UNIVERSITY OF SOUTHAMPTON

FACULTY OF PHYSICAL AND APPLIED SCIENCES

Electronics and Computer Science

Two Dimensional Stereoscopic Mapping Robot

by

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

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

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UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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TWO DIMENSIONAL STEREOSCOPIC MAPPING ROBOT

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This paper describes the research, design, build and testing of a stereoscopic mapping robot. Two cameras are used to locate objects and calculate distances to solid items. This allows an occupancy map to be built up of the unknown area. The object detection is done by a normalised cross correlation and uses derived equations to find distances. The camera used is an OV7670 by OmniVision delivering QVGA sized images. The end product will be a mobile wheeled robot that explores an unknown area. Multiple modules of the design have been developed and tested and all aspects will be brought together onto an AVR32 for the final product.

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List of Symbols

I^2C	Inter-Integrated Circuit
TWI	Two Wire Interface
SCCB	Serial Camera Control Bus
SPI	Serial Peripheral Interface
kB	KiloBytes
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

This report documents the designing, testing and building of a stereoscopic mapping robot. The end product will be a small, two wheeled robot with a roller ball, that will autonomously search and map an unkown area and produce an occupancy map of the searched area.

Stereoscopy in computer vision is the ability to calculate the locations and depths using images from two cameras that are used to triangulate and estimate distances (Saxena et al. (2007)). By using two cameras on the same plane, separated by a set horizontal distance, the depth of the observed scene can be perceived by the system.

An occupancy map is a representation of an area where a location is given a value of either *free, occupied* or *unkown*Thrun (2003). Three dimensional occupancy maps can also be generated, such as the OctoMap (Wurm et al. (2010)). Objects can also be tracked using an occupancy map and statistics (Fleuret et al. (2007)).

The purpose of a mapping robot is to build a representation of the area around it. This then facilitates the use of any application that requires prior knowledge of the area. One algorithm that is used to build up an occupancy map is the S.L.A.M. algorithm (Thrun and Montemerlo (2006)) and is used in other mapping robots(Se et al. (2002)). Accurate mapping robots tend to use laser range finders (Ruhnke et al. (2011)).

Stereovision is a small section of computer vision which is widely used in many applications, including Microsofts Xbox Kinect (Microsoft (2012)), where stereo vision is used to locate a game player in order to use their movements to control

