     //    print_dbg("  Working Buff = ");
357     //    print_dbg_char(WorkingBuffer[Status]);
358 }
359 file_close();
360 return STATUS_OK;
361 }

363 void SaveBitmap(uint16_t *Image, int width, int height, char *FileName)
364 {
365     int i, j, k;
366     uint8_t *Buffer;

368     nav_filelist_reset();
369     if(nav_filelist_findname((FS_STRING)FileName, false))
370     {
371         nav_setcwd((FS_STRING)FileName, true, false);
372         nav_file_del(false);
373     }
374     nav_file_create((FS_STRING)FileName);
375     file_open(FOPEN_MODE_W);
376     //write a modified bitmap header
377     //Calculate which is the biggest:
378     i = width * 2;
379     if(height > i)
380         i = height;
381     if(DIBHEADERSIZE > i)
382         i = DIBHEADERSIZE;

384     Buffer = malloc(i);

386     for(i = 0; i < BMPHEADERSIZE; i++)//copy all the header
387     {
388         Buffer[i] = BMPHeader[i];
389     }
390     //edit the size field
391     j = width * height * 2 + BMPHEADERSIZE + DIBHEADERSIZE;
392     for(i = 0; i < 4; i++)
393     {
394         Buffer[i + 2] = (uint8_t)(j >> 8*i);
395     }

397     file_write_buf(Buffer, BMPHEADERSIZE);
```

```

399 //DIB Header
400 for(i = 0; i < DIBHEADERSIZE; i++)
401 {
402     Buffer[i] = DIBHead[i];
403 }
404 Buffer[4] = (uint8_t)(width & 0xFF);
405 Buffer[5] = (uint8_t)((width >> 8) & 0xFF);
406 Buffer[6] = (uint8_t)((width >> 16) & 0xFF);
407 Buffer[7] = (uint8_t)((width >> 24) & 0xFF);

409 Buffer[8] = (uint8_t)(height & 0xFF);
410 Buffer[9] = (uint8_t)((height >> 8) & 0xFF);
411 Buffer[10] = (uint8_t)((height >> 16) & 0xFF);
412 Buffer[11] = (uint8_t)((height >> 24) & 0xFF);

414 file_write_buf(Buffer, DIBHEADERSIZE);

416 for(i = 0; i < height ; i++ )
417 {
418     for(j = 0; j < width ; j++)
419     {
420         //Copy the data across.

422         /*Buffer[j] = Image[i*width + j];*/
423         Buffer[(2 * j) + 1] = (uint8_t)(Image[i*width + j]);
424         Buffer[(2 * j)] = (uint8_t)(Image[i*width + j] >> 8);
425     }
426     if(file_write_buf(Buffer, width * 2) != (width * 2))
427     {
428         print_dbg("\n\rFile write error.");
429     }

431 //      j = width % 4;
432 //      if(j != 0)
433 //          {//Padding is needed to make things 4 byte aligned
434 //              file_write_buf(Buffer, j);
435 //          }
436     }

440     free(Buffer);
441     file_close();
442 }

444 #define BMP_HEADER_FILESIZE_OFFSET      2
445 #define BMP_HEADER_OFFSETTOARRAY_OFFSET 10
446 #define DIB_V5_WIDTH_OFFSET            4
447 #define DIB_V5_HEIGHT_OFFSET          8
448 #define DIB_V5_BITCOUNT_OFFSET        14
449 #define DIB_V5_IMAGESIZE_OFFSET       20

451 int ReadBigEndian(uint8_t *Buffer, int Offset, uint size)
452 {
453     int retVal, i;
454     retVal = 0; //initialise value
455     for(i = 0; i < size; i++)
456     {

```

```
457     retVal |= Buffer[Offset + i] << (i * 8);
458 }
459 return (Buffer[Offset]) | (Buffer[Offset + 1] << 8) | (Buffer[Offset + 2] <<
460     16) | (Buffer[Offset + 3] << 24);
461 }
462 void ReadBitmap(char *Filename, Image_t *image)
463 {
464 //  Image_t image;
465     int i, j, FileSize, OffsetToArray, temp, BitCount, ImageSize;
466     uint8_t Buffer[128];
467     nav_filelist_reset();
468     if(nav_filelist_findname((FS_STRING)Filename, false) == false)//if the file
469         doesn't exist
470     {
471         print_dbg("\n\rFile ");
472         print_dbg(Filename);
473         print_dbg("\n\r does not exist;");
474         return;
475     }
476     nav_setcwd((FS_STRING)Filename, false, false);
477     file_open(FOPEN_MODE_R);
478     //Read Header
479     file_read_buf(Buffer, BMPHEADERSIZE);
480     //Check for BM to confirm it is a Bitmap
481     if((Buffer[0] != 'B') || (Buffer[1] != 'M'))
482     {
483         print_dbg("\n\rBitmap Parse Fail 'BM';");
484         return;
485     }
486     //Extract file size and offset to pixel array
487     FileSize = ReadBigEndian(Buffer, BMP_HEADER_FILESIZE_OFFSET, 4);
488     OffsetToArray = ReadBigEndian(Buffer, BMP_HEADER_OFFSETTOARRAY_OFFSET, 4);

