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

Supervisor: Prof. Steve Gunn
Examiner: Prof. Mark Zwolinski

22nd March, 2013

Turn off iNotes!

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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Abstract Needed!

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Listings

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	Seperation 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.

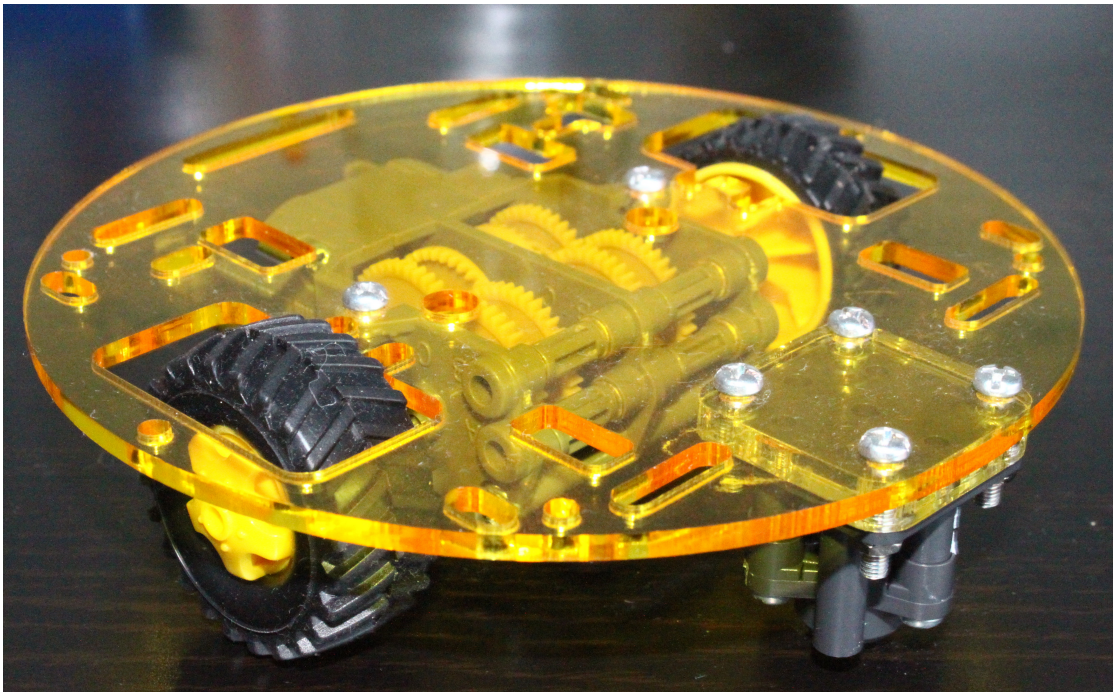


Figure 1.1: The base of the robot

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 Stellaris	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, USART, 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

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 I used to gain the operation required. This code streamed continuous video to a TFT

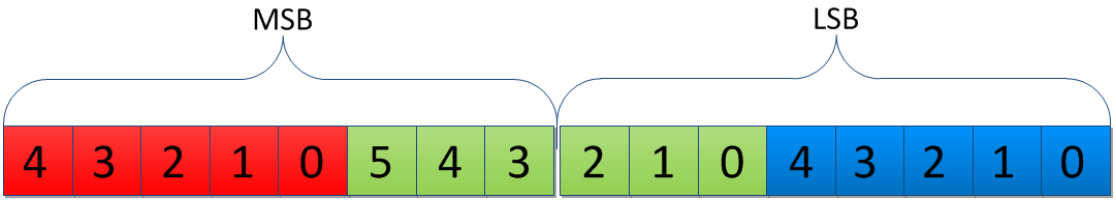


Figure 3.1: RGB565 pixel format

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 used of the built-in interrupt-driven I^2C interface (named TWI in Atmel AVRs)[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 Image (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 C 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.

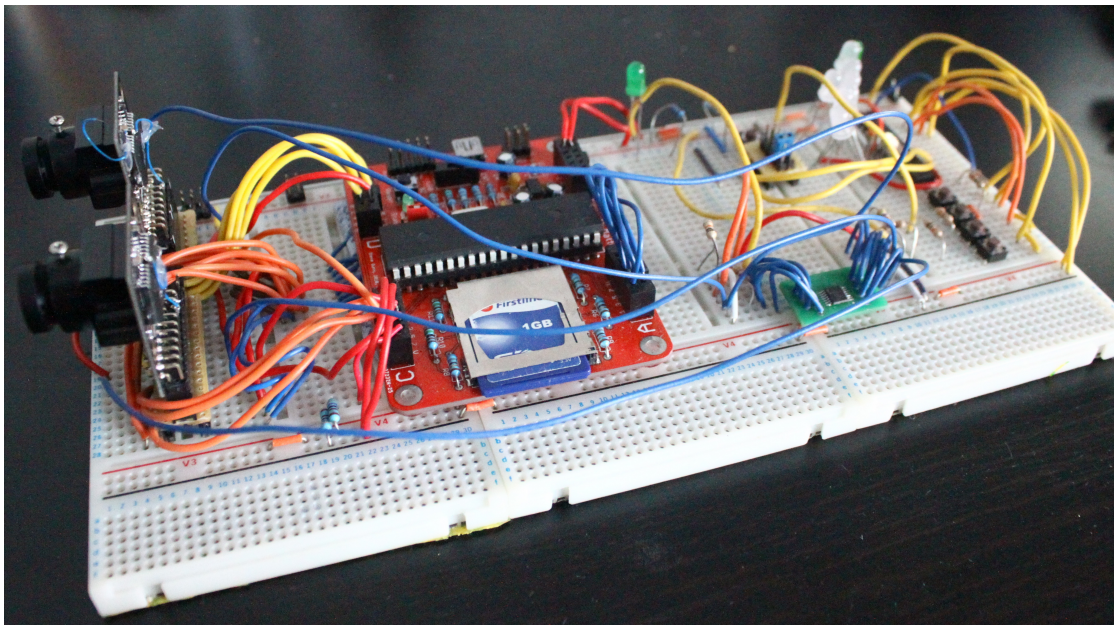


Figure 3.4: Prototype of Dual Camera operation.

3.3 Circuit Development

3.3.1 Stereo Camera Development

Figure B.2 shows the circuit diagram for the prototype. This uses the Il Matto development board for the main microcontroller. The prototype can be seen in figure 3.4. This circuit captured and stored two images from the cameras to the SD card.

3.3.2 Motor Driver Development

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

3.3.2.1 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 tippex 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

3.3.2.2 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.

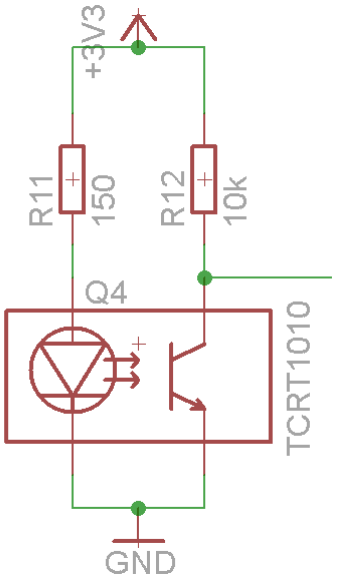


Figure 3.5: Circuit diagram of Optosensor

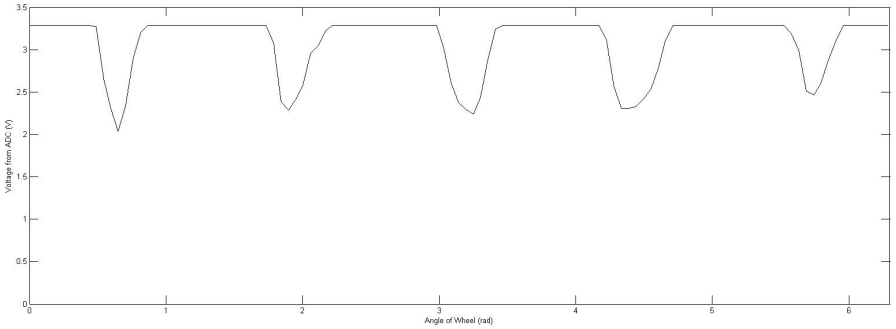


Figure 3.6: Graph of Wheel Angle against the Voltage read by the AVR

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 AVRs. This can be set up to run an interrupt service routine when the voltage crosses a threshold. 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.

$$Interrupts = D \times \frac{IPR}{C_w} \tag{3.1}$$

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

$$D_R = A \times \frac{C_b}{360} \tag{3.2}$$

Combining equations (3.1) and (3.2) gives:

$$Interrupts = A \times \frac{IPR}{C_w} \times \frac{C_b}{360} \tag{3.3}$$

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.

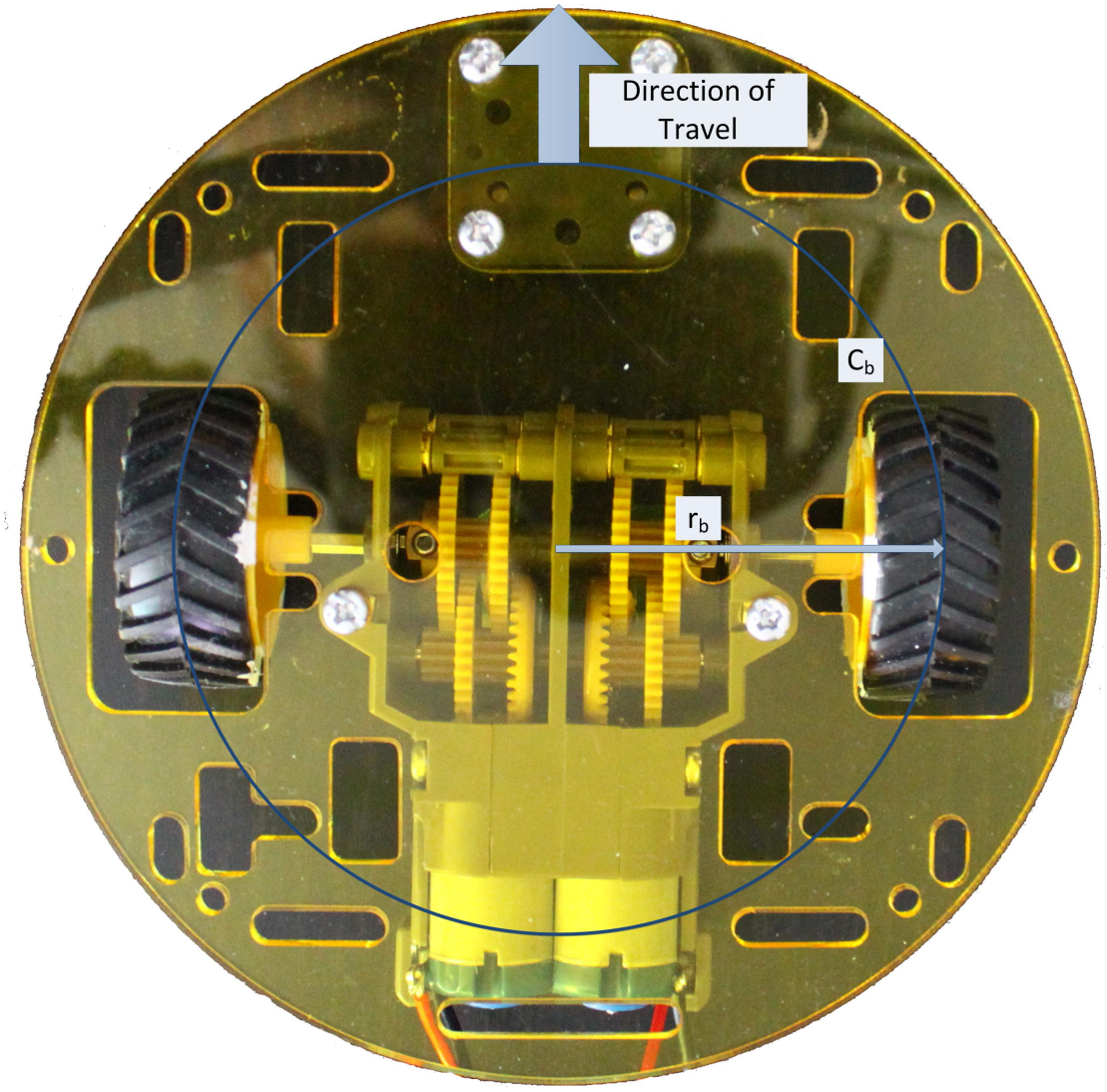
The final code can be seen in appendix D

3.3.2.3 Testing

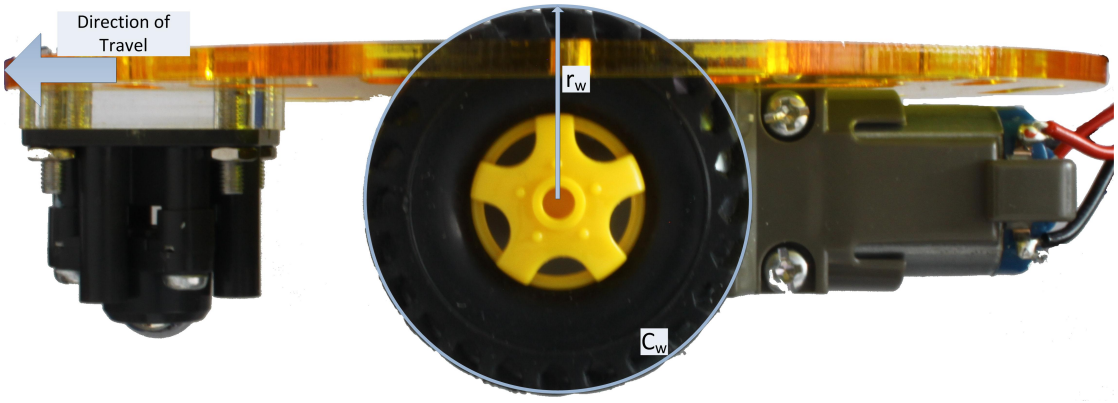
Need to get the motors to work reasonably first

3.3.2.4 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 capactitors 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

Component	Cost per unit (£)	Quantity	Cost (£)	Source
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	£82.84	

Table 3.3: A table of all components used and their costs.

onto the board so the PCB could be mounted on to the robot base easily. The overall dimensions of the PCB were $100mm \times 70mm$. A full list of components and cost of each is documented in table 3.3

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 E. 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:

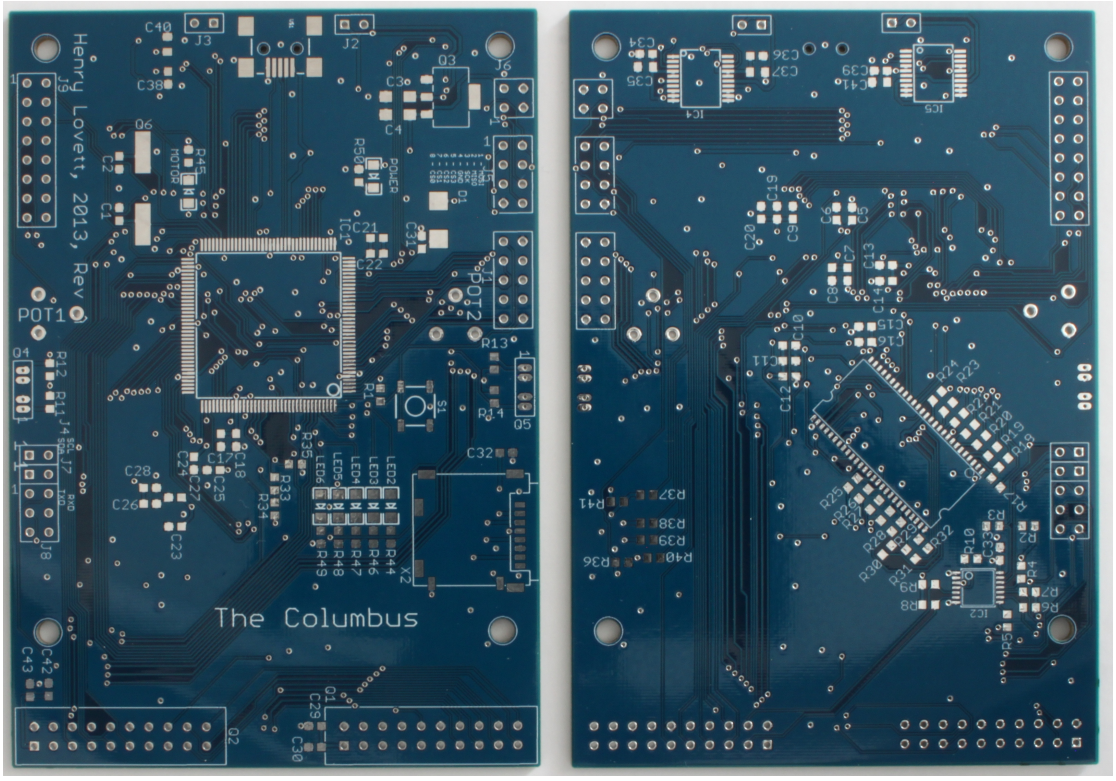


Figure 3.8: PCB with no components. Left: Top View. Right: Bottom View

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 folowing 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

```
////////////////////////////////////////////////
// UART Test ///////////////////////////////////
////////////////////////////////////////////////
uint8_t ch;
while (true) {
  ch = usart_getchar(DBG_USART); // get one input character
  if (ch) {
    print_dbg(ch); // echo to output
  }
  if(ch == 13)
    break;
}
```

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

```
////////////////////////////////////////////////
// SD Card Test ////////////////////////////////
////////////////////////////////////////////////
print_dbg("\n\n\rSD Card Memory Test:\n\r");
// Test if the memory is ready - using the control access memory abstraction
   layer (/SERVICES/MEMORY/CTRL_ACCESS/)
if (mem_test_unit_ready(LUN_ID_SD_MMC_SPI_MEM) == CTRL_GOOD)
{
  // Get and display the capacity
  mem_read_capacity(LUN_ID_SD_MMC_SPI_MEM, &VarTemp);
  print_dbg("OK:\t");
  //printf_ulong((VarTemp + 1) >> (20 - FS_SHIFT_B_TO_SECTOR));
  i = ((VarTemp + 1) >> (20 - FS_SHIFT_B_TO_SECTOR));
  print_dbg_ulong(i);
  print_dbg("MB\r\n");
  print_dbg("SD Card Okay.\n\r");
}
```

```
17    else
18    {
19      // Display an error message
20      print_dbg("Not initialized: Check if memory is ready...\r\n");
21    }
22    nav_reset();
23    // Use the last drive available as default.
24    nav_drive_set(nav_drive_nb() - 1);
25    // Mount it.
26    nav_partition_mount();
27    nav_filelist_reset();
28    if(nav_filelist_findname((FS_STRING)LOG_FILE, false))
29    {
30      print_dbg("\n\rLog File Already Exists\n\rAttempting to delete...");
31      nav_setcwd((FS_STRING)LOG_FILE, true, false);
32      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.");

41    if(nav_file_create((FS_STRING)LOG_FILE) == true)
42      print_dbg("\n\rSuccess!");
43    else
44      print_dbg("\n\rNot worked...");
45    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;

23  }
24  print_dbg("\rSDRAM filled with test pattern       \r\n");
```

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

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_Chan_Sel(I2C_CHANNEL_0);
14        print_dbg("\n\rScanning Channel 0\n\r");
15      }
16      else {
```