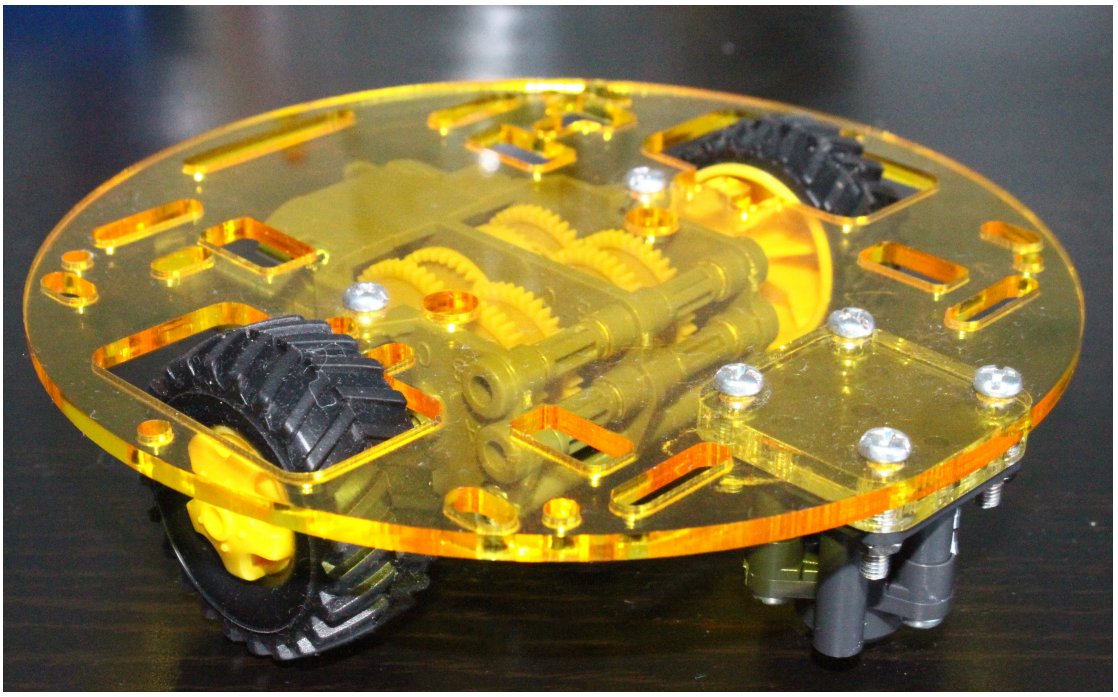


Figure 1.1: The base of the robot will use

the game. Mrovlje and Vrančić (2008) uses stereovision to be able to locate the distance to a marker.

The stereovision mapping robot discussed in this report is a low cost alternative to other robots which use laser range finders or high quality cameras (Se et al. (2002)). The robot will use the base seen in figure 1.1 and use two OmniVision OV7670 cameras delivering up to VGA format images.

Chapter 2

Research

The research done for this project is split into three sections:

1. Hardware
2. Software, broken down into:
   (a) Firmware
   (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.

For this comparison, the Stellaris by Texas Instruments will be examined. 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, PWN, ADCs and have Flash, SRAM and EEPROM memory.

Atmel have a variety of products in the microcontroller market. They range from 8-bit, low clock speed devices for the hobbyist, the ATMega and ATTiny series to an improved 8-bit variant, XMega, and a 32-bit design, AT32UC3C. XMegas and AVR32s tend to have higher clock speeds than the ATMegas. The AVR core is also a Harvard RISC architecture, but mainly 8-bit. Atmel devices often have on board peripherals such as I^2C(called TWI on AVRs), SPI, 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). 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 and SPI or I^2Cbus. 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. It 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 microcontroller 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 (2012c). 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

Initial Hardware and Firmware Development

For initial development, the *Il Matto* board, designed by Steve Gunn, which has an ATMega644P, was used. The system is clocked at 16MHz and has an on-board SD card connector.

The following section is broken down into the following parts:

1. Camera Code
2. SD Card
3. Circuit and PCB Development

3.1 Camera

The camera used is an OV7670 by OmniVision. It is mounted onto a break out board and connected to a AL422B FIFO Buffer. The breakout board has all passive components needed and a 24MHz clock mounted. The schematic for the device can be seen in Appendix 2.

Original code for the camera operation was given by Steve Gunn, of which I used to gain the operation required. The code streamed continuous video to a TFT screen. The operation required was to take a single photo.

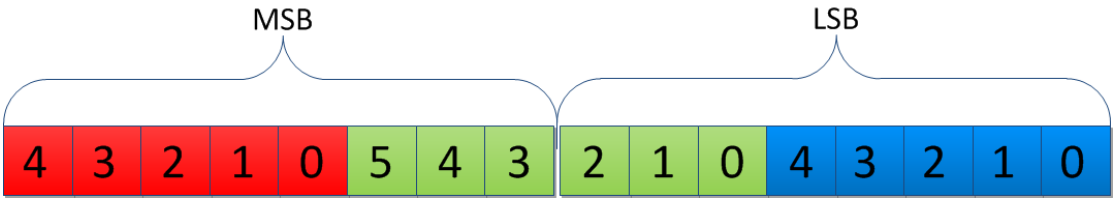


Figure 3.1: RGB565 pixel format

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. 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 an 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 AVRs (ATMegas typically clocked at 12-16MHz) to be able to respond to the camera quick enough. This highlights the importance of 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 AVR to enable WEN. The operation is then automatic and all the data is clocked into the buffer until the second interrupt of VSYNC where WEN is disabled. At this point, the entire frame of data is stored in the buffer.

[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

To obtain the data from the buffer, the AVR sets output enable and manually pulses the read clock. Valid data is available on the input port chosen. 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) 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 was decided is used as FAT file system. This allows data to 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.

The buffers have an output enable pin so the data bus can be shared by both cameras to the AVR. All buffer function pins are driven from pins, although a demultiplexer could be used if pins are short. 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 method 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 from one and then the other by the AVR.