489     file_read_buf(Buffer, DIBHEADERSIZE);
490     temp = ReadBigEndian(Buffer, 0, 4);
491     if(temp != 0x7C) //check it is a V5 BMP DIB Header
492     {
493         print_dbg("\n\rBMP Parse: DIB Header not V5;");
494         return;
495     }
496     image->Width= ReadBigEndian(Buffer, DIB_V5_WIDTH_OFFSET, 4);
497     image->Height = ReadBigEndian(Buffer, DIB_V5_HEIGHT_OFFSET, 4);
498     BitCount = ReadBigEndian(Buffer, DIB_V5_BITCOUNT_OFFSET, 2);
499     ImageSize = ReadBigEndian(Buffer, DIB_V5_IMAGESIZE_OFFSET, 4);
500     print_dbg("\n\rBitmap Width = ");
501     print_dbg_ulong(image->Width);
502     print_dbg("\n\rBitmap Height = ");
503     print_dbg_ulong(image->Height);
504     print_dbg("\n\rBitmap File Size = ");
505     print_dbg_ulong(FileSize);
506     print_dbg("\n\rBitmap Offset to Array = ");
507     print_dbg_ulong(OffsetToArray);
508     print_dbg("\n\rBitmap Image Bitcount = ");
509     print_dbg_ulong(BitCount);
510     print_dbg("\n\rBitmap Image Size = ");
511     print_dbg_ulong(ImageSize);

512     file_seek(OffsetToArray, FS_SEEK_SET);
```

```

513     j = 0;
514     image->ImagePtr = mspace_malloc(sdram_msp, image->Height * image->Width);
515     for(i = 0; i < ImageSize; i += 2)
516     {
517         image->ImagePtr[j++] = (file_getc() << 8) | (file_getc());
518     }
519     file_close();
520     nav_filelist_reset();
521     return;
522 }
```

G.1.1.15 TWI.c

..../Code/The_Columbus/ColumbusTest/src/CustomDevices/TWI.c

```

1  /*
2   *  TWI.c
3   *
4   *  Created: 27/02/2013 10:51:19
5   *  Author: hslovett
6   */
7
8 #include "CustomDevices/CustomDevices.h"
9 #include <asf.h>
10
11 #define TARGET_ADDRESS      0x0          ///! Target's TWI address
12 #define TARGET_ADDR_LGT      3            ///! Internal Address length
13 #define VIRTUALMEM_ADDR     0x123456    ///! Internal Address
14 #define TWIM_MASTER_SPEED    50000       ///! Speed of TWI
15
16
17 void twim_init (void)
18 {
19     int8_t status;
20     /**
21     * \internal
22     * PIN 2 & 3 in Header J24 can be used in EVK1104
23     * PIN 1 & 2 in Header J44 can be used in UC3C_EK
24     * \endinternal
25     */
26     const gpio_map_t TWIM_GPIO_MAP = {
27     {AVR32_TWIMSO_TWCK_0_0_PIN, AVR32_TWIMSO_TWCK_0_0_FUNCTION},
28     {AVR32_TWIMSO_TWD_0_0_PIN, AVR32_TWIMSO_TWD_0_0_FUNCTION}
29 };
30
31 // Set TWIM options
32 const twi_options_t TWIM_OPTIONS = {
33     .pba_hz = FOSCO,
34     .speed = TWIM_MASTER_SPEED,
35     .chip = TARGET_ADDRESS,
36     .smbus = false,
37 };
38 // TWIM gpio pins configuration
39 gpio_enable_module (TWIM_GPIO_MAP,
```

```
40     sizeof (TWIM_GPIO_MAP) / sizeof (TWIM_GPIO_MAP[0]));  
  
42 // Initialize as master.  
43 status = twim_master_init (&AVR32_TWIMO, &TWIM_OPTIONS);  
  
45 }
```


References

- Atmel Corporation. *AVR311: TWI Slave*, 2007.
- Atmel Corporation. [Uc3c-ek rev 2 schematic](#), 2009.
- Atmel Corporation. *AT32UC3C0512C Datasheet*, 2012a.
- Atmel Corporation. *ATMega644P Datasheet*, 2012b.
- Atmel Corporation. [Atmel software framework](#), 2012c.
- Atmel Corporation. *ATXMega256A3BU Datasheet*, 2012d.
- PCB Cart. [Pcb manufacturer](#), 2013.
- Electronic Lives Manufacturing. [Fatfs - generic fat file system module](#), 2012.
- Farnell. [Farnell online store](#), 2012.
- Wayne Fulton. [Image file formats - jpg, tif, png, gif. which to use?](#), 2010.
- I. Haller and S. Nedevschi. Design of interpolation functions for subpixel-accuracy stereo-vision systems. *Image Processing, IEEE Transactions on*, 21(2):889–898, 2012.
- Rostam Affendi Hamzah, Sani Irwan Md Salim, and Hasrul Nisham Rosly. An effective distance detection of obstacles in stereo vision application. *Canadian Journal on Electrical and Electronics Engineering*, 1(3):49–53, 2010.
- Jin Liu and Xiaofeng Lin. Equalization in high-speed communication systems. *Circuits and Systems Magazine, IEEE*, 4(2):4–17, 2004.
- Jernej Mrovlje and Damir Vrančić. Distance measuring based on stereoscopic pictures. Technical report, University of Ljubljana, 2008.
- Mark Nixon and Alberto S Aguado. *Feature Extraction & Image Processing for Computer Vision*. Academic Press, 2012.

- OmniVision. *OmniVision Serial Camera Control Bus (SCCB) Functional Specification*, 2007.
- Philips. *UM10204*, 20012.
- Phillips. *PCA9542A : 2-channel I²C-bus multiplexer and interrupt logic*, 2009.
- Texas Instruments. *Stellaris LM3S9B96 Datasheet*, 2012.
- Edwin Tjandranegara. *Distance estimation algorithm for stereo pair images*, 2005.
- D.M. Tsai and C.T. Lin. *Fast normalized cross correlation for defect detection*, 2003.
- Vishay Semiconductors. *TCRT1000, TCRT1010 Datasheet*, 2012.
- F. Zhao, Q. Huang, and W. Gao. Image matching by normalized cross-correlation. In *Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on*, volume 2, pages II–II. IEEE, 2006.