```
17        //Channel 1
18        PCA9542A_Chan_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    }
41    noErrors = 0;
42    //Check cameras exist
43    PCA9542A_Chan_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 3.3.2.3. 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
```

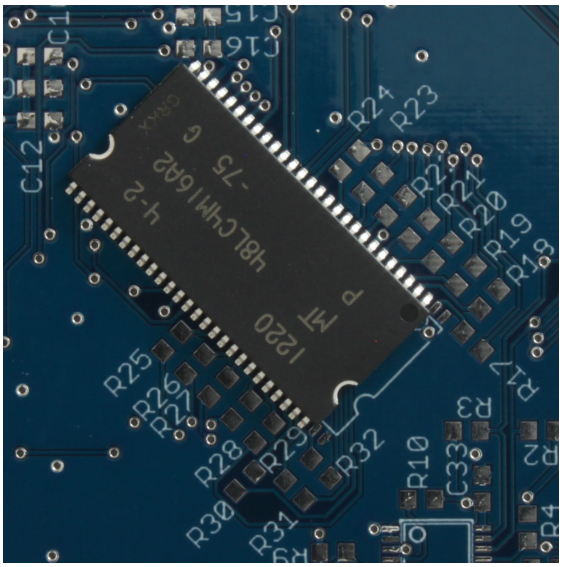


Figure 3.9: SDRAM Chip shown against its footprint.

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 that 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.

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 used 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 3.4 shows some examples of the problematic data bits. The data written should match the data read back.

Table 3.4: 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 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

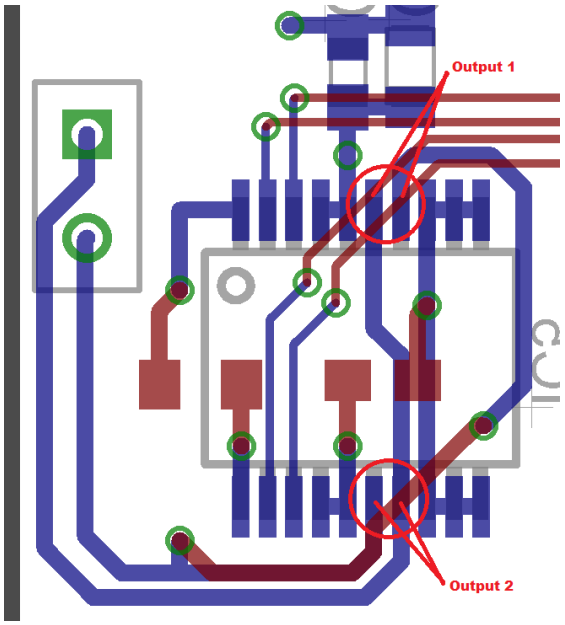


Figure 3.10: Motor Driver error. Outputs incorrectly connected

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.

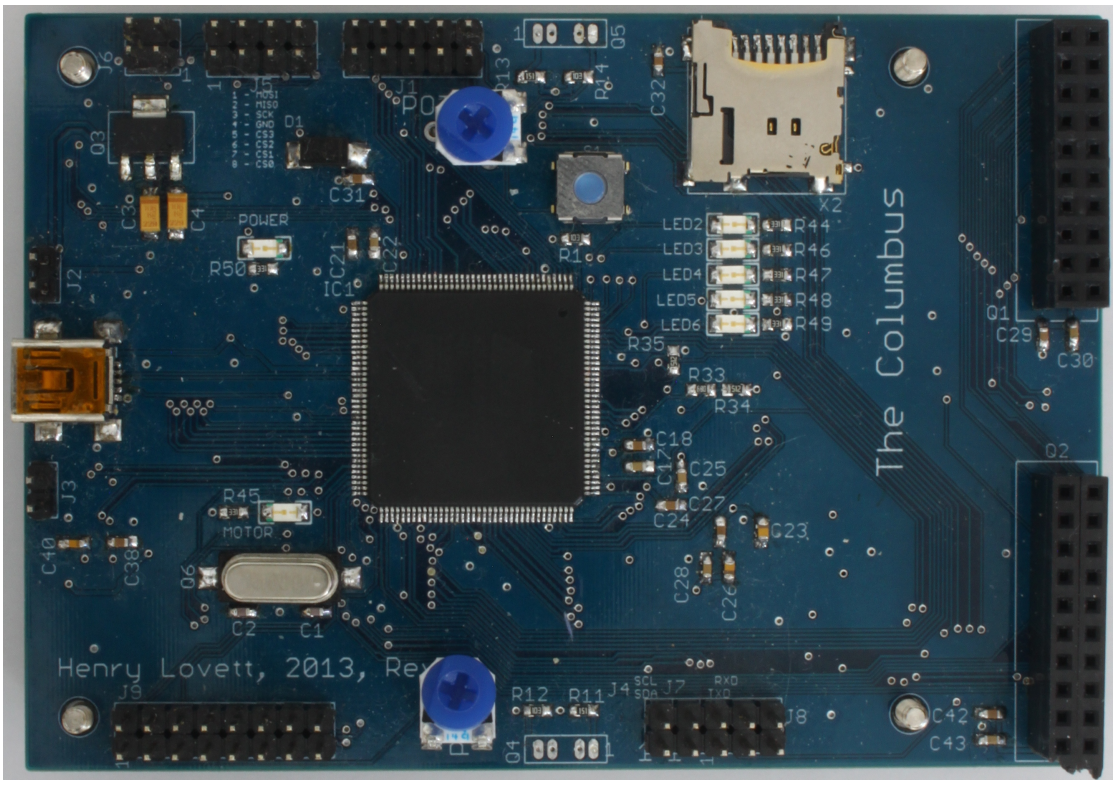
For future PCBs, more care will be taken in circuit design, with prototyping of circuits with the hardware that will be used. This will highlight any pin specific

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.

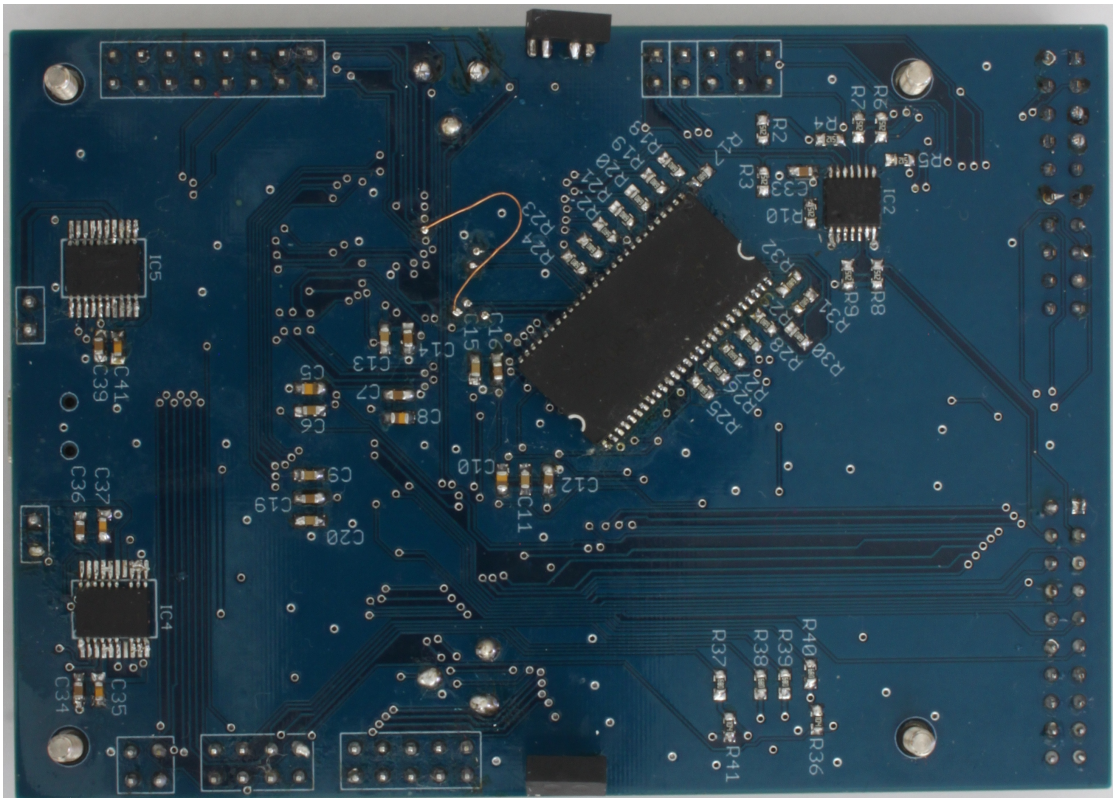
The PCB itself, was a success. It was a complex PCB with many potential things that could have gone wrong. It was the first PCB I had designed and was a four layer board, using some devices that I did not have experience with. All devices are functional (with a few small modifications) on the PCB so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

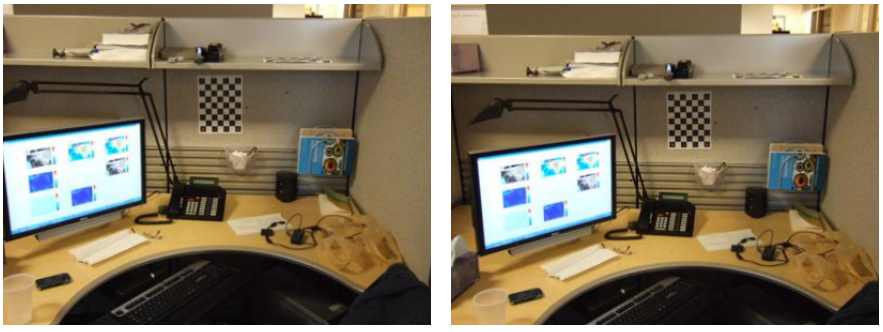
Figure 3.11: Pictures of the built PCB.

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

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

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

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

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

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

Where n is the number of pixels in A and B,
σ is the standard deviation of the image, and
$\bar{A}$ is the a 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 a 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 a 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 operates slowly on a microcontroller without any.

4.1.4 Comparison

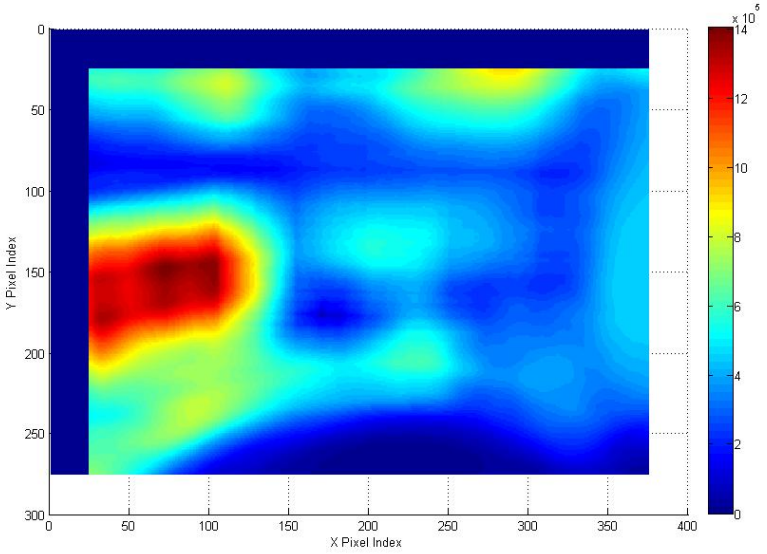
To compare these equations, a 50 by 50 window taken from the right picture was compared with the left image over the entire valid range. The coordinates on the graph give the centre pixel of the calculation.

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)).

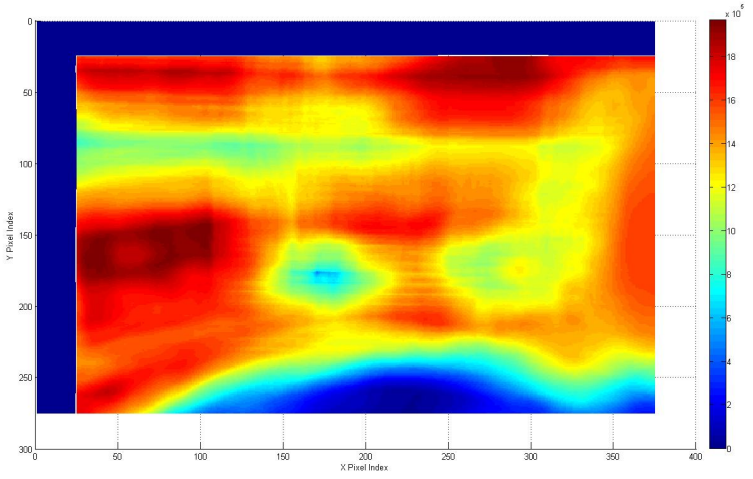
SAD results in figure 4.2(b) show large areas of matching. A minimum occurs around the location expected$(170, 175)$ of a value of 5.66×10^4. However, along the bottom of the image, where a dark area occurs below the desk in the lower part of figures 4.1, the SAD algorithm detects a greater comparison, 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.

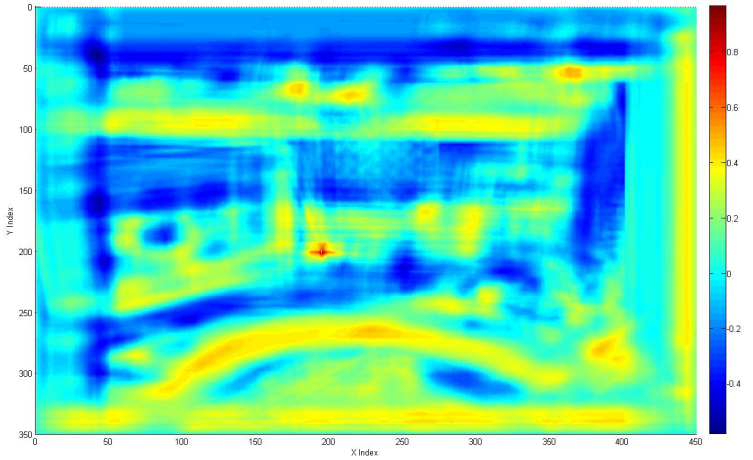
The NCC results are visible in figure 4.2(c). A match can be seen at coordinate $(195, 201)$ with a peak value of 0.9654. The coordinate is different to the previous results because the cross correlation works over the boundary of the image creating more results. The dimensions of the image are 300×400,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