A major problem now occurred with using the I^2Cinterface to set up both cameras. The camera has a set I^2Caddress of 21_{16}, which cannot be changed. Multiple I^2Cdevices 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^2Cmultiplexer. 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. Space for the code then has to be made and this code cannot be reused.

An I^2Cmultiplexer 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^2CMUX 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 and simplify the operation and reduce the code size so an I^2CMUX will be used. A suitable multiplexer is the Phillips PCA9542A (Phillips (2009)).

Operation to read an image is identical to using one camera. 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.

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.

	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))

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 much 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 data. Appendix 2 shows the make up of a Bitmap File that was used.

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

Figure 3.3: An Example Image taken using the OV7670 and stored as a Bitmap on the 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 ATMega 168 was added on the I^2Cbus to act as a port extender. The ATMega168 accepts a read or write, places the written data on Port D and reads in the lower nibble of 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 Atmel Corporation (2007), written for IAR Compiler. This code was altered to compile with GCC under Atmel Studio. AVRs contain a hardware based I^2Cprotocol 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.

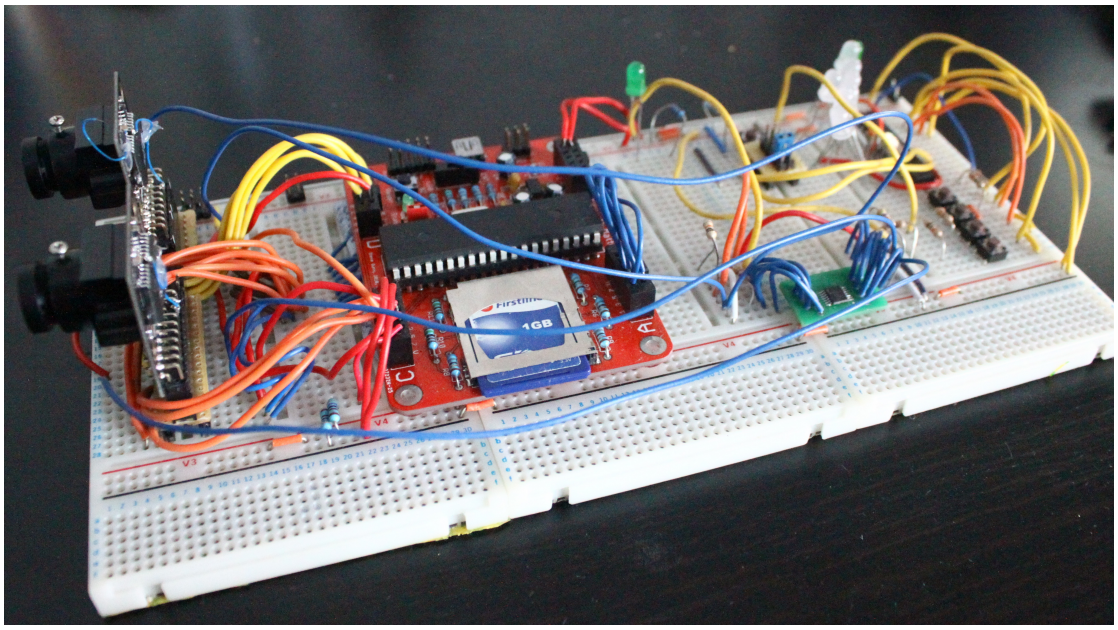


Figure 3.4: Prototype of Dual Camera operation.

3.3 Circuit and PCB Development

3.3.1 Il Matto Development

Figure 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.

Chapter 4

Investigation into Vision Algorithms

4.1 Comparison

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 of image to compare to of 50× 50 pixels of the same part of the image.

(a) Left Image (b) Right Image

Figure 4.1: Stereoscopic Test Images from MATLAB Examples

4.1.1 Sum of Absolue 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 takes each sub image and subtracts the observed sub image 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.

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,

containing division and the necessity to square root a number in order to calculate the standard deviation. These operations are rarely implemented in hardware and are time consuming to carry out. They also require floating point registers and operates slowly on a microcontroller with a small amount of floating point registers.

4.1.4 Comparison