$$B = B_1 + B_2 = D\tan(\varphi_1) + D\tan(\varphi_2) \tag{4.4}$$

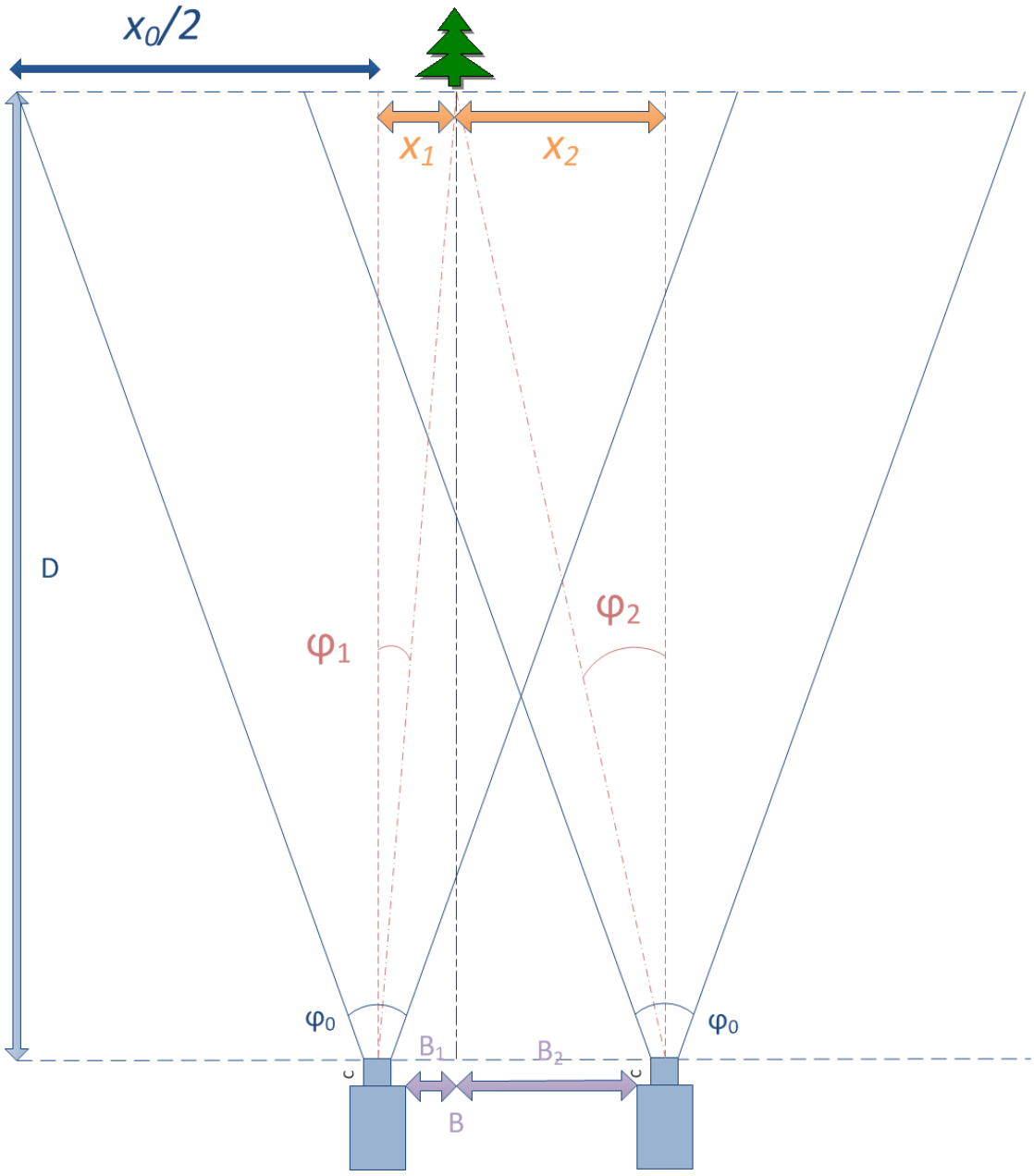


Figure 4.3: Problem 1 - Object is between the Cameras

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

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

$$D \tan(\varphi_1) = x_1 \tag{4.7}$$

Dividing (4.7) by (4.6)

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

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

This can also be shown for the right camera:

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

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

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

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:

$$D.\tan(\varphi_1) = x_1 \tag{4.12}$$

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

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

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

and similarly

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

$$\theta = \varphi_2 - \varphi_1 \tag{4.17}$$

Using the sine equality rule:

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

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

$$D = \cos(\varphi_1).R \tag{4.20}$$

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

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

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:

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

Where φ_2 can be found from equation 4.16.

4.2.1.4 Summary

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

Object is between the two cameras:

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

Object is to the same side in both images:

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

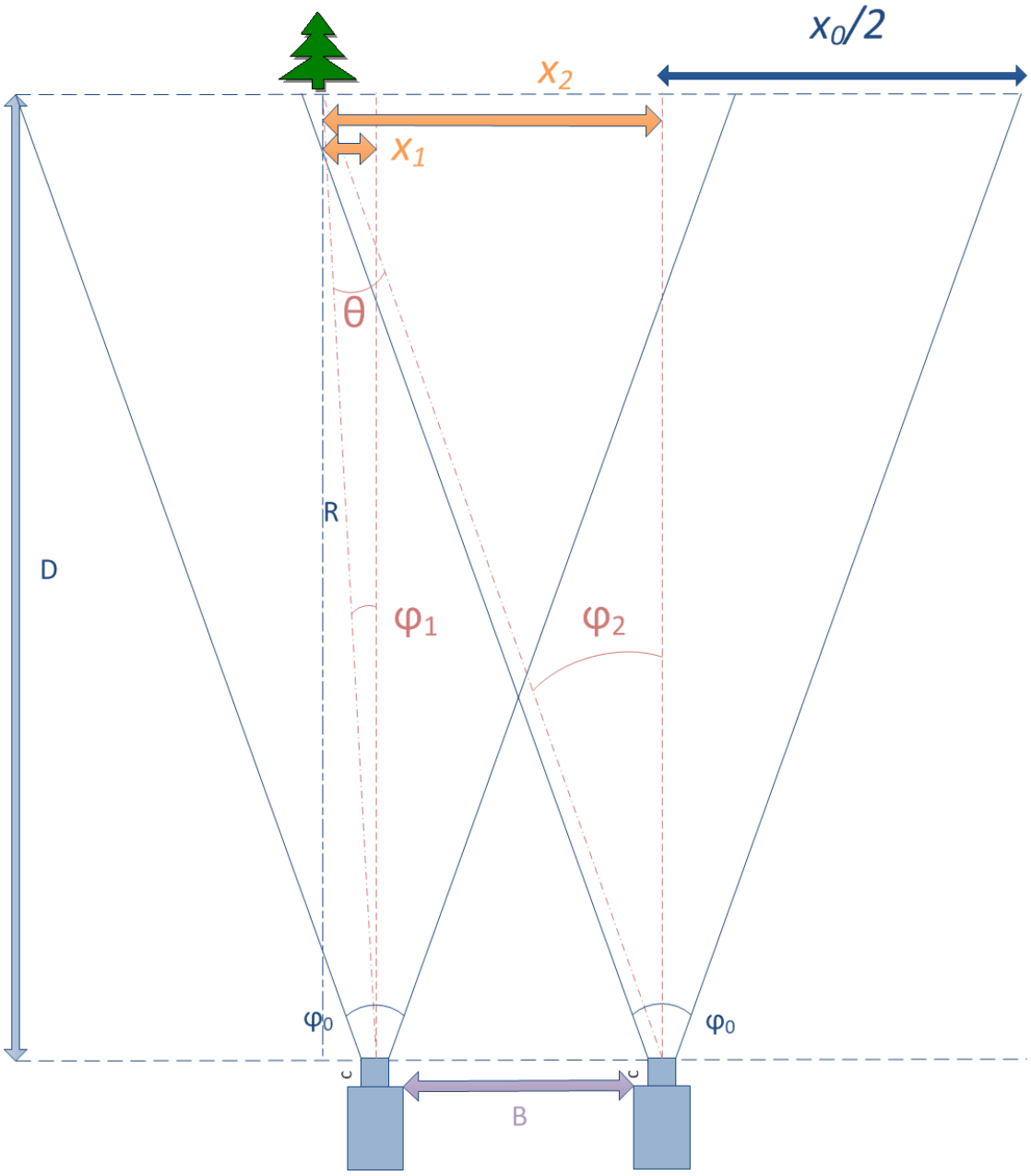


Figure 4.4: Problem 2 - Object is to the same side in both cameras

Object is directly in front of a camera:

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

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.

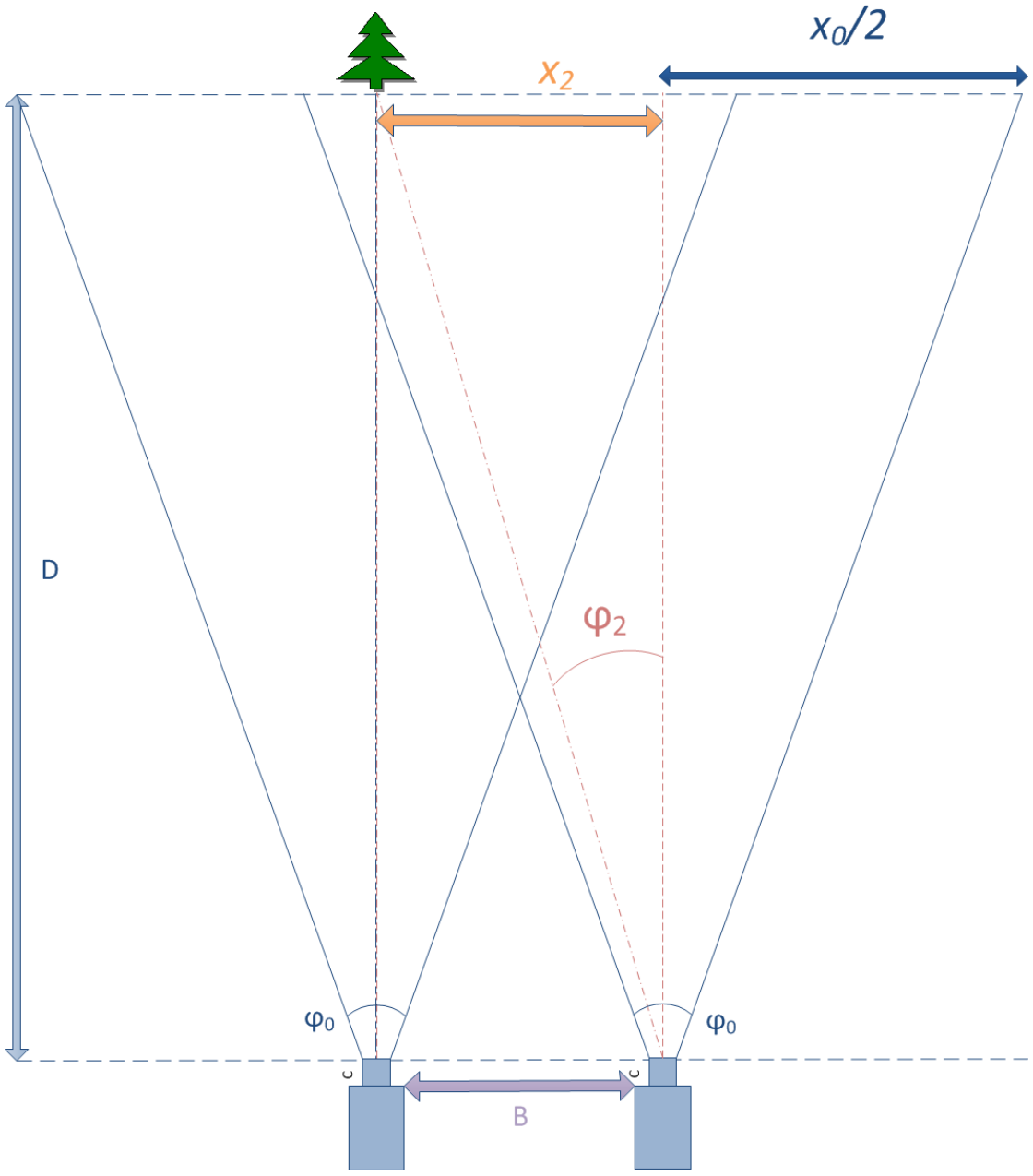


Figure 4.5: Problem 3 - Object is directly in front of a camera

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.

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-\jmath 2\pi ft}dt \tag{4.26}$$

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.

$$X[k] = \sum_{0}^{N-1} x[n]e^{-\jmath \Omega_0 kn} \tag{4.27}$$

Where Ω_0 is the sample frequency

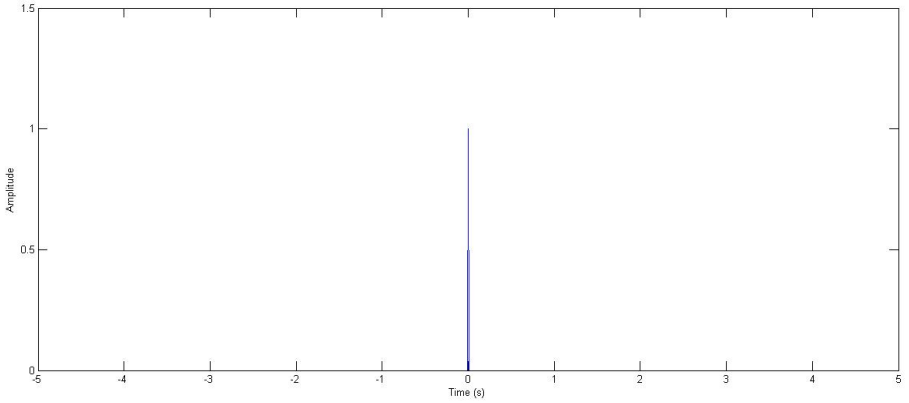
Why this is relevant to my project - what am I using it for?

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$f(t) \in \Re$.

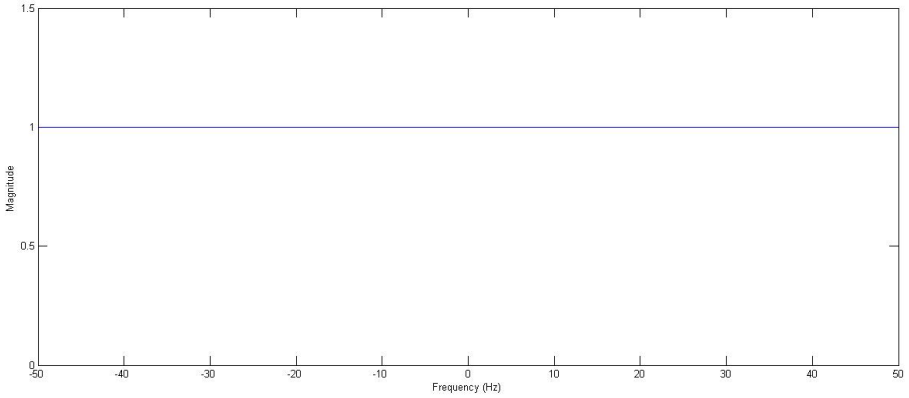
$$\int_{-\infty}^{\infty} f(\tau)g(t-\tau)d\tau = f(t) * g(t) = X(f) \cdot Y(f) \tag{4.28}$$

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

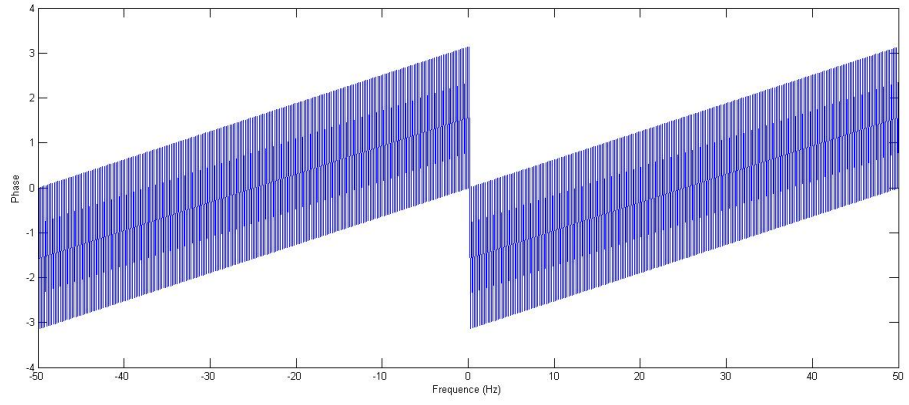
$$f(t) \star g(t) = f(t) * g(-t) = F(f) \cdot G(-f) \tag{4.30}$$



(a) A graph showing a Dirac Function

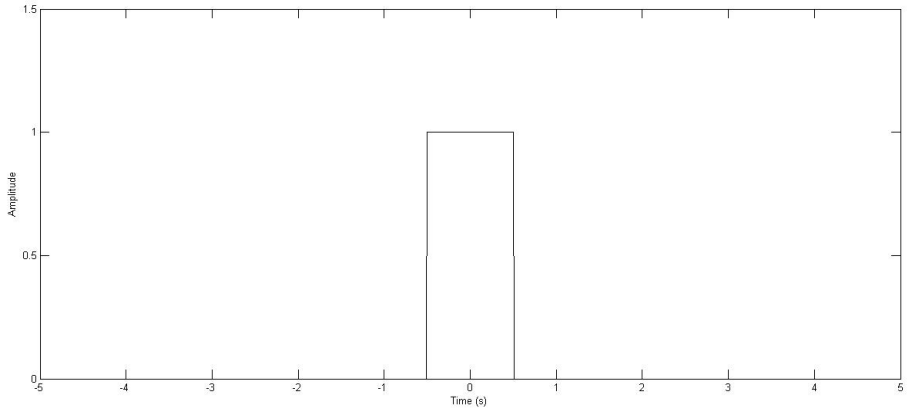


(b) A graph showing the magnitude of the Fourier transform of the Dirac Function

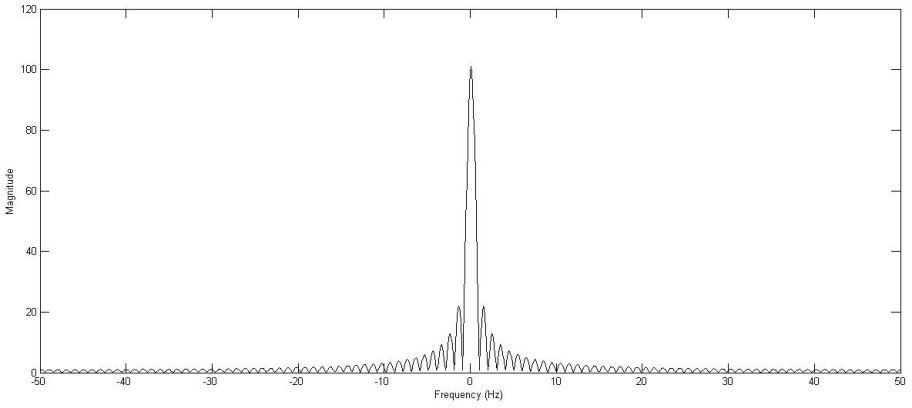


(c) A graph showing the phase of the Fourier transform of the Dirac Function

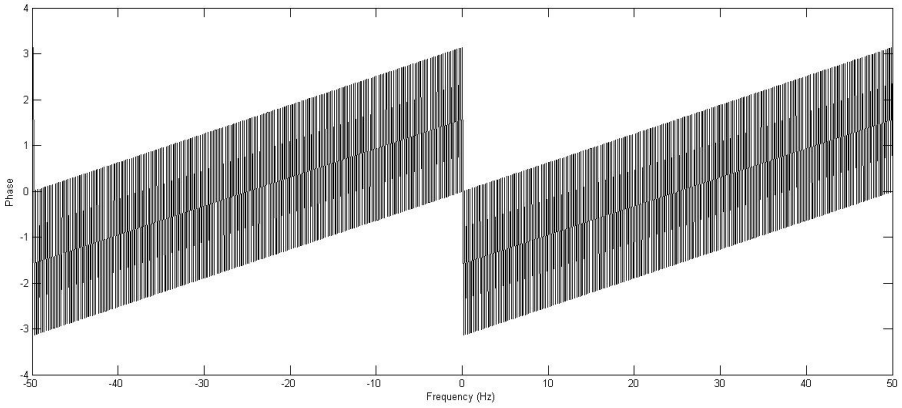
Figure 4.6: A Dirac signal and the phase and magnitude of its Fourier Transform



(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)

$$F(u,v) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y) e^{-2\pi\jmath(xu+yv)} dxdy \tag{4.31}$$

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

Examples

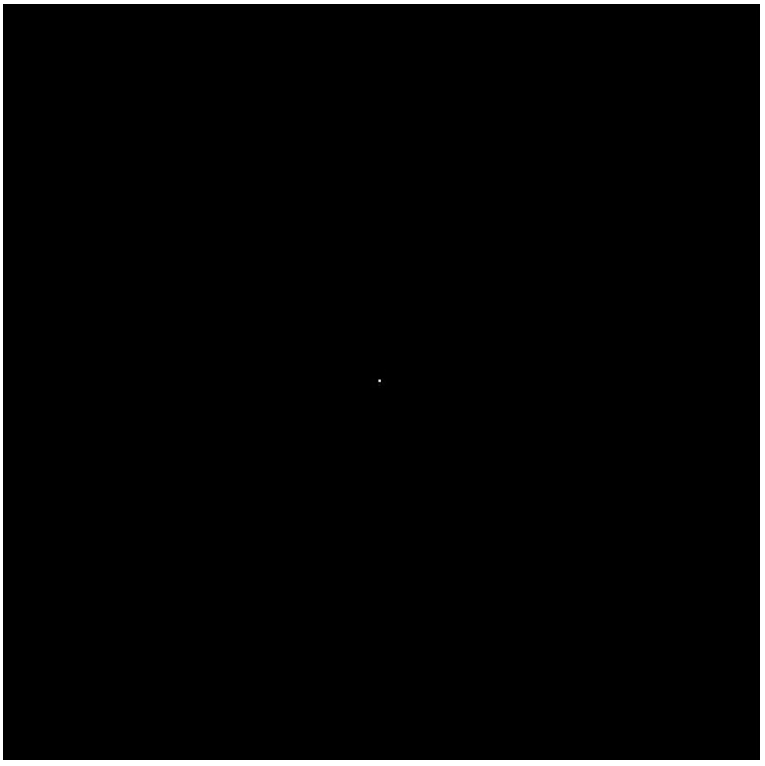
Figures 4.8 and 4.9 show the two dimensional equivalent test signals of figures 4.6(a) and 4.7(a) and the phase and magnitudes of their Fourier Transforms. There is a direct similarity between the 1D and 2D spectra; the magnitudes of the Dirac (figures 4.6(b) and 4.8(b)) are both constant values and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

2D FFT and restrictions

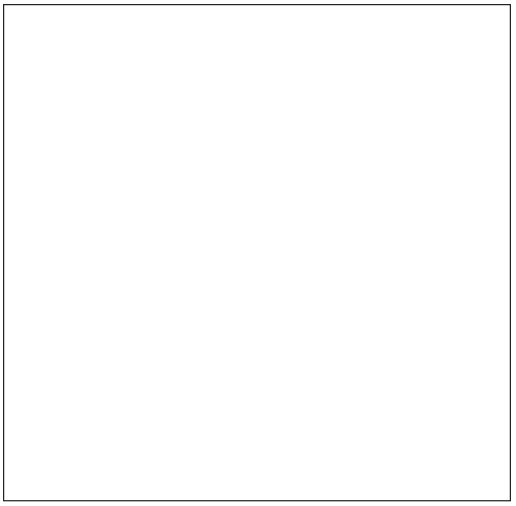
The 2D Fourier transform can also be optimised to a fast Fourier transform algorithm in a similar way as the 1D case. The algorithm, sometimes referred to as the Butterfly transform, is briefly discussed in Nixon and Aguado (2012) where is is explained that the algorithm can be easily applied to images 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:

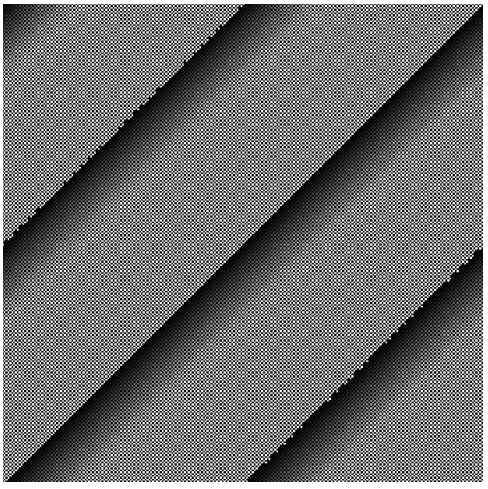
1. Calculate the 1D FFT of each of the rows of the 2D data. (An FFT of data of length n returns an array, also of length n)



(a) An image of a 2D Dirac Function

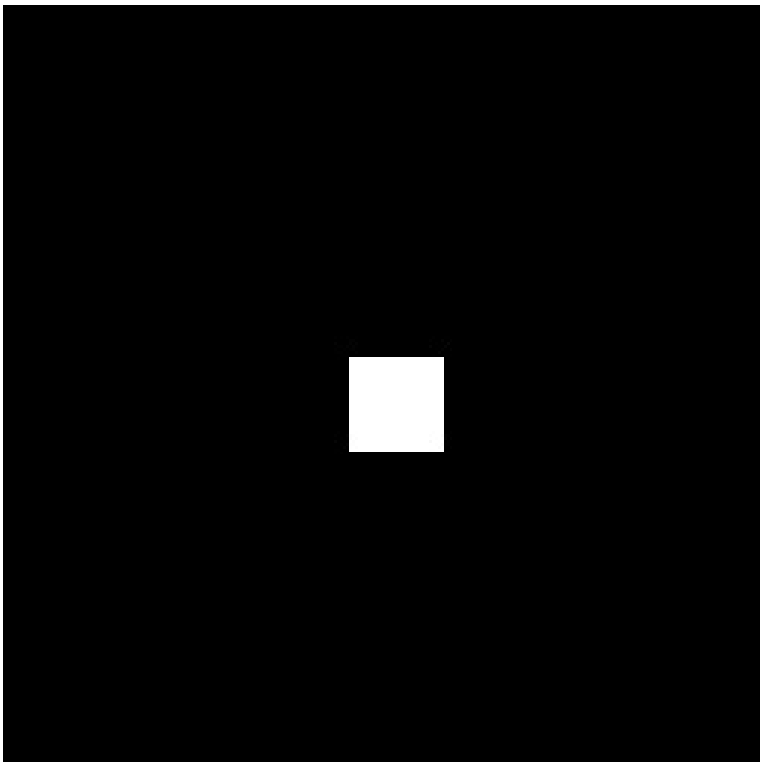


(b) An image of the magnitude of the Fourier transform of the 2D Dirac Function

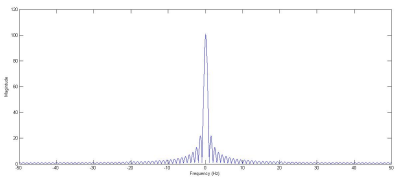


(c) An image of the phase of the Fourier transform of the 2D Dirac Function

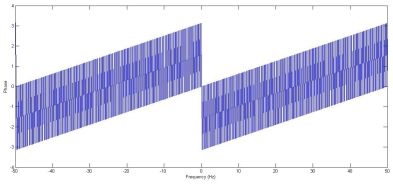
Figure 4.8: A 2D Dirac signal and the phase and magnitude of its Fourier Transform



(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 D.1.1.6 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

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

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

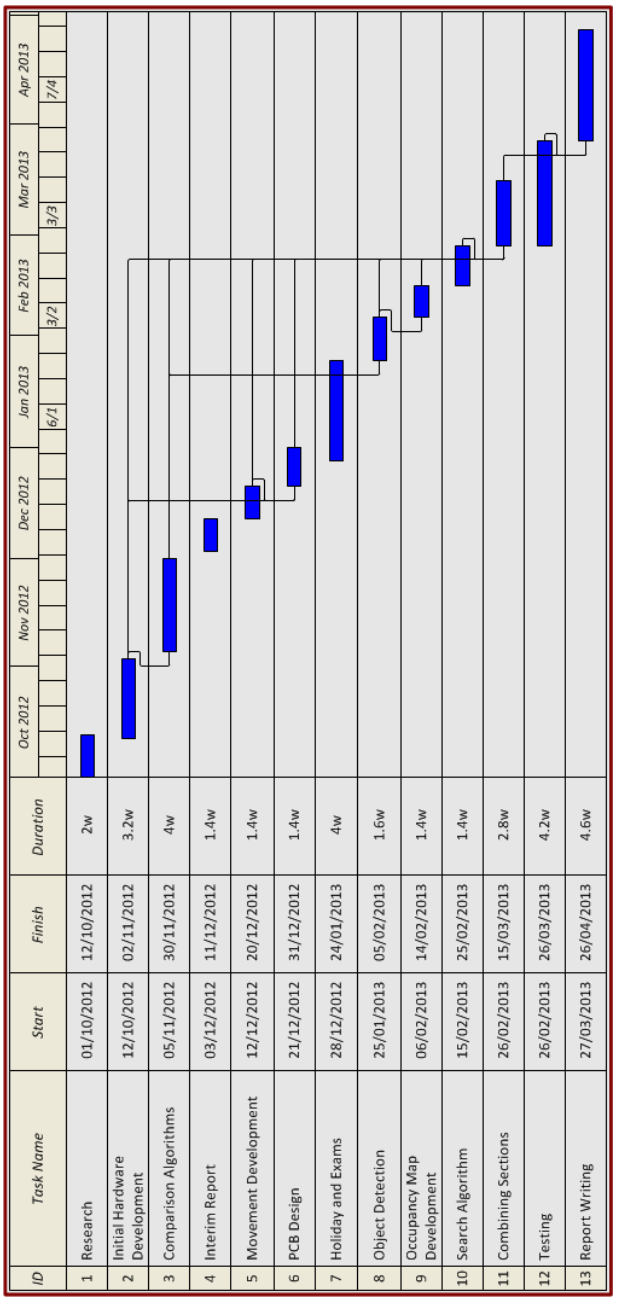


Figure A.1: Gantt Chart of how time will be spent in the areas of the project

Appendix B

Circuit Diagrams

B.1 OV7670 Breakout Board Schematic

B.2 Il Matto and Dual Camera Schematic

B.3 The Columbus Circuit Diagram

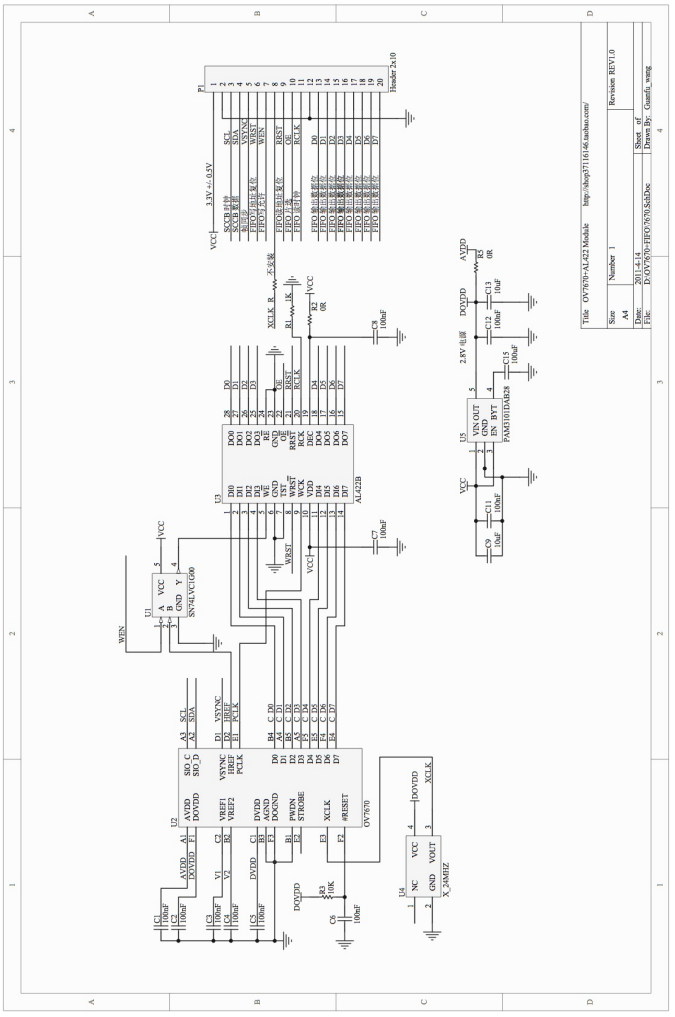


Figure B.1: The circuit diagram for the OV7670 breakout board

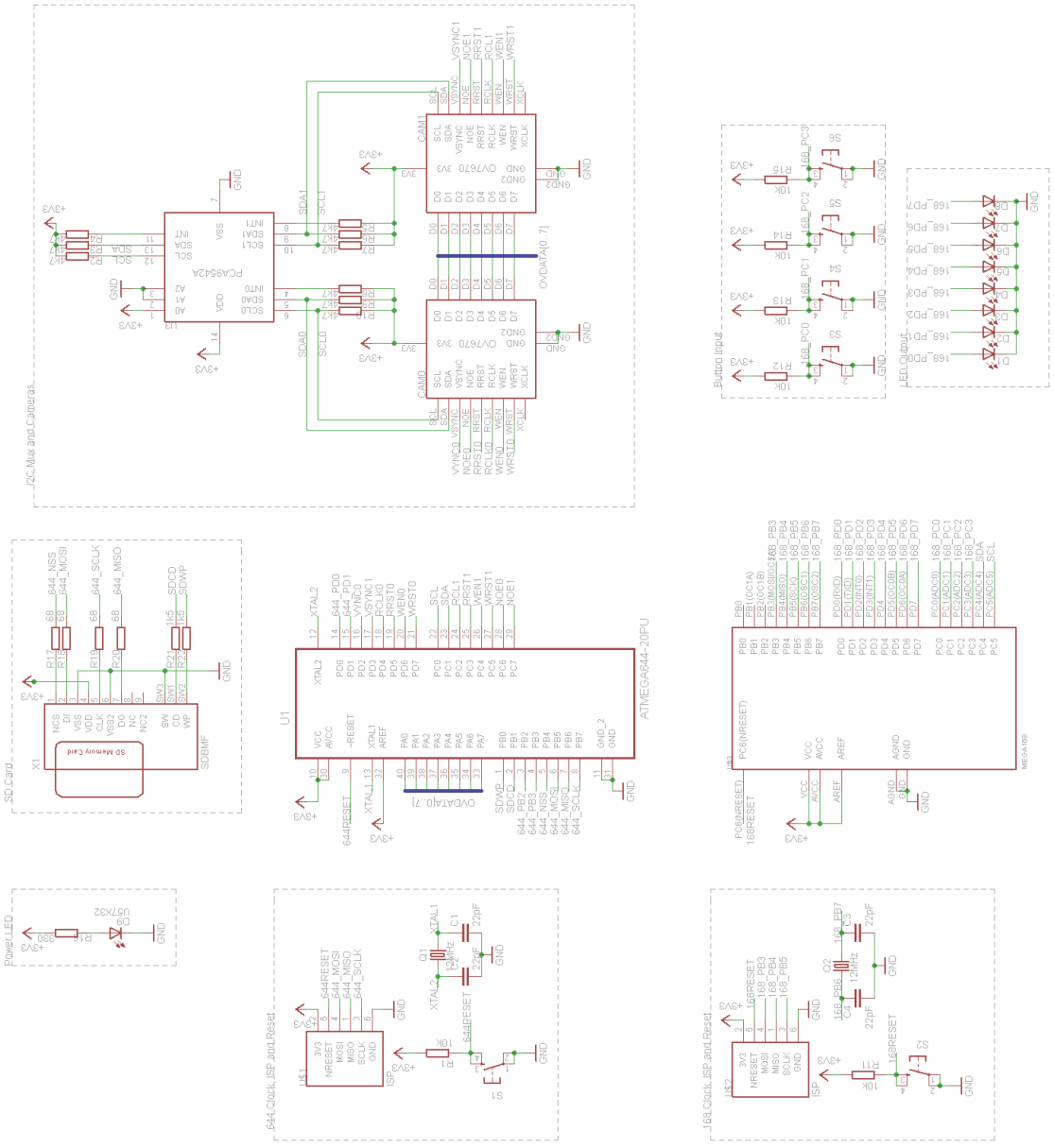


Figure B.2: The circuit diagram for Dual Cameras using the Il Matto Board

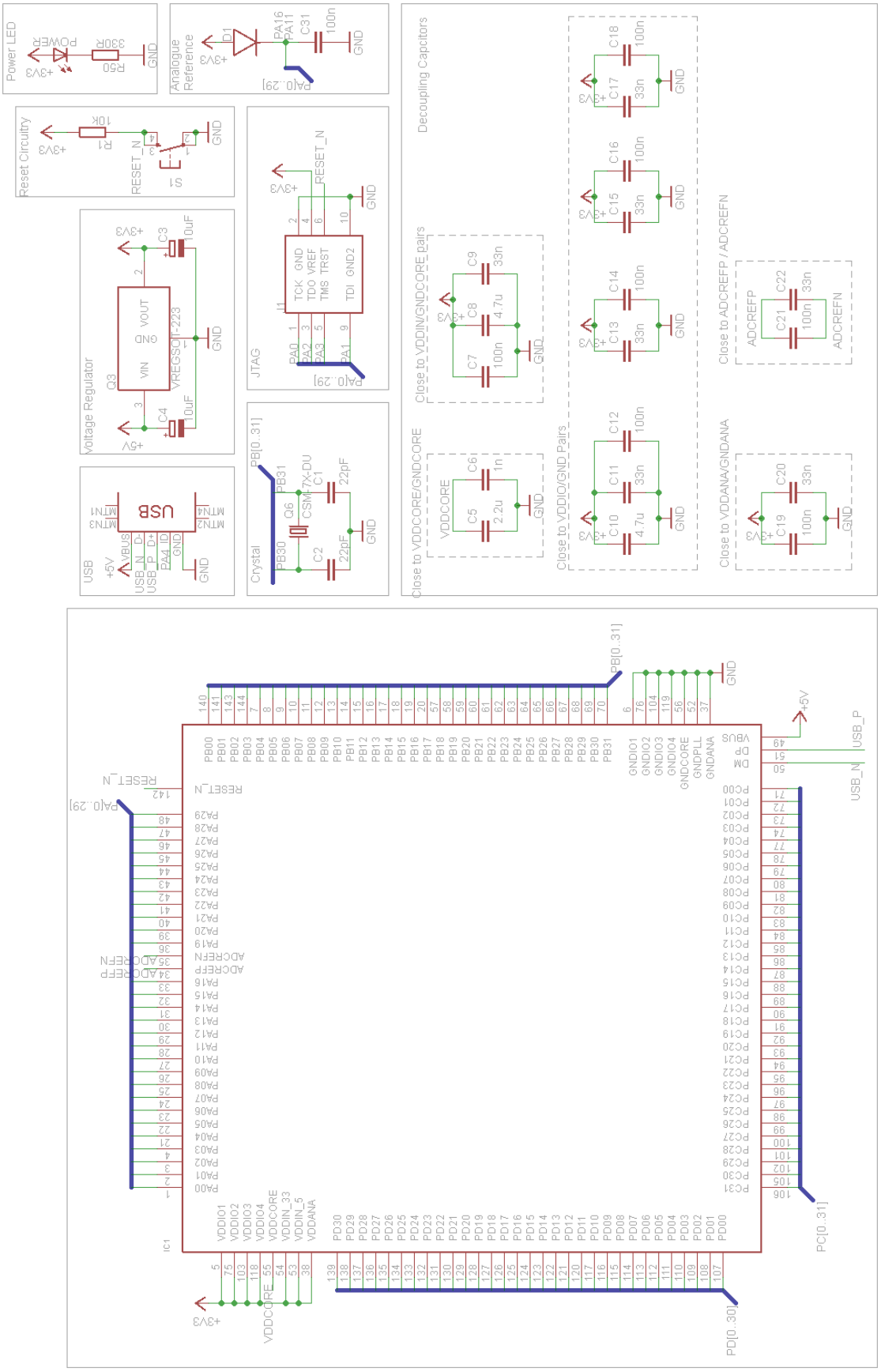


Figure B.3: The Columbus Circuit Diagram Page 1

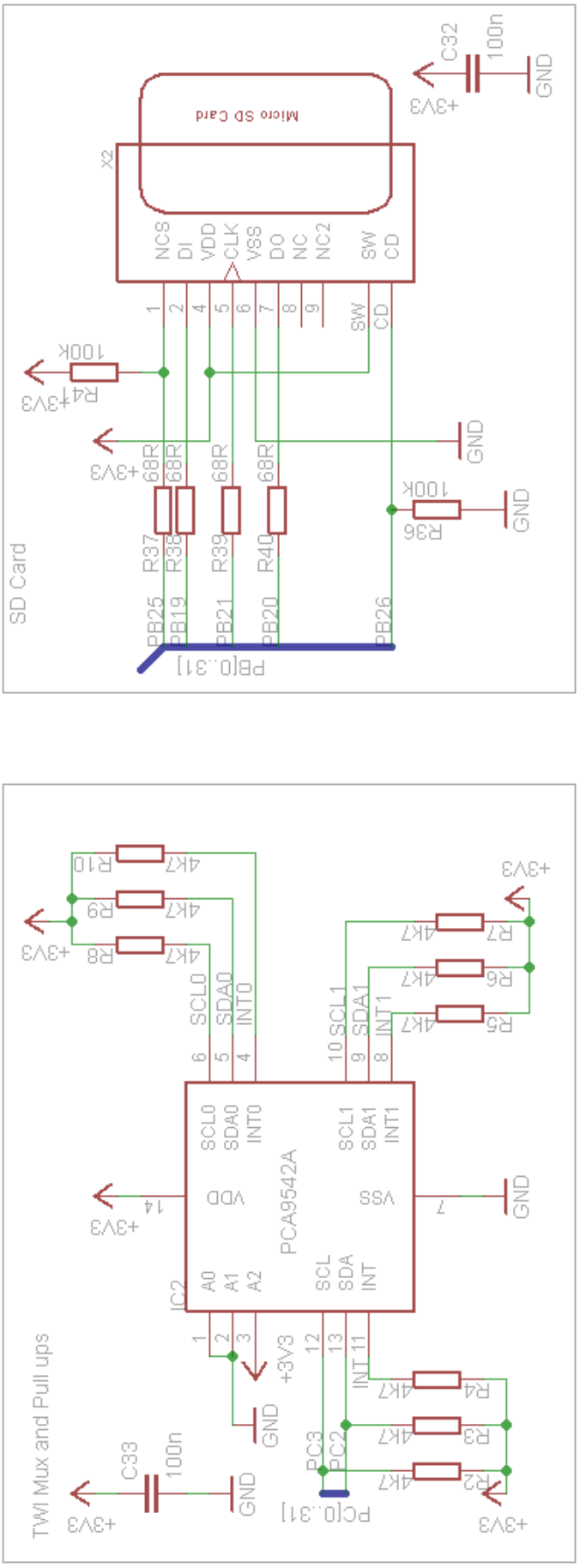


Figure B.4: The Columbus Circuit Diagram Page 2

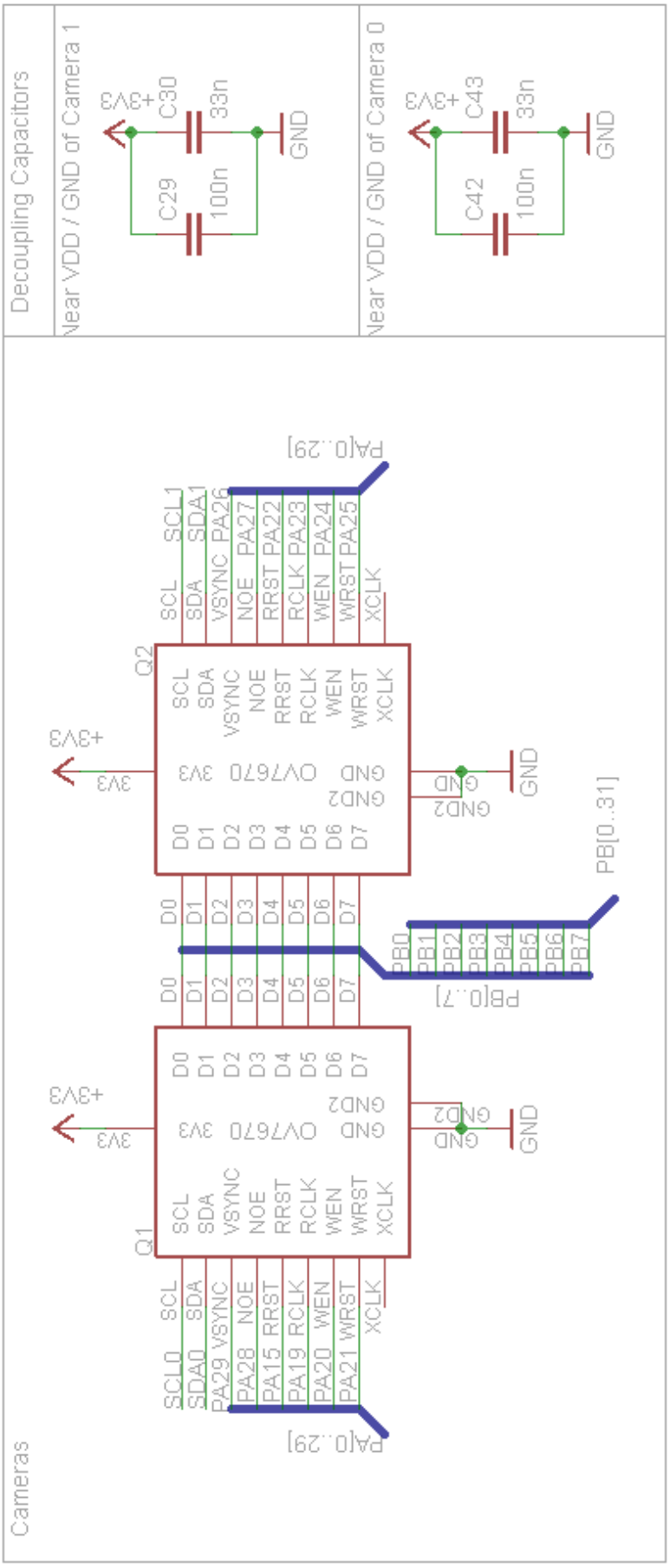


Figure B.5: The Columbus Circuit Diagram Page 3

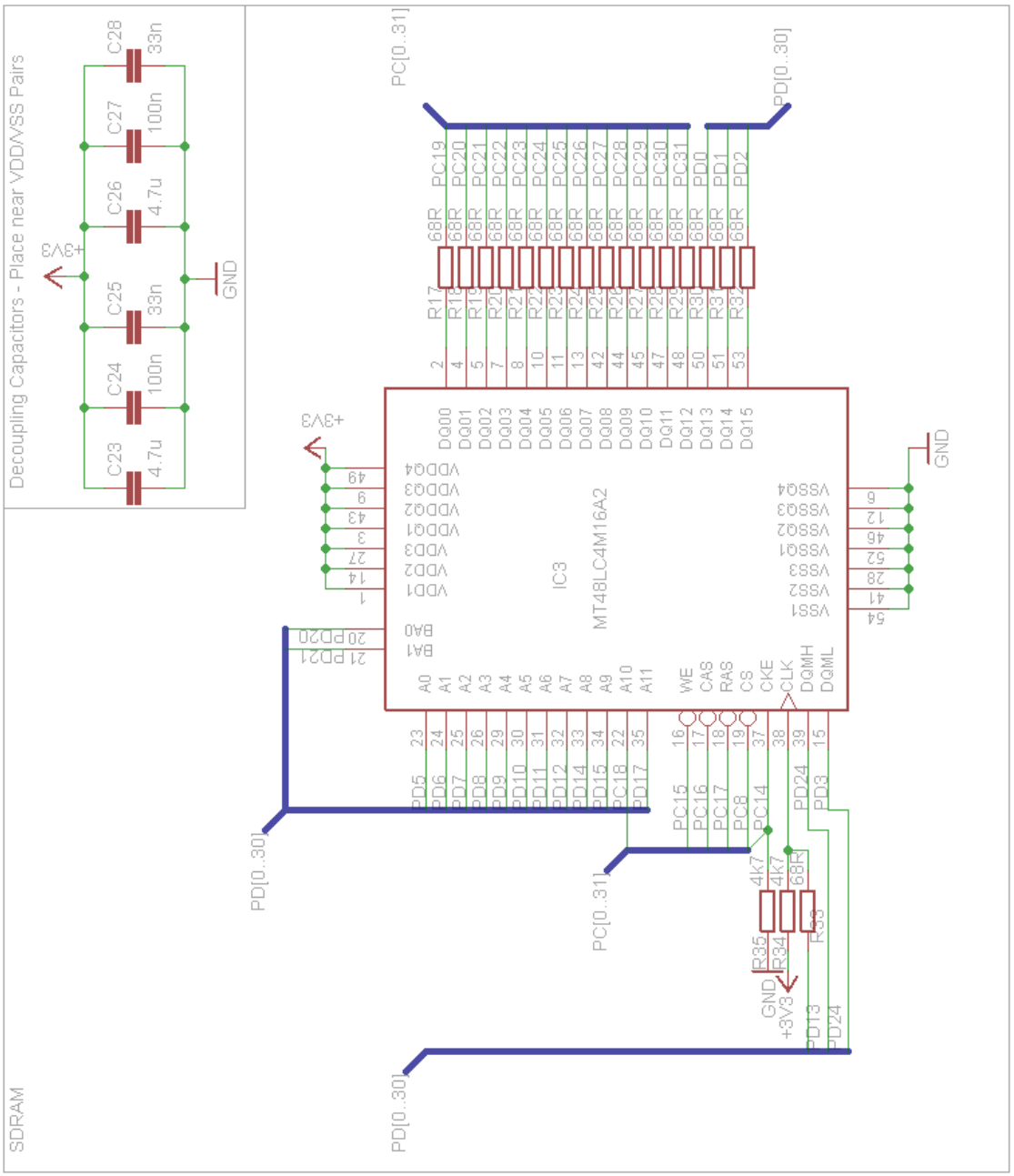


Figure B.6: The Columbus Circuit Diagram Page 4

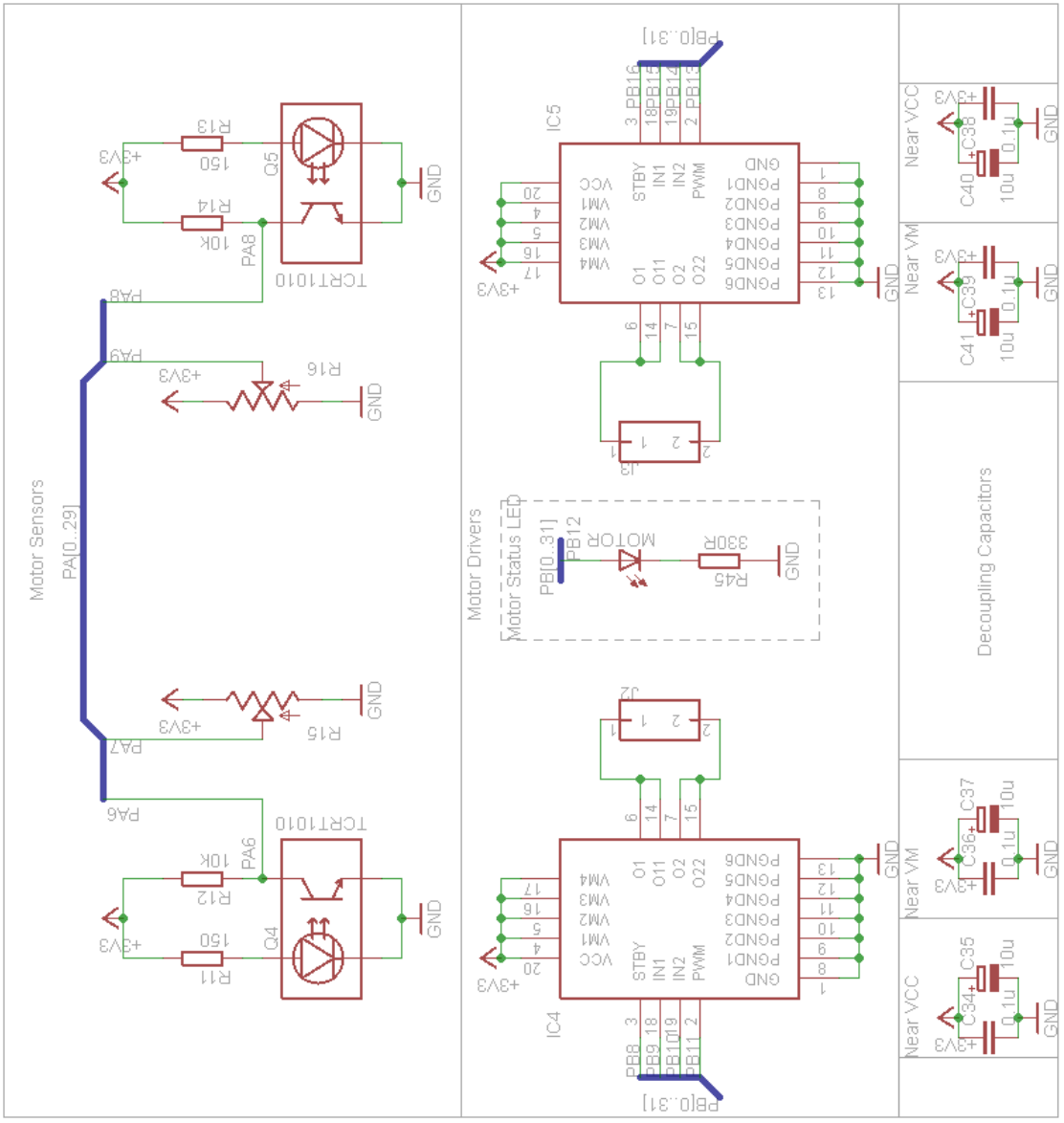


Figure B.7: The Columbus Circuit Diagram Page 5

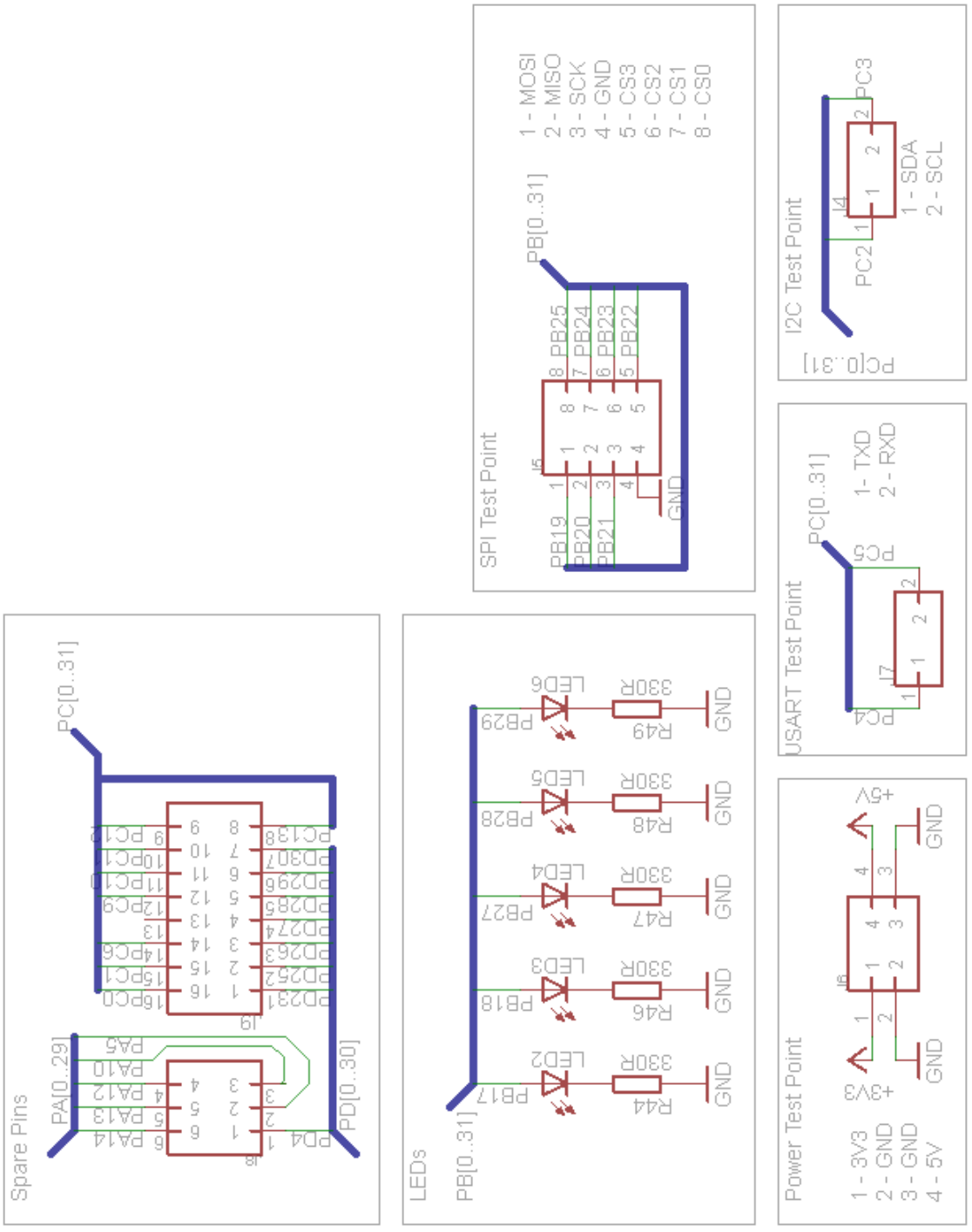


Figure B.8: The Columbus Circuit Diagram Page 6

Appendix C

Bitmap File Format

C.1 Bitmap File Format

Table C.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

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

Table C.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 C.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 D

Source Code

D.1 C Code for AVR

D.1.1 The Columbus Source Code

D.1.1.1 main.c

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

```
/**
 * \file
 *
 * \brief Empty user application template
 *
 */

/*
 * Include header files for all drivers that have been imported from
 * Atmel Software Framework (ASF).
 */
#define DSP32_FORMAT 24
#include <asf.h>
#include <conf_board.h>
#include "CustomDevices/CustomDevices.h"
#include "conf_sd_mmc_spi.h"
#include "fat.h"
#include "file.h"
#include "navigation.h"
#include "fastmath.h"
#include "delay.h"

//REF : http://www.chris.com/ASCII/index.php?art=transportation/nautical
#define ASCII_SHIP "\t\t\t             |    |    | \n\r \
\t\t\t           )_)  )_)  )_) \n\r \
```

```
\t\t\t           )___))___))___)\\  \n\r\
\t\t\t           )____)____)_____)\\\\ \n\r \
\t\t\t         _____|____|____|____\\\\\\__ \n\r \
\t\t\t---------\\                   /--------- \n\r \
\t\t\t  ^^^^^ ^^^^^^^^^^^^^^^^^^^^ \n\r \
\t\t\t    ^^^^      ^^^^     ^^^    ^^\n\r \
\t\t\t         ^^^^      ^^^\n\r"

 #define COLUMBUS " _______  _______  _                 _______  ______
         _______ \n\r(  ____ \\(  ___  )( \\      |\\     /|(       )(  ___ \\
     |\\     /|(  ____ \\\n\r| (    \\/| (   ) || (      | )   ( || () () || (
       ) )| )   ( || (    \\/\n\r| |      | |   | || |      | |   | || || ||
    || (__/ / | |   | || (_____ \n\r| |      | |   | || |      | |   | || |(_)
    | ||  __ (  | |   | |(_____  )\n\r| |      | |   | || |      | |   | || |
      | || (  \\ \\ | |   | |      ) |\n\r| (____/\\| (___) || (____/\\| (___)
     || )   ( || )___) )| (___) |/\\____) |\n\r(_______/(_______)(_______/(
    _______)|/     \\||______/ (_______)\\_______)\n\n\r"
#define THE "\t\t\t_________          _______ \n\r \t\t\t\\__   __/|\\     /|(
      ____ \\ \n\r \t\t\t   ) (   | )   ( || (    \\/\n\r\t\t\t   | |   | (___
    ) || (__    \n\r \t\t\t   | |   |  ___  ||  __)   \n\r \t\t\t   | |   | (
      ) || (      \n\r \t\t\t   | |   | )   ( || (____/\\\n\r \t\t\t   )_(
    |/     \\|(_______/\n\r"

#define PROMPT "\n\r$>"

#define HELP  "\n\rColumbus Prompt Help:\n\r\
        ? : Shows this prompt\n\r \
        c : converts the working buffer from integer to fixed point\n\r\
        D : Frees the Memory pointed to by the Working Buffer \n\r \
        r : displays the contents of the working buffer\n\r\
        R : Reads contents of signal.bin, representing 1D Signal. Integers,
    Big Endian\n\r\
        T : Reads contents of signal2d.bin, representing 2D Signal. \n\r \
        s : saves the working buffer\n\r\
        P : Takes and stores Stereo Photos \n\r \
        1 : computes the One Dimensional FFT of the working buffer. Returns
    magnitude.\n\r\
        2 : Computes the Two Dimensional FFT of the Working Buffer. \n\r \
        "

void Get_Line( char * CommandBuffer )
{
  int c = 0;

  while(c != 13)
  {
    c = usart_getchar(DBG_USART);
    if(c == '\b')
    {
      CommandBuffer--;
      *(CommandBuffer) = 0;
    }
    else
    {
      *(CommandBuffer) = c;
      CommandBuffer++;
    }
    print_dbg_char(c);
```

```
70    }
71    usart_putchar(DBG_USART, 6);
72  }

74  #define COMMAND_BUFFER_SIZE   32
75  int main (void)
76  {
77    Image_t image;
78    unsigned long i, j, tmp = 0;
79    char *Ptr;
80  //  volatile unsigned long *sdram = SDRAM;
81    char CommandBuffer[COMMAND_BUFFER_SIZE];
82    int *Working_Buffer = NULL;
83    int SizeOfWorking_Buffer = 0;
84    A_ALIGNED dsp16_complex_t *ComplexBuffer;
85    int SizeOfComplex_Buffer = 0;
86    Columbus_Status.SD_Card = &SD_Status;
87    Columbus_Status.Cameras = &OV7670_Status;
88    Columbus_Status.I2CMux = &PCA9542A;
89    Columbus_Status.SD_Card = &SD_Status;
90    Columbus_Status.Motors = &Motor_Control;
91    board_init();
92    print_dbg("\n\r");
93    print_dbg(THE);
94    print_dbg(COLUMBUS);
95    print_dbg(ASCII_SHIP);
96    System_Test();


99    //print_dbg("\n\rResetting Motors.");

101 //  Motors_Reset();
102 //  while(Motors_Moving() == true)
103 //    ;
104   if(Columbus_Status.Status != STATUS_OK)
105   {
106     while(1)
107     {
108       LED2_SET;
109       LED3_SET;
110       LED4_SET;
111       LED5_SET;
112       LED6_SET;
113       delay_ms(500);
114       LED2_CLR;
115       LED3_CLR;
116       LED4_CLR;
117       LED5_CLR;
118       LED6_CLR;
119       delay_ms(500);
120     }//inifinte loop
121   }


124   print_dbg("\n\rColumbus Ready!");
125   // Insert application code here, after the board has been initialized.
126   while(1)
127   {
```

```
128       print_dbg(PROMPT);
129       Get_Line(CommandBuffer);
130       Ptr = CommandBuffer;
131       switch(*Ptr++)
132       {
133         case '?':
134           print_dbg(HELP);
135           break;

137         case '1'://1d FFT (w/ memallocs)
138           print_dbg("\r1D FFT;");
139           FFT1D(Working_Buffer);
140           break;
141         case '2':
142           print_dbg("\r2D FFT;");
143           FFT2Dabs(Working_Buffer);
144           break;
145         case '3':
146           print_dbg("\rComplex FFT2D:");
147           SizeOfComplex_Buffer = FFT_SIZE * FFT_SIZE;
148           ComplexBuffer = mspace_malloc(sdram_msp,  SizeOfComplex_Buffer *
      sizeof(ComplexBuffer));
149           FFT2DCOMPLEX(Working_Buffer, ComplexBuffer, SizeOfWorking_Buffer);
150           break;

152         case 'B':
153           print_dbg("\rReading Bitmap;");
154           ReadBitmap("Image_R_0.bmp", &image);
155           print_dbg("\n\rBitmap Data Returned:\n\rImage Height = ");
156           print_dbg_ulong(image.Height);
157           print_dbg("\n\rImage Width = ");
158           print_dbg_ulong(image.Width);
159           break;

161         case 'c':
162           print_dbg("\rConverting Working Buffer to Fixed Point");
163           for(i = 0; i < SizeOfWorking_Buffer ; i++)
164           {
165             Working_Buffer[i] = DSP16_Q (Working_Buffer[i]);
166           }
167           break;

169         case 'C':
170           print_dbg("\rConverting Working Buffer back from Fixed Point");
171           j = DSP16_Q(1);
172           for(i = 0; i < SizeOfWorking_Buffer ; i++)
173           {
174             Working_Buffer[i] = Working_Buffer[i] / j;
175           }
176           break;

178         case 'D':
179           print_dbg("\rFreeing Working Buffer");
180           mspace_free(sdram_msp, Working_Buffer);
181           break;

183         case 'i':
184           print_dbg("\rImage info:");
```

```
185           print_dbg("\n\rImage Pointer = ");
186           print_dbg_ulong(image.ImagePtr);
187           print_dbg("\n\rImage Height = ");
188           print_dbg_ulong(image.Height);
189           print_dbg("\n\rImage Width = ");
190           print_dbg_ulong(image.Width);
191           break;

193         case 'I':
194           print_dbg("\rInverse Fourier Transform;");
195           IFFT2D(ComplexBuffer);
196           break;

198         case 'k':
199           print_dbg("\rComplex Buffer:\n\r[");
200           for (i = 0; i < SizeOfComplex_Buffer; i ++)
201           {
202             print_dbg_ulong(ComplexBuffer[i].real);
203             print_dbg(" + j");
204             print_dbg_ulong(ComplexBuffer[i].imag);
205             print_dbg(", ");
206           }
207           print_dbg("]\n\r");
208           break;
209         case 'M': //Motor Related
210           while(*Ptr == ' ')
211             Ptr++; //Find next non - space char

213           switch(*(Ptr++))
214           {
215             case 'q': // Reset Motors
216               print_dbg("\rResetting Motors");
217               Motors_Reset();
218               break;

220             case 'F': //Move Forward
221               while(*Ptr == ' ')
222                 Ptr++; //Find next non - space char
223               i = atoi(Ptr);
224               Motors_Move(i);
225               break;
226             case 'T':
227               while(*Ptr == ' ')
228               Ptr++; //Find next non - space char
229               i = atoi(Ptr);
230               Motors_Rotate(i);
231               break;
232             case 'l':
233               Motor_Stop(MOTOR_L);
234               break;
235             case 'L':
236               Columbus_Status.Motors->Left_Count = INTERRUPTS_PER_REVOLUTION +
    1;
237               Columbus_Status.Motors->Left_State = FORWARD;
238               Motor_Start(MOTOR_L);
239               Motors_Execute();
240               break;
241             case 'r':
```

```
242             Motor_Stop(MOTOR_R);
243             break;
244           case 'R':
245             Columbus_Status.Motors->Right_Count = INTERRUPTS_PER_REVOLUTION +
      1;
246             Columbus_Status.Motors->Right_State = FORWARD;
247             Motor_Start(MOTOR_R);
248             Motors_Execute();
249             break;
250           default:
251             print_dbg("\rCommand Not Recognised");
252             break;
253         }

255         break;

257       case 'p':
258         print_dbg("\rPreparing Image;");
259         PrepareImage(&image);
260         print_dbg("\rImage Prepared!");
261         break;

263       case 'P'://take a photo
264         FIFO_Reset(CAMERA_LEFT | CAMERA_RIGHT);
265         print_dbg("\rTaking Photos");
266         if(TakePhoto(CAMERA_LEFT | CAMERA_RIGHT) == CAMERAS_BUSY){
267           print_dbg("Cameras Busy");
268           break;
269         }
270         while(Photos_Ready() == false)
271           ;

273         if(Store_Both_Images() == true)
274           print_dbg("\n\rImages Stored Successfully!");
275         break;

277       case 'r':
278         if (Working_Buffer == 0)
279         {
280           print_dbg("\rWorking Buffer Not Initialised");
281           break;
282         }
283         print_dbg("\rWorking Buffer:\n\r[");
284         for(i = 0; i < SizeOfWorking_Buffer; i++)
285         {
286           print_dbg_ulong(Working_Buffer[i]);
287           print_dbg(", ");
288         }
289         print_dbg("\b\b]\n\r");
290         break;
291       case 'R':
292         Working_Buffer = mspace_malloc(sdram_msp, FFT_SIZE);
293         SizeOfWorking_Buffer = FFT_SIZE;
294         print_dbg("\rReading in signal.bin");
295         ReadSignal(Working_Buffer);
296         break;

298       case 's'://save the working buffer
```

```
299           print_dbg("\rSaving Working Buffer;");
300           SaveBuff(Working_Buffer, SizeOfWorking_Buffer);
301           break;

303         case 'S':
304           print_dbg("\rSaving Bitmap;");
305           SaveBitmap(image.ImagePtr, image.Width, image.Height, "ResavedImage.
      bmp");
306           print_dbg("\rSaved Bitmap!;");
307           break;

309         case 'T':
310           print_dbg("\rReading in 2D Signal");
311           Working_Buffer = mspace_malloc(sdram_msp, FFT_SIZE * FFT_SIZE);
312           SizeOfWorking_Buffer = FFT_SIZE * FFT_SIZE;
313           Read2DSignal(Working_Buffer);
314           break;
315         case 'v':
316           print_dbg("\rColumbus Status:");
317           print_dbg("\n\rSD Card:\n\rStatus: ");
318           print_dbg_ulong(Columbus_Status.SD_Card->Status);
319           print_dbg("\n\rMemory Size : ");
320           print_dbg_ulong(Columbus_Status.SD_Card->Memory_size);
321           print_dbg("\n\rMotors:");
322           print_dbg("\n\rLeft State : ");
323           print_dbg_ulong(Columbus_Status.Motors->Left_State);
324           print_dbg("\n\rLeft Count : ");
325           print_dbg_ulong(Columbus_Status.Motors->Left_Count);
326           print_dbg("\n\rRight State : ");
327           print_dbg_ulong(Columbus_Status.Motors->Right_State);
328           print_dbg("\n\rRight Count : ");
329           print_dbg_ulong(Columbus_Status.Motors->Right_Count);
330           print_dbg("\n\rCameras:");
331           print_dbg("\n\rStatus : ");
332           print_dbg_ulong(Columbus_Status.Cameras->Status);
333           print_dbg("\n\rVSYNC0 State : ");
334           print_dbg_ulong(Columbus_Status.Cameras->VSYNC0_State);
335           print_dbg("\n\rVSYNC1 State : ");
336           print_dbg_ulong(Columbus_Status.Cameras->VSYNC1_State);
337           print_dbg("\n\rI2C Mux:");
338           print_dbg("\n\rStatus : ");
339           print_dbg_ulong(Columbus_Status.I2CMux->Status);
340           print_dbg("\n\rChannel Selected : ");
341           print_dbg_ulong(Columbus_Status.I2CMux->ChannelSelected);
342           break;

344 //        case 'o'://testing storing a complex
345 //          print_dbg("\rFreeing Complex Buffer");
346 //          mspace_free(sdram_msp, ComplexBuffer);
347 //          print_dbg("\n\rAssiging Space to the Complex Buffer;");
348 //          SizeOfComplex_Buffer = 10;
349 //          ComplexBuffer = mspace_malloc(sdram_msp, 10*sizeof(ComplexBuffer));
350 //          if(ComplexBuffer == NULL)
351 //          {
352 //            print_dbg("\n\rAssign Failed;");
353 //            break;
354 //          }
355 //          for(i = 0; i < SizeOfComplex_Buffer; i++)
```

```
356 //         {
357 //           ComplexBuffer[i].imag = i;
358 //           ComplexBuffer[i].real = i;
359 //         }
360 //         for(i = 0; i < SizeOfComplex_Buffer; i ++)
361 //         {
362 //           print_dbg("\n\r");
363 //           print_dbg_ulong(ComplexBuffer[i].real);
364 //           print_dbg(" + j");
365 //           print_dbg_ulong(ComplexBuffer[i].imag);
366 //         }
367 //         print_dbg("\n\rFreeing Complex Buffer");
368 //         mspace_free(sdram_msp, ComplexBuffer);
369 //         SizeOfComplex_Buffer = 0;
370 //         break;

372       default:
373         print_dbg("\rCommand Not Recognised;");
374         break;
375     }
376   }
377 }
```

D.1.1.2 Bitmap.c

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

```
1  /*
2   * Bitmap.c
3   *
4   * Created: 16/02/2013 23:14:34
5   *  Author: hslovett
6   */
7  #include "CustomDevices/CustomDevices.h"

9  const uint8_t DIBHead[DIBHEADERSIZE] = {  0x7C, 0x00, 0x00, 0x00, //Number of
       bytes
10                 0x40, 0x01, 0x00, 0x00, //Width - 320
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
```

```
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Colour Space Endpoints
                    0x00, 0x00, 0x00, 0x00, //Gamma Red
                    0x00, 0x00, 0x00, 0x00, //Gamma Green
                    0x00, 0x00, 0x00, 0x00, //Gamma Blue
                    0x03, 0x00, 0x00, 0x00, //Intent - Photo
                    0x00, 0x00, 0x00, 0x00, //ICC Profile Data
                    0x00, 0x00, 0x00, 0x00, //ICC Profile Size
                    0x00, 0x00, 0x00, 0x00}; //Reserved

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

D.1.1.3 CustomDevices.h

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

```
/*
 * CustomDevices.h
 *
 * Created: 16/02/2013 14:30:50
 *  Author: hslovett
 */


#ifndef CUSTOMDEVICES_H_
#define CUSTOMDEVICES_H_

//Camera
#include "CustomDevices/OV7670.h"
//I2C Mux
#include "CustomDevices/PCA9542A.h"
//MotorDriver
#include "CustomDevices/MotorDriver.h"
//SDCard
#include "CustomDevices/SD_Card.h"
//Image Processing Functions
#include "CustomDevices/ImageProcessor.h"

typedef struct {
  int Status;
  SD_Status_t *SD_Card;
  Motor_Control_t *Motors;
  OV7670_t *Cameras;
  PCA9542A_t *I2CMux;
} Columbus_Status_t;
```

```
#define SD_ERR     0x1
#define CAM_ERR    0x2
#define I2CMux_ERR  0x4

#define FFT_SIZE 16

mspace sdram_msp;
Columbus_Status_t Columbus_Status;
//TWI Methods
void twim_init (void);
void System_Test();
#endif /* CUSTOMDEVICES_H_ */
```

D.1.1.4 dummy.c

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

```
"
    xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
    "
```

D.1.1.5 ImageProcessor.h

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

```
/*
 * ImageProcessor.h
 *
 * Created: 28/02/2013 17:46:37
 *  Author: hslovett
 */


#ifndef IMAGEPROCESSOR_H_
#define IMAGEPROCESSOR_H_

#define BMP_FORMAT_RGB565     1
#define BMP_FORMAT_RGB555     2
#define BMP_FORMAT_GREYSCALE    3
#define BMP_FORMAT_1xUINT     4
#define BMP_FORMAT_2xUINT8T     5
typedef struct {
  uint16_t *ImagePtr;
  int Height;
  int Width;
  uint8_t Format;
  } Image_t;
```

```
26 int FFT1D(int *Signal);
27 int FFT2Dabs(int *Signal);
28 int log_2(int i);
29
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 #endif /* IMAGEPROCESSOR_H_ */
```

D.1.1.6 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"
9
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
       established this is a integer power of 2)
20   {
21     i >>= 1;
22     ret++;
23   }
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 reult 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      }

66      //Do Fourier
67      dsp16_trans_complexfft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
68      //Copy back
69      for(j = 0; j < FFT_SIZE; j++){
70        ComplexBuffer[i + j * FFT_SIZE].imag =  Result_C_1D[j].imag;
71        ComplexBuffer[i + j * FFT_SIZE].real =  Result_C_1D[j].real;
72      }
73    }
74    return;
75  }

77  //One Dimensional Fast Fourier Transform
78  int FFT1D( int *Signal)
79  {
80  //  int size = 64;
81    int log2Size, i =0;
82  //  double a;
83  //  log2Size = log_2(size);
84  //  if(log2Size & 1) //if it is an odd power of two
85  //    return 0;

87    //am I making this all too complex for myself?! May just stick to defined
      size of 256.
88  //  A_ALIGNED dsp32_complex_t *vect1;
89  //  A_ALIGNED dsp32_t *vect2;

91  //  vect1 = mspace_malloc(sdram_msp, (sizeof(dsp32_complex_t) * size));
92  //  vect2 = mspace_malloc(sdram_msp, (sizeof(dsp32_t) * size));

94    //Defined Sizes
```

```
96    A_ALIGNED dsp16_complex_t vect1[FFT_SIZE];
97    A_ALIGNED dsp16_t vect2[FFT_SIZE];
98    for(i = 0; i < FFT_SIZE; i++)
99    {
100     vect2[i] = Signal[i];
101   }
102   dsp16_trans_realcomplexfft(vect1, vect2, log_2(FFT_SIZE));
103   dsp16_vect_complex_abs(vect2, vect1, FFT_SIZE);
104   for(i = 0; i < FFT_SIZE; i++)
105   {
106     Signal[i] = vect2[i] * FFT_SIZE;
107   }
108 //  mspace_free(sdram_msp, vect1);
109 //  mspace_free(sdram_msp, vect2);
110   return Signal;
111 }

113 int FFT2Dabs( int *Signal )
114 {
115   int i, j = 0;
116   int Ptr;
117   Ptr = 0;
118   A_ALIGNED dsp16_complex_t Input_C_1D[FFT_SIZE];
119   A_ALIGNED dsp16_complex_t Result_C_1D[FFT_SIZE];
120   A_ALIGNED dsp16_complex_t Result_C_2D[FFT_SIZE*FFT_SIZE];
121   A_ALIGNED dsp16_t Input_R_1D[FFT_SIZE];

123   //Stage 1 - FFT Real values from Signal. Store VERTICALLY in Result_2D
124   for(i = 0; i < FFT_SIZE; i ++) //for each row
125   {
126 //    print_dbg("\n\rInput to FFT: \n\r[");
127     for(j = 0; j < FFT_SIZE; j++)
128     {
129       Input_R_1D[j] = Signal[Ptr++]; //copy the data across
130 //      print_dbg_ulong(Input_R_1D[j]);
131 //      print_dbg(", ");
132     }
133 //    print_dbg("\b\b]");
134     //Do the FFT
135     dsp16_trans_realcomplexfft(Result_C_1D, Input_R_1D, log_2(FFT_SIZE));
136     //Copy data into 2D reult TRANSPOSED
137 //    print_dbg("\n\rOutput of FFT:\n\r[");
138     for(j = 0; j < FFT_SIZE; j++)
139     {
140       Result_C_2D[i + (j * FFT_SIZE)].imag = Result_C_1D[j].imag * FFT_SIZE;//
    scale back up
141       Result_C_2D[i + (j * FFT_SIZE)].real = Result_C_1D[j].real * FFT_SIZE;
142 //      print_dbg_ulong(Result_C_2D[i + (j * FFT_SIZE)].real);
143 //      print_dbg(" + j");
144 //      print_dbg_ulong(Result_C_2D[i + (j * FFT_SIZE)].imag);
145 //      print_dbg(" , ");
146     }
147 //    print_dbg("\b\b]");
148   }
149   //Stage 2 - FFT Complex Values from Result_2D, put back into Rows

151   for(i = 0; i < FFT_SIZE; i++)//for each row
152   {
```

```
153 //    print_dbg("\n\rInput to FFT: \n\r[");
154     for(j = 0; j < FFT_SIZE; j++)//copy the data across
155     {
156       Input_C_1D[j].imag = Result_C_2D[j + i * FFT_SIZE].imag;
157       Input_C_1D[j].real = Result_C_2D[j + i * FFT_SIZE].real;
158 //      print_dbg_ulong(Input_C_1D[j].real);
159 //      print_dbg(" + j");
160 //      print_dbg_ulong(Input_C_1D[j].imag);
161 //      print_dbg(" , ");
162     }
163 //    print_dbg("\b\b]");
164     //Do Fourier
165     dsp16_trans_complexfft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
166     //Copy back

168 //    print_dbg("\n\rOutput to FFT: \n\r[");
169 //    for(j = 0; j < FFT_SIZE; j++)//copy the data across
170 //    {
171 //      print_dbg_ulong(Result_C_1D[j].real);
172 //      print_dbg(" + j");
173 //      print_dbg_ulong(Result_C_1D[j].imag);
174 //      print_dbg(" , ");
175 //    }
176 //    print_dbg("\b\b]");
177     //Calculate Abs and put back into Signal TRANSPOSED
178     dsp16_vect_complex_abs(Input_R_1D, Result_C_1D, FFT_SIZE);

180     for(j = 0; j < FFT_SIZE; j++)
181     {
182       Signal[i + (j*FFT_SIZE)] = Input_R_1D[j] * FFT_SIZE;
183     }
184   }
185   return Signal;
186 }




191 void PrepareImage(Image_t *Image)
192 {
193   int row, col;
194   uint16_t *PreparedImage;
195   //Allocate some memory in the RAM
196   PreparedImage = mspace_malloc(sdram_msp, 256*256 );

198   //print_dbg("\n\rPrepared Image Pointer = ");
199   //print_dbg_ulong(PreparedImage);
200   for(row = 0; row < 256; row ++)
201   {
202     for(col = 0; col < 256; col++)
203     {
204       if(row < 240)
205         PreparedImage[row*256 + col] = Image->ImagePtr[row * 256 + col];
206       else
207         PreparedImage[row *256 + col] = 0;//Image->ImagePtr[(row - 240) * 256
    + col + 32];
208     }
209   }
```

```
211   mspace_free(sdram_msp, Image->ImagePtr); //free up the old image
212   Image->ImagePtr = PreparedImage; //move the pointer to the prepared image
213   Image->Height = 256;
214   Image->Width = 256;
215   //SaveBitmap(PreparedImage, 256, 256, "PreparedImage.bmp");
216   //mspace_free(sdram_msp, PreparedImage);
217   //return PreparedImage;
218 }


221 //**********************************
222 // Method:    IFFT2D
223 // FullName:  IFFT2D
224 // Access:    public
225 // Returns:   void
226 // Qualifier:
227 // Parameter: dsp16_complex_t * Signal
228 //**********************************
229 void IFFT2D (dsp16_complex_t *Signal) //Need to test this!
230 {
231   int i, j = 0;
232   int Ptr;
233   Ptr = 0;
234   A_ALIGNED dsp16_complex_t Input_C_1D[FFT_SIZE];
235   A_ALIGNED dsp16_complex_t Result_C_1D[FFT_SIZE];
236   A_ALIGNED dsp16_complex_t Result_C_2D[FFT_SIZE*FFT_SIZE];
237   A_ALIGNED dsp16_t Input_R_1D[FFT_SIZE];


240   //Stage 1 - FFT Real values from Signal. Store VERTICALLY in Result_2D
241   for(i = 0; i < FFT_SIZE; i ++) //for each row
242   {
243     for(j = 0; j < FFT_SIZE; j++)
244     {
245       Input_C_1D[j].real = Signal[Ptr].real; //copy the data across
246       Input_C_1D[j].imag = Signal[Ptr].imag;
247     }

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

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

259   }
260   //Stage 2 - FFT Complex Values from Result_2D, put back into Rows


263   for(i = 0; i < FFT_SIZE; i++)//for each row
264   {

266     for(j = 0; j < FFT_SIZE; j++)//copy the data across
```

```
267     {
268       Input_C_1D[j].imag = Result_C_2D[j + i * FFT_SIZE].imag;
269       Input_C_1D[j].real = Result_C_2D[j + i * FFT_SIZE].real;

271     }

273     //Do Fourier
274     dsp16_trans_complexifft(Result_C_1D, Input_C_1D, log_2(FFT_SIZE));
275     //Copy back


278     //Put back into Signal TRANSPOSED
279     //dsp16_vect_complex_abs(Input_R_1D, Result_C_1D, FFT_SIZE);

281     for(j = 0; j < FFT_SIZE; j++)
282     {
283       Signal[i + j * FFT_SIZE].imag =   Result_C_1D[j].imag;
284       Signal[i + j * FFT_SIZE].real =   Result_C_1D[j].real;
285       //Signal[i + (j*FFT_SIZE)] = Input_R_1D[j] * FFT_SIZE;
286     }
287   }

289   //return Signal;
290 }

292 void ComplexMultiply(dsp16_complex_t *Result_Input1, dsp16_complex_t *Input2,
      int size)
293 {
294   int i = 0;
295   dsp16_complex_t c;
296   for(i = 0; i < size; i++)
297   {
298     //(a+jb).(c+jd) = (ac - bd) + j(ad + bc)
299     c.real = (Result_Input1[i].real * Input2[i].real) - (Result_Input1[i].imag
       * Input2[i].imag);
300     c.imag = (Result_Input1[i].real * Input2[i].imag) + (Result_Input1[i].imag
       * Input2[i].real);
301     Result_Input1[i].imag = c.imag;
302     Result_Input1[i].real = c.real;
303   }
304 }
```

D.1.1.7 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  */
```

```
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

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


24 #define ENABLE_ACA_INTERRUPT    //{AVR32_ACIFA1.ier = 1;}
25 #define DISABLE_ACA_INTERRUPT   //{AVR32_ACIFA1.idr = 1;}
26 #define ENABLE_ACB_INTERRUPT    //{AVR32_ACIFA1.ier = 2;}
27 #define DISABLE_ACB_INTERRUPT   //{AVR32_ACIFA1.idr = 2;}
28 #define INTERRUPTS_PER_REVOLUTION 5 //Interrupts caused per full rotation of a
       wheel
29 #define CIRCUMFERENCE_WHEEL_MM    116 //in millimeters
30 #define CIRCUMFERENCE_WHEEL_CM    12 //in centimeters
31 #define MIN_RESOLUTION        CIRCUMFERENCE_WHEEL_CM /
      INTERRUPTS_PER_REVOLUTION
32 #define C_ROT_MM          276
33 #define ROTATION_CONST        (INTERRUPTS_PER_REVOLUTION * C_ROT_MM) / (
      CIRCUMFERENCE_WHEEL_MM * 360)
34 //Type Defs
35 typedef struct {
36   int Left_State;
37   int Right_State;
38   int Left_Count;
39   int Right_Count;
40   } Motor_Control_t;

42 //Globals
43 pwm_opt_t pwm_opt;                // PWM option config.
44 avr32_pwm_channel_t pwm_channel;
45 Motor_Control_t Motor_Control;

47 void Motor_Init();
48 void Motor_Go();
49 void Analogue_Comparator_Init();
50 void Motor_Start(int Motors);
51 void Motors_Reset(void);
52 void Motor_Stop(int Motors);
53 bool Motors_Moving();
54 void Motors_Move(int centimetres_fwd)/*Move this amount forward in centimeters
       */;
55 void Motors_Execute();
56 void Motors_Rotate(int angle_degs);
57 /*static void ACInterruptHandler(void);*/
58 #endif /* MOTORDRIVER_H_ */
```

D.1.1.8 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"*/



21 static void local_start_highfreq_clock(void)
22 {
23   const scif_pll_opt_t opt = {
24             .osc = SCIF_OSC0,      // Sel Osc0/PLL0 or Osc1/PLL1
25             .lockcount = 16,       // lockcount in main clock for the PLL wait
       lock
26             .div = 1,              // DIV=1 in the formula
27             .mul = 6,              // MUL=7 in the formula
28             .pll_div2 = 1,         // pll_div2 Divide the PLL output frequency
       by 2 (this settings does not change the FVCO value)
29             .pll_wbwdisable = 0,  // pll_wbwdisable 1 Disable the Wide-Bandith
        Mode (Wide-Bandwith mode allow a faster startup time and out-of-lock time
       ). 0 to enable the Wide-Bandith Mode.
30             .pll_freq = 1,         // Set to 1 for VCO frequency range 80-180
       MHz, set to 0 for VCO frequency range 160-240Mhz.
31   };
32   // Switch main clock to Osc0.
33 //  pcl_switch_to_osc(PCL_OSC0, FOSC0, OSC0_STARTUP);

35   /* Setup PLL0 on Osc0, mul=7 ,no divisor, lockcount=16, ie. (16Mhzx7)/(div2)
        = 56MHz output */
36   scif_pll_setup(SCIF_PLL0, &opt); // lockcount in main clock for the PLL wait
        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;
67
68    ML_IN1_CLR;
69    ML_IN2_CLR;
70
71    MR_IN1_CLR;
72    MR_IN2_CLR;
73
74    Motor_Control.Left_Count = 0;
75    Motor_Control.Right_Count = 0;
76    Motor_Control.Left_State = STOP;
77    Motor_Control.Right_State = STOP;
78
79    avr32_pwm_channel_t pwm_channel = {{0}, // cmr
80                        {0}, // cdty
81                        {0}, // cdtyupd
82                        {0}, // cprd
83                        {0}, // cprdupd
84                        {0}, // ccnt
85                        {0}, // dt
86                        {0}};// dtupd  ;  One channel config.
87  /*  unsigned int channel_id;*/
88
89    // Start PLL for PWM
90    local_start_highfreq_clock();
91    // Start Enable Generic Clock with PLL as source clock
92    pwm_start_gc();
93
94
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); //
        PWM1 Low
99    gpio_enable_module_pin(ML_PWM_H_PIN, ML_PWM_H_FUNCTION);
100   gpio_enable_module_pin(MR_PWM_H_PIN, MR_PWM_H_FUNCTION); //PWM1 Low
101   //gpio_enable_module_pin(M1_PWM_H_PIN, M1_PWM_H_FUNCTION);
102   // PWM controller configuration.
103   pwm_opt.diva = AVR32_PWM_DIVA_CLK_OFF;
```

```
104    pwm_opt.divb = AVR32_PWM_DIVB_CLK_OFF;
105    pwm_opt.prea = AVR32_PWM_PREA_CCK;
106    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  =
         PWM_SYNC_UPDATE_MANUAL_WRITE_MANUAL_UPDATE;
111    pwm_opt.sync_channel_select[0]    = false;
112    pwm_opt.sync_channel_select[1]    = false;
113    pwm_opt.sync_channel_select[2]    = false;
114    pwm_opt.sync_channel_select[3]    = false;
115    pwm_opt.cksel                     = PWM_CKSEL_GCLK;
116    pwm_init(&pwm_opt);

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

121    // Channel configuration
122    pwm_channel.CMR.dte    = 0;        // Enable Deadtime for complementary Mode
123    pwm_channel.CMR.dthi   = 0;        // Deadtime Inverted on PWMH
124    pwm_channel.CMR.dtli   = 0;        // Deadtime Not Inverted on PWML
125    pwm_channel.CMR.ces    = 0;        // 0/1 Channel Event at the End of PWM
         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.cdty       = 50;       // Channel duty cycle, should be < CPRD.
130    pwm_channel.cprd       = 200;       // Channel period.

132  /*  channel_id = M0_PWM_CHANNEL_ID;*/
133    pwm_channel_init(ML_PWM_CHANNEL_ID, &pwm_channel); // Set channel
         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
         configuration to channel 0
137    //pwm_start_channels((1 << channel_id));  // Start channel 0 & 1.
138    Analogue_Comparator_Init();
139  }
140  __attribute__((__interrupt__)) static void ACInterruptHandler(void)
141  {
142    //print_dbg("\n\rACIFA Interrupt Entered.");
143    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
          movement on left wheel
175       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     {POT0_AC1AP1_PIN, POT0_AC1AP1_FUNCTION},
189     {POT1_AC1BP1_PIN, POT1_AC1BP1_FUNCTION},
190     {SENSE0_AC1AN1_PIN, SENSE0_AC1AN1_FUNCTION},
191     {SENSE1_AC1BN1_PIN, SENSE1_AC1BN1_FUNCTION},
192     };
194     gpio_enable_module(ACIFA_GPIO_MAP, sizeof(ACIFA_GPIO_MAP) / sizeof(
          ACIFA_GPIO_MAP[0]));
195     //Make it an interrupt
196     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     POT0_AC1AP1_INPUT,
203     SENSE0_AC1AN1_INPUT,
204     FOSC0);
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     FOSC0);
213     //    //Reset Wheels
```

```
214     /*    Motor_Go(FORWARD);*/
215     //M0_IN1_CLR;
216     //    M1_IN1_CLR;
217     //    while(acifa_is_aca_inp_higher(&AVR32_ACIFA1) == false)
218     //      ;
219     //    M0_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 <<
          AVR32_ACIFA_ACAINT));//Enable ACBINT and ACAINT
229     ENABLE_ACA_INTERRUPT;
230     ENABLE_ACB_INTERRUPT;
231     AVR32_ACIFA1.ier = 3; //enable interrupts
232     //acifa_enable_interrupt_toggle(&AVR32_ACIFA1, ACIFA_COMP_SELA);
233     //acifa_enable_interrupt_toggle(&AVR32_ACIFA1, ACIFA_COMP_SELB);
234     acifa_enable_interrupt_inp_lower(&AVR32_ACIFA1, ACIFA_COMP_SELA);
235     acifa_enable_interrupt_inp_lower(&AVR32_ACIFA1, ACIFA_COMP_SELB);
236     acifa_start(&AVR32_ACIFA1, (ACIFA_COMP_SELA|ACIFA_COMP_SELB));




241     INTC_register_interrupt(&ACInterruptHandler,AVR32_ACIFA1_IRQ ,
          AVR32_INTC_INT0);

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     }

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     }

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) / (
          int)CIRCUMFERENCE_WHEEL_CM;
335     print_dbg("\n\rNumber of interrupts to move = ");
336     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   }

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

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

D.1.1.9 OV7670.h

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

```
/*
 * OV7670.h
 *
 * Created: 15/02/2013 13:12:00
 *  Author: hslovett
 */


#ifndef OV7670_H_
#define OV7670_H_
#include <asf.h>
////////////////////////////////////////////////////////////////////////
//  Constants
////////////////////////////////////////////////////////////////////////
#define HEIGHT        240
#define WIDTH       320
#define PIXELSIZE     2
#define SETTINGS_LENGTH   167
#define OV7670_ADDR     0x21

#define CAMERA_LEFT     1
#define CAMERA_RIGHT    2

#define CAMERA_LEFT_ERR   0x10
#define CAMERA_RIGHT_ERR  0x20

#define BMPHEADERSIZE 14
#define DIBHEADERSIZE 124 //v5
#define FILESIZE 153738
////////////////////////////////////////////////////////////////////////
//  Globals
////////////////////////////////////////////////////////////////////////
const char default_settings[SETTINGS_LENGTH][2];
const uint8_t DIBHead[DIBHEADERSIZE];
const uint8_t BMPHeader[BMPHEADERSIZE];
typedef struct {
  uint8_t Status;
  bool Camera_0_Found;
  bool Camera_1_Found;
  bool Camera_0_Error;
  bool Camera_1_Error;
  uint8_t VSYNC0_State;
  uint8_t VSYNC1_State;
  } OV7670_t ;

OV7670_t OV7670_Status;

#define IDLE      0
#define TAKE_PHOTO    1
#define TAKING_PHOTO  2
#define TAKEN_PHOTO   3
#define CAMERAS_BUSY  4

#define Image0Name  "Image_L_%d.bmp"
#define Image1Name  "Image_R_%d.bmp"
////////////////////////////////////////////////////////////////////////
//  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_ */
```

D.1.1.10 OV7670.c

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

```
/*
 * OV7670.c
 *
 * Created: 15/02/2013 13:12:12
 *  Author: hslovett
 */


#include <asf.h>
#include "CustomDevices/CustomDevices.h"
#include "stdio.h"
#include "delay.h"
// Camera
// #include "CustomDevices/OV7670.h"
// I2C Mux
// #include "CustomDevices/PCA9542A.h"
// MotorDriver
// /*#include "CustomDevices/MotorDriver.h"*/
// SDCard
// #include "CustomDevices/SD_Card.h"

__attribute__((__interrupt__)) static void VSYNC0_Handler (void)
{
  //print_dbg("\n\rVSYNC0 Detected!");
  eic_clear_interrupt_line(&AVR32_EIC, VSYNC_0_LINE);
  //VSYNC_0_DISABLE_INTERRUPT;
  switch(OV7670_Status.VSYNC0_State)
  {
    case(TAKE_PHOTO):
      FIFO_0_WEN_SET;
      OV7670_Status.VSYNC0_State = TAKING_PHOTO;
      break;

    case(TAKING_PHOTO):
      FIFO_0_WEN_CLR;
      OV7670_Status.VSYNC0_State = TAKEN_PHOTO;
      break;

    case (TAKEN_PHOTO):
      FIFO_0_WEN_CLR;
      break;

    case(IDLE):
    default:
      VSYNC_0_DISABLE_INTERRUPT;
      FIFO_0_WEN_CLR;
      OV7670_Status.VSYNC0_State = IDLE;
      break;
  }
}

__attribute__((__interrupt__)) static void VSYNC1_Handler (void)
{
  //print_dbg("\n\rVSYNC1 Detected!");
  eic_clear_interrupt_line(&AVR32_EIC, VSYNC_1_LINE);
  //VSYNC_1_DISABLE_INTERRUPT;
    switch(OV7670_Status.VSYNC1_State)
    {
```

```
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;

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;

71          case (TAKEN_PHOTO):
72          FIFO_1_WEN_CLR;
73          //print_dbg("\n\rCase: Taken Photo;");
74          break;

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_TWIM0, &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_TWIM0, &Buff, 1, OV7670_ADDR, false);
102   if(status != STATUS_OK)
103     return status;

105   status = twim_read(&AVR32_TWIM0, &Buff, 1, OV7670_ADDR, false);
106   *Data = Buff[0];

108   return status;

110 }
111 void OV7670_Init()
112 {

114   //Check Cameras Exist
115   PCA9542A_Chan_Sel(I2C_CHANNEL_0);
116   if (twim_probe(&AVR32_TWIM0, OV7670_ADDR) == STATUS_OK)
```

```
117       OV7670_Status.Camera_0_Found = true;
118     else
119       OV7670_Status.Camera_0_Found = false;
120
121     PCA9542A_Chan_Sel(I2C_CHANNEL_1);
122     if (twim_probe(&AVR32_TWIM0, OV7670_ADDR) == STATUS_OK)
123       OV7670_Status.Camera_1_Found = true;
124     else
125       OV7670_Status.Camera_1_Found = false;
126
127
128     //Iniialise Cameras
129     if(OV7670_Status.Camera_0_Found)
130     {
131       PCA9542A_Chan_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_Chan_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
      ][1]))
170         {
171           print_dbg("\n\rCamera Initialise Fail");
172           //return FAIL;
```

```
173           OV7670_Status.Camera_1_Error = true;
174           OV7670_Status.Status = ERR_DEVICE;
175           break;
176         }
177         delay_ms(1);
178       }
179     }
180     PCA9542A_Chan_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
        interrupt
195     gpio_enable_pin_pull_up(VSYNC_0_PIN);
196     //Initialise EIC
197     eic_init(&AVR32_EIC, &eic_options, 1);
198     eic_options.eic_line = VSYNC_0_LINE;
199     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     }

281   }

283   int TakePhoto(uint8_t Cameras)
284   {

286     //Only want to take pictures on cameras found
```

```
287   if(((OV7670_Status.VSYNC0_State != IDLE) || !OV7670_Status.Camera_0_Found)
        && ((OV7670_Status.VSYNC1_State != IDLE) || !OV7670_Status.Camera_1_Found)
        )
288     return CAMERAS_BUSY; //wait for cameras to be idle if they are found

290   if(Cameras & CAMERA_LEFT)
291     OV7670_Status.VSYNC0_State = TAKE_PHOTO;

293   if(Cameras & CAMERA_RIGHT)
294     OV7670_Status.VSYNC1_State = TAKE_PHOTO;
295   eic_clear_interrupt_line(&AVR32_EIC, VSYNC_1_LINE);
296   eic_clear_interrupt_line(&AVR32_EIC, VSYNC_0_LINE);
297   VSYNC_0_ENABLE_INTERRUPT;
298   VSYNC_1_ENABLE_INTERRUPT;

300   return TAKING_PHOTO;

302 }

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;

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;

337   if(status)
338     return true;
339   else
340     return false;
341 }
```

```
345 bool Store_Both_Images()
346 {
347   if(Photos_Ready() == false)
348     return false;
349
350   Store_Image_1();
351   FIFO_Reset(CAMERA_RIGHT);
352
353   Store_Image_0();
354   FIFO_Reset(CAMERA_LEFT);
355
356   OV7670_Status.VSYNC0_State = IDLE;
357   OV7670_Status.VSYNC1_State = IDLE;
358   return true;
359 }
360 // void Store_Image_0()
361 // {
362 //  int i,j;
363 //  //Image0
364 //  //make file
365 //  //delete file if it exits 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 // }

429 // void Store_Image_1()
430 // {
431 //  int i, j;
432 //  uint8_t buffer[WIDTH * 2];
433 //  char Filename_buff[15];
434 //    //uint8_t *Buffer_ram;
435 //    //Buffer_ram = mspace_malloc(sdram_msp, WIDTH * 2);
436 // //    if(Buffer_ram == NULL)
437 // //    {
438 // //      print_dbg("\n\rBuffer allocation fail.\n\r");
439 // //      return;
440 // //    }
441 //  i = 0;
442 //  //make file
443 //  //delete file if it exits already
444 //  nav_filelist_reset();
445 //  while(1)
446 //  {
447 //    sprintf(&Filename_buff, Image1Name, i++);
448 //    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 exits 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     }
526
527     //Image1
528     //reset read pointer
529     FIFO_1_nRRST_CLR;
530
531     FIFO_1_RCLK_SET;
532     delay_us(10);
533     FIFO_1_RCLK_CLR;
534     FIFO_1_nRRST_SET;
535
536     //enable output
537     FIFO_1_nOE_CLR;
538     //  uint8_t buffer[WIDTH * 2];
539
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     }
555
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   }
561
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 exits already
572     nav_filelist_reset();
573     while(1)
574     {
```

```
575       sprintf(&Filename_buff, Image0Name, i++);
576       if(nav_filelist_findname((FS_STRING)Filename_buff, false))
577       {
578         ;
579       }
580       else
581       {
582         break;
583       }
584     }

586     //Image1
587     //reset read pointer
588     FIFO_0_nRRST_CLR;

590     FIFO_0_RCLK_SET;
591     delay_us(10);
592     FIFO_0_RCLK_CLR;
593     FIFO_0_nRRST_SET;

595     //enable output
596     FIFO_0_nOE_CLR;
597     //  uint8_t buffer[WIDTH * 2];

599     for(j = 0; j < HEIGHT * WIDTH; j++)
600     {
601       FIFO_0_RCLK_SET;
602       delay_us(10);
603       Buffer_ram[j] = ((AVR32_GPIO.port[1].pvr) & 0xFF);//CAMERA_INPUT;
604       delay_us(10);
605       FIFO_0_RCLK_CLR;
606       delay_us(10);
607       FIFO_0_RCLK_SET;
608       delay_us(10);
609       Buffer_ram[j] |= (((AVR32_GPIO.port[1].pvr) & 0xFF) << 8);//CAMERA_INPUT;
610       delay_us(10);
611       FIFO_0_RCLK_CLR;
612       delay_us(10);
613     }

615     FIFO_0_nOE_SET;//disable output
616   /*  file_close();*/
617     SaveBitmap(Buffer_ram, WIDTH, HEIGHT, Filename_buff);
618     mspace_free(sdram_msp, Buffer_ram);
619   }
```

D.1.1.11 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
```

```
 *  Author: hslovett
 */

#include "CustomDevices/CustomDevices.h"

const char default_settings[SETTINGS_LENGTH][2]=
{
{OV_TSLB, 0x04},
{OV_COM15, 0xd0},//RGB565 / RGB555
{OV_COM7, 0x14},
{OV_HREF, 0x80},
{OV_HSTART, 0x16},
{OV_HSTOP, 0x04},
{OV_VSTRT, 0x02},
{OV_VSTOP, 0x7b},//0x7a,
{OV_VREF, 0x06},//0x0a,
{OV_COM3, 0x00}, //MSB and LSB swapped
{OV_COM14, 0x00},//
{OV_SCALING_XSC, 0x00},
{OV_SCALING_YSC, 0x00},
{OV_SCALING_DCWCTR, 0x11},
{OV_SCALING_PCLK_DIV, 0x00},//
{0xa2, 0x02},
{OV_CLKRC, 0x01},
{OV_GAM1, 0x20},
{OV_GAM2, 0x1c},
{OV_GAM3, 0x28},
{OV_GAM4, 0x3c},
{OV_GAM5, 0x55},
{OV_GAM6, 0x68},
{OV_GAM7, 0x76},
{OV_GAM8, 0x80},
{OV_GAM9, 0x88},
{OV_GAM10, 0x8f},
{OV_GAM11, 0x96},
{OV_GAM12, 0xa3},
{OV_GAM13, 0xaf},
{OV_GAM14, 0xc4},
{OV_GAM15, 0xd7},
{OV_GAM16, 0xe8},
{OV_COM8, 0xe0},
{OV_GAIN, 0x00},//AGC
{OV_AECH, 0x00},
{OV_COM4, 0x00},
{OV_COM9, 0x20},//0x38, limit the max gain
{OV_HIST6, 0x05},
{OV_HIST12, 0x07},
{OV_AEW, 0x75},
{OV_AEB, 0x63},
{OV_VPT, 0xA5},
{OV_HIST0, 0x78},
{OV_HIST1, 0x68},
{OV_HIST2, 0x03},//0x0b,
{OV_HIST7, 0xdf},//0xd8,
{OV_HIST8, 0xdf},//0xd8,
{OV_HIST9, 0xf0},
{OV_HIST10, 0x90},
{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, 0x0a},
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_MTXS, 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
```

```
};
```

D.1.1.12 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_Chan_Sel(unsigned char Channel);
#endif /* PCA9542A_H_ */
```

D.1.1.13 PCA9542A.c

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

```
/*
 * PCA9542A.c
 *
 * Created: 15/02/2013 12:21:36
```

```
 *  Author: hslovett
 */

#include <asf.h>
#include "CustomDevices/CustomDevices.h"
//Camera
/*#include "CustomDevices/OV7670.h"*/
//I2C Mux
/*#include "CustomDevices/PCA9542A.h"*/
//MotorDriver
/*#include "CustomDevices/MotorDriver.h"*/
//SDCard
/*#include "CustomDevices/SD_Card.h"*/

int PCA9542A_Init()
{
  int status = twim_probe(&AVR32_TWIM0, PCA9542A_ADDR);
  if (status != STATUS_OK)
  {
    PCA9542A.Status = DEVICE_NOT_FOUND;
    return DEVICE_NOT_FOUND;
  }
  char buff[2] = {NO_SELECT, 0};
  status = twim_write(&AVR32_TWIM0, &buff, 1, PCA9542A_ADDR, false);
  PCA9542A.Status = STATUS_OK;
  PCA9542A.ChannelSelected = NO_SELECT;
  return status;
}


void PCA9542A_Chan_Sel(unsigned char Channel)
{
  int status = 0;
  char buff[2] = {Channel, 0};
  status = twim_write(&AVR32_TWIM0, &buff, 1, PCA9542A_ADDR, false);
  if(status == STATUS_OK)
  {
    PCA9542A.ChannelSelected = Channel;
  }
  else
  {
    PCA9542A.Status = ERR_PROTOCOL;
  }
}
```

D.1.1.14 SD_Card.h

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

```
/*
 * SD_Card.h
 *
 * Created: 10/02/2013 17:11:51
 *  Author: hslovett
```

```
 */


#ifndef SD_CARD_H_
#define SD_CARD_H_
#include "ImageProcessor.h"
#define SIGNAL_FILE "signal.bin"
#define  TWOD_SIGNAL_FILE "signal2d.bin"

typedef struct {
  uint8_t Status;
  uint32_t Memory_size;
  } SD_Status_t;
SD_Status_t SD_Status;

void local_pdca_init(void);
void sd_mmc_resources_init(void);
static void pdca_int_handler(void);
void wait();
void Log_Write_ulong(unsigned long n);
void Log_Write(char *buff, int length);
void SaveBuff( int * WorkingBuffer , int size);
int Read2DSignal( int * WorkingBuffer );
int ReadSignal( int * WorkingBuffer );
void SaveBitmap(uint16_t *Image, int width, int height, char *FileName);
//void ReadBitmap(char *Filename);
void ReadBitmap(char *Filename, Image_t *image);
#endif /* SD_CARD_H_ */
```

D.1.1.15 SD_Card.c

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

```
/*
 * SD_Card.c
 *
 * Created: 10/02/2013 17:11:58
 *  Author: hslovett
 */
//Camera
/*#include "CustomDevices/OV7670.h"*/
//I2C Mux
/*#include "CustomDevices/PCA9542A.h"*/
//MotorDriver
/*#include "CustomDevices/MotorDriver.h"*/
//SDCard
/*#include "CustomDevices/SD_Card.h"*/
#include "CustomDevices/CustomDevices.h"
#include "conf_sd_mmc_spi.h"
#include <asf.h>

// Dummy char table
const char dummy_data[] =
#include "dummy.h"
```

```
22 ;
23 // PDCA Channel pointer
24 volatile avr32_pdca_channel_t* pdca_channelrx ;
25 volatile avr32_pdca_channel_t* pdca_channeltx ;
26 // Used to indicate the end of PDCA transfer
27 volatile bool end_of_transfer;
28 // Local RAM buffer for the example to store data received from the SD/MMC
       card
29 volatile char ram_buffer[1000];


32 void wait()
33 {
34   volatile int i;
35   for(i = 0 ; i < 5000; i++);
36 }
37 /* interrupt handler to notify if the Data reception from flash is
38  * over, in this case lunch the Memory(ram_buffer) to USART transfer and
39  * disable interrupt*/

41 static void pdca_int_handler(void)
42 {
43   // Disable all interrupts.
44   Disable_global_interrupt();

46   // Disable interrupt channel.
47   pdca_disable_interrupt_transfer_complete(AVR32_PDCA_CHANNEL_SPI_RX);

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

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

58   end_of_transfer = true;
59 }

61 /*! \brief Initializes SD/MMC resources: GPIO, SPI and SD/MMC.
62  */
63 void sd_mmc_resources_init(void)
64 {
65   // GPIO pins used for SD/MMC interface
66   static const gpio_map_t SD_MMC_SPI_GPIO_MAP =
67   {
68     {SD_MMC_SPI_SCK_PIN,  SD_MMC_SPI_SCK_FUNCTION },  // SPI Clock.
69     {SD_MMC_SPI_MISO_PIN, SD_MMC_SPI_MISO_FUNCTION},  // MISO.
70     {SD_MMC_SPI_MOSI_PIN, SD_MMC_SPI_MOSI_FUNCTION},  // MOSI.
71     {SD_MMC_SPI_NPCS_PIN, SD_MMC_SPI_NPCS_FUNCTION}   // Chip Select NPCS.
72   };

74   // SPI options.
75   spi_options_t spiOptions =
76   {
77     .reg          = SD_MMC_SPI_NPCS,
78     .baudrate     = SD_MMC_SPI_MASTER_SPEED,  // Defined in conf_sd_mmc_spi.h.
```

```
79      .bits          = SD_MMC_SPI_BITS,          // Defined in conf_sd_mmc_spi.h.
80      .spck_delay    = 0,
81      .trans_delay   = 0,
82      .stay_act      = 1,
83      .spi_mode      = 0,
84      .modfdis       = 1
85    };

87    // Assign I/Os to SPI.
88    gpio_enable_module(SD_MMC_SPI_GPIO_MAP,
89                       sizeof(SD_MMC_SPI_GPIO_MAP) / sizeof(SD_MMC_SPI_GPIO_MAP
        [0]));

91    // Initialize as master.
92    spi_initMaster(SD_MMC_SPI, &spiOptions);

94    // Set SPI selection mode: variable_ps, pcs_decode, delay.
95    spi_selectionMode(SD_MMC_SPI, 0, 0, 0);

97    // Enable SPI module.
98    spi_enable(SD_MMC_SPI);

100   // Initialize SD/MMC driver with SPI clock (PBA).
101   sd_mmc_spi_init(spiOptions, PBA_HZ);
102 }

104 /*! \brief Initialize PDCA (Peripheral DMA Controller A) resources for the SPI
        transfer and start a dummy transfer
105  */
106 void local_pdca_init(void)
107 {
108   // this PDCA channel is used for data reception from the SPI
109   pdca_channel_options_t pdca_options_SPI_RX ={ // pdca channel options

111     .addr = ram_buffer,
112     // memory address. We take here the address of the string dummy_data. This
        string is located in the file dummy.h

114     .size = 512,                               // transfer counter: here the
      size of the string
115     .r_addr = NULL,                            // next memory address after 1st
        transfer complete
116     .r_size = 0,                               // next transfer counter not
      used here
117     .pid = AVR32_PDCA_CHANNEL_USED_RX,         // select peripheral ID - data
      are on reception from SPI1 RX line
118     .transfer_size = PDCA_TRANSFER_SIZE_BYTE  // select size of the transfer:
      8,16,32 bits
119   };

121   // this channel is used to activate the clock of the SPI by sending a dummy
        variables
122   pdca_channel_options_t pdca_options_SPI_TX ={ // pdca channel options

124     .addr = (void *)&dummy_data,               // memory address.
125                                                // We take here the address of
      the string dummy_data.
```

```
126                                                 // This string is located in the
       file dummy.h
127       .size = 512,                              // transfer counter: here the
      size of the string
128       .r_addr = NULL,                           // next memory address after 1st
       transfer complete
129       .r_size = 0,                              // next transfer counter not
      used here
130       .pid = AVR32_PDCA_CHANNEL_USED_TX,        // select peripheral ID - data
      are on reception from SPI1 RX line
131       .transfer_size = PDCA_TRANSFER_SIZE_BYTE  // select size of the transfer:
      8,16,32 bits
132     };

134     // Init PDCA transmission channel
135     pdca_init_channel(AVR32_PDCA_CHANNEL_SPI_TX, &pdca_options_SPI_TX);

137     // Init PDCA Reception channel
138     pdca_init_channel(AVR32_PDCA_CHANNEL_SPI_RX, &pdca_options_SPI_RX);

140     //! \brief Enable pdca transfer interrupt when completed
141     INTC_register_interrupt(&pdca_int_handler, AVR32_PDCA_IRQ_0, AVR32_INTC_INT1
        );  // pdca_channel_spi1_RX = 0

143   }

145   #define BUFFER_FILENAME   "Buffer.bin"
146   void SaveBuff( int * WorkingBuffer , int size)
147   {
148     //If the file exists, delete it
149     if(nav_filelist_findname((FS_STRING)BUFFER_FILENAME, false))
150     {
151       nav_setcwd((FS_STRING)BUFFER_FILENAME, false, false);
152       nav_file_del(false);
153     }
154     nav_file_create((FS_STRING)BUFFER_FILENAME);
155     nav_setcwd((FS_STRING)BUFFER_FILENAME, false, true);
156     file_open(FOPEN_MODE_APPEND);
157     file_write_buf(WorkingBuffer, size * sizeof(WorkingBuffer));
158     file_close();
159   }

161   void Log_Write(char *buff, int length)
162   {
163     nav_setcwd((FS_STRING)LOG_FILE, true, false);
164     file_open(FOPEN_MODE_APPEND);
165     if(length == -1)
166       length = sizeof(buff);
167     file_write_buf(buff, length);
168     file_close();
169   }
170   void Log_Write_ulong(unsigned long n)
171   {
172     char tmp[11];
173     int i = sizeof(tmp) - 1;

175     // Convert the given number to an ASCII decimal representation.
176     tmp[i] = '\0';
```

```
177     do
178     {
179     tmp[--i] = '0' + n % 10;
180     n /= 10;
181     } while (n);

183     // Transmit the resulting string with the given USART.
184     Log_Write(tmp + i, -1);
185   }

187   int ReadSignal( int * WorkingBuffer )
188   {
189     bool status_b;
190     int Status, temp;
191     char c = 0;
192     if(Columbus_Status.SD_Card->Status != STATUS_OK)
193       return ERR_IO_ERROR;
194     nav_filelist_reset();
195     nav_setcwd((FS_STRING)SIGNAL_FILE, false, false);
196     status_b = file_open(FOPEN_MODE_R);
197     if(status_b == false)
198     {
199       print_dbg("File Open Error");
200       return ERR_IO_ERROR;
201     }


204     //Status = file_read_buf(WorkingBuffer, 16);
205     for(Status = 0; Status < FFT_SIZE; Status++)
206     {
207   //    print_dbg("\n\r Read from file: ");
208       c = 0;
209       temp = 0;
210       temp |= file_getc() << 24;
211       temp |= file_getc() << 16;
212       temp |= file_getc() << 8;
213       temp |= file_getc();

215   //    print_dbg_char(c);

217       WorkingBuffer[Status] = temp;
218   //    print_dbg("  Working Buff = ");
219   //    print_dbg_char(WorkingBuffer[Status]);
220     }
221     file_close();
222     return STATUS_OK;
223   }

225   int Read2DSignal( int * WorkingBuffer )
226   {
227     bool status_b;
228     int Status, temp;
229     char c = 0;
230     if(Columbus_Status.SD_Card->Status != STATUS_OK)
231     return ERR_IO_ERROR;
232     nav_filelist_reset();
233     nav_setcwd((FS_STRING)TWOD_SIGNAL_FILE, false, false);
234     status_b = file_open(FOPEN_MODE_R);
```

```
235     if(status_b == false)
236     {
237       print_dbg("File Open Error");
238       return ERR_IO_ERROR;
239     }


242     //Status = file_read_buf(WorkingBuffer, 16);
243     for(Status = 0; Status < FFT_SIZE * FFT_SIZE; Status++)
244     {
245       //    print_dbg("\n\r Read from file: ");
246       c = 0;
247       temp = 0;
248       temp |= file_getc() << 24;
249       temp |= file_getc() << 16;
250       temp |= file_getc() << 8;
251       temp |= file_getc();

253       //    print_dbg_char(c);

255       WorkingBuffer[Status] = temp;
256       //    print_dbg("  Working Buff = ");
257       //    print_dbg_char(WorkingBuffer[Status]);
258     }
259     file_close();
260     return STATUS_OK;
261   }

263   void SaveBitmap(uint16_t *Image, int width, int height, char *FileName)
264   {
265     int i, j, k;
266     uint8_t *Buffer;

268     nav_filelist_reset();
269     if(nav_filelist_findname((FS_STRING)FileName, false))
270     {
271       nav_setcwd((FS_STRING)FileName, true, false);
272       nav_file_del(false);
273     }
274     nav_file_create((FS_STRING)FileName);
275     file_open(FOPEN_MODE_W);
276     //write a modified bitmap header
277     //Calculate which is the biggest:
278     i = width * 2;
279     if(height > i)
280       i = height;
281     if(DIBHEADERSIZE > i)
282       i = DIBHEADERSIZE;

284     Buffer = malloc(i);

286     for(i = 0; i < BMPHEADERSIZE; i++)//copy all the header
287     {
288       Buffer[i] = BMPHeader[i];
289     }
290     //edit the size field
291     j = width * height * 2 + BMPHEADERSIZE + DIBHEADERSIZE;
292     for(i = 0; i < 4; i ++)
```

```
293     {
294       Buffer[i + 2] = (uint8_t)(j >> 8*i);
295     }
296
297     file_write_buf(Buffer, BMPHEADERSIZE);
298
299     //DIB Header
300     for(i = 0; i < DIBHEADERSIZE; i ++)
301     {
302       Buffer[i] = DIBHead[i];
303     }
304     Buffer[4] = (uint8_t)(width & 0xFF);
305     Buffer[5] = (uint8_t)((width >> 8) & 0xFF);
306     Buffer[6] = (uint8_t)((width >> 16) & 0xFF);
307     Buffer[7] = (uint8_t)((width >> 24) & 0xFF);
308
309     Buffer[8] = (uint8_t)(height & 0xFF);
310     Buffer[9] = (uint8_t)((height >> 8) & 0xFF);
311     Buffer[10] = (uint8_t)((height >> 16) & 0xFF);
312     Buffer[11] = (uint8_t)((height >> 24) & 0xFF);
313
314     file_write_buf(Buffer, DIBHEADERSIZE);
315
316     for(i = 0; i < height ; i++ )
317     {
318       for(j = 0; j < width ; j++)
319       {
320         //Copy the data across.
321
322         /*Buffer[j] = Image[i*width + j];*/
323         Buffer[(2 * j) + 1] = (uint8_t)(Image[i*width + j]);
324         Buffer[(2 * j)] = (uint8_t)(Image[i*width + j] >> 8);
325       }
326       if(file_write_buf(Buffer, width * 2) != (width * 2))
327       {
328         print_dbg("\n\rFile write error.");
329       }
330
331 //      j = width % 4;
332 //      if(j != 0)
333 //      {//Padding is needed to make things 4 byte aligned
334 //        file_write_buf(Buffer, j);
335 //      }
336     }
337
338
339
340     free(Buffer);
341     file_close();
342 }
343
344 #define BMP_HEADER_FILESIZE_OFFSET    2
345 #define BMP_HEADER_OFFSETTOARRAY_OFFSET 10
346 #define DIB_V5_WIDTH_OFFSET       4
347 #define DIB_V5_HEIGHT_OFFSET      8
348 #define DIB_V5_BITCOUNT_OFFSET      14
349 #define DIB_V5_IMAGESIZE_OFFSET     20
```

```
351 int ReadBigEndian(uint8_t *Buffer, int Offset, uint size)
352 {
353   int retVal, i;
354   retVal = 0; //initialise value
355   for(i = 0; i < size; i++)
356   {
357     retVal |= Buffer[Offset + i] << (i * 8);
358   }
359   return (Buffer[Offset]) | (Buffer[Offset + 1] << 8) | (Buffer[Offset + 2] <<
        16) | (Buffer[Offset + 3] << 24);
360 }
361 void ReadBitmap(char *Filename, Image_t *image)
362 {
363 //  Image_t image;
364   int i, j, FileSize, OffsetToArray, temp, BitCount, ImageSize;
365   uint8_t Buffer[128];
366   nav_filelist_reset();
367   if(nav_filelist_findname((FS_STRING)Filename, false) == false)//if the file
        doesn't exist
368   {
369     print_dbg("\n\rFile ");
370     print_dbg(Filename);
371     print_dbg("\n\r does not exist;");
372     return;
373   }
374   nav_setcwd((FS_STRING)Filename, false, false);
375   file_open(FOPEN_MODE_R);
376   //Read Header
377   file_read_buf(Buffer, BMPHEADERSIZE);
378   //Check for BM to confirm it is a Bitmap
379   if((Buffer[0] != 'B') || (Buffer[1] != 'M'))
380   {
381     print_dbg("\n\rBitmap Parse Fail 'BM';");
382     return;
383   }
384   //Extract file size and offset to pixel array
385   FileSize = ReadBigEndian(Buffer, BMP_HEADER_FILESIZE_OFFSET, 4);
386   OffsetToArray = ReadBigEndian(Buffer, BMP_HEADER_OFFSETTOARRAY_OFFSET, 4);

388   file_read_buf(Buffer, DIBHEADERSIZE);
389   temp = ReadBigEndian(Buffer, 0, 4);
390   if(temp != 0x7C) //check it is a V5 BMP DIB Header
391   {
392     print_dbg("\n\rBMP Parse: DIB Header not V5;");
393     return;
394   }
395   image->Width= ReadBigEndian(Buffer, DIB_V5_WIDTH_OFFSET, 4);
396   image->Height = ReadBigEndian(Buffer, DIB_V5_HEIGHT_OFFSET, 4);
397   BitCount = ReadBigEndian(Buffer, DIB_V5_BITCOUNT_OFFSET, 2);
398   ImageSize = ReadBigEndian(Buffer, DIB_V5_IMAGESIZE_OFFSET, 4);
399   print_dbg("\n\rBitmap Width = ");
400   print_dbg_ulong(image->Width);
401   print_dbg("\n\rBitmap Height = ");
402   print_dbg_ulong(image->Height);
403   print_dbg("\n\rBitmap File Size = ");
404   print_dbg_ulong(FileSize);
405   print_dbg("\n\rBitmap Offset to Array = ");
406   print_dbg_ulong(OffsetToArray);
```

```
407     print_dbg("\n\rBitmap Image Bitcount = ");
408     print_dbg_ulong(BitCount);
409     print_dbg("\n\rBitmap Image Size = ");
410     print_dbg_ulong(ImageSize);

412     file_seek(OffsetToArray, FS_SEEK_SET);
413     j = 0;
414     image->ImagePtr = mspace_malloc(sdram_msp, image->Height * image->Width);
415     for(i = 0; i < ImageSize; i += 2)
416     {
417       image->ImagePtr[j++] = (file_getc()<<8) | (file_getc());
418     }
419     file_close();
420     nav_filelist_reset();
421     return;
422   }
```

D.1.1.16 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    */

8   #include "CustomDevices/CustomDevices.h"
9   #include <asf.h>

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


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_TWIMS0_TWCK_0_0_PIN, AVR32_TWIMS0_TWCK_0_0_FUNCTION},
28    {AVR32_TWIMS0_TWD_0_0_PIN, AVR32_TWIMS0_TWD_0_0_FUNCTION}
29    };

31    // Set TWIM options
32    const twi_options_t TWIM_OPTIONS = {
33      .pba_hz = FOSC0,
```

```
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_TWIM0, &TWIM_OPTIONS);

45  }
```

Appendix E

PCB Design

E.1 PCB Top Side

E.2 PCB Bottom Side

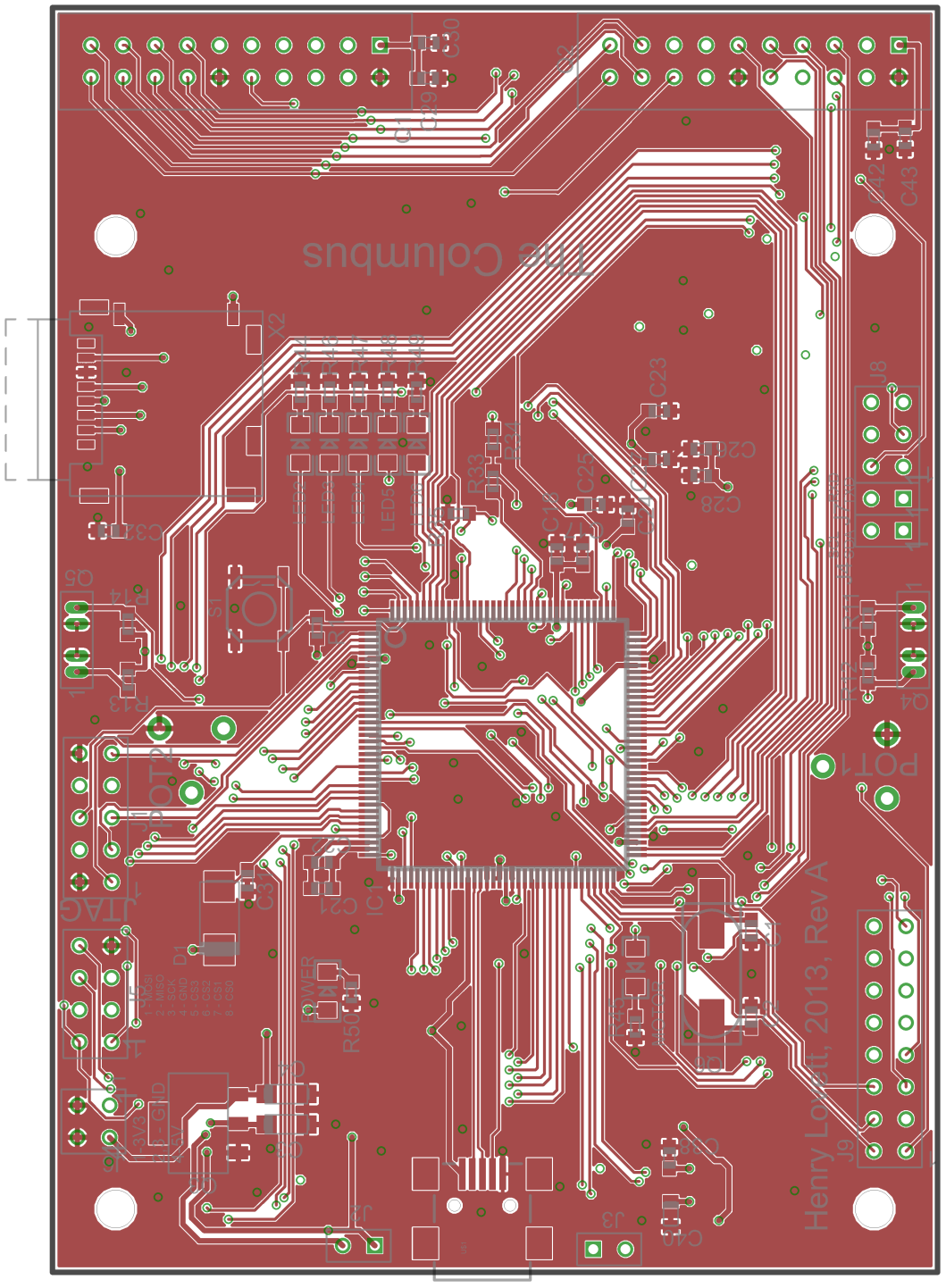


Figure E.1: The Top side of the CAD Design of the PCB

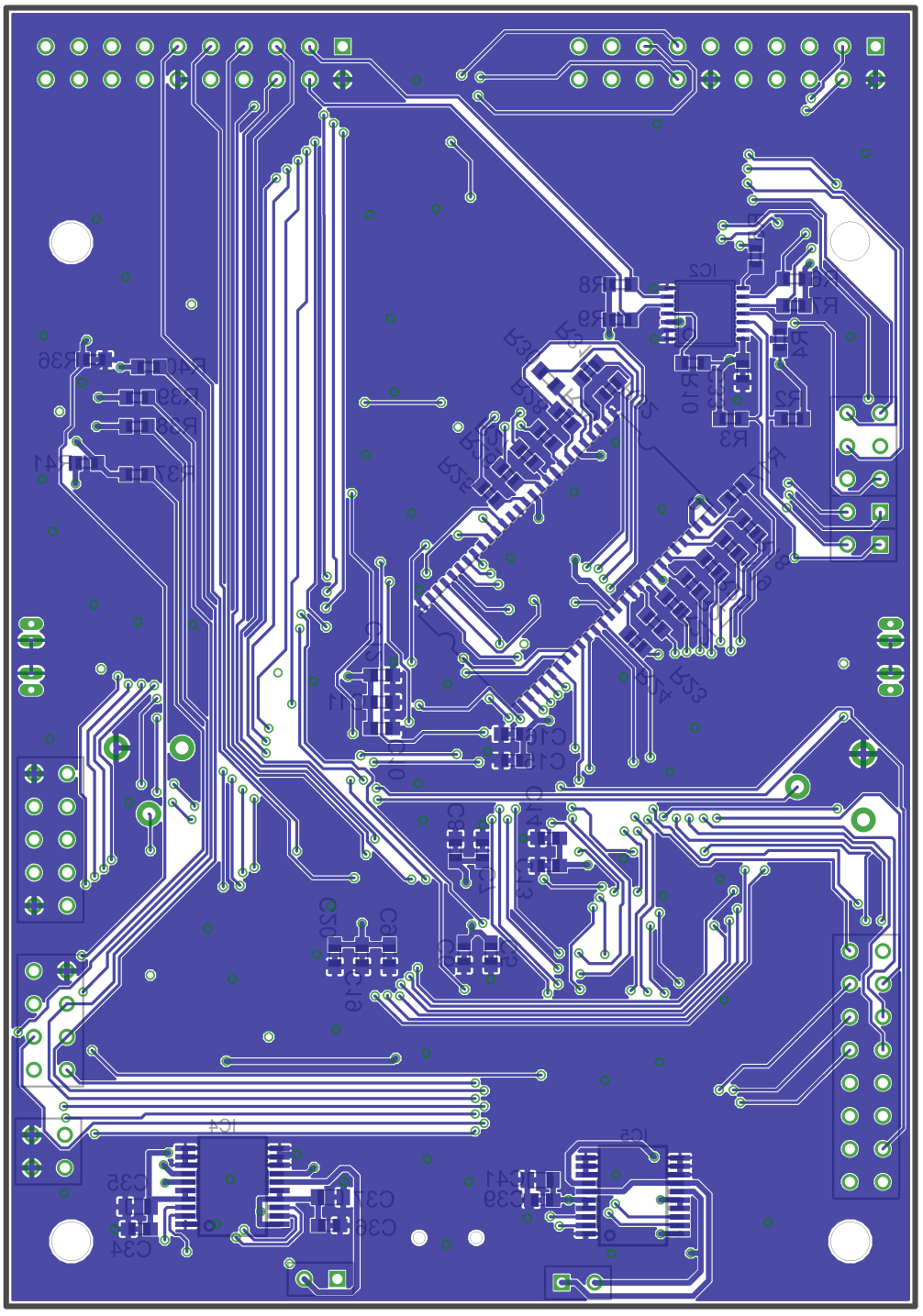


Figure E.2: The Bottom side of the CAD Design of the PCB

Appendix F

Contents of Files

Contents:

Circuit Diagrams

Code

Documents

Matlab

ProjectBrief

Report

References

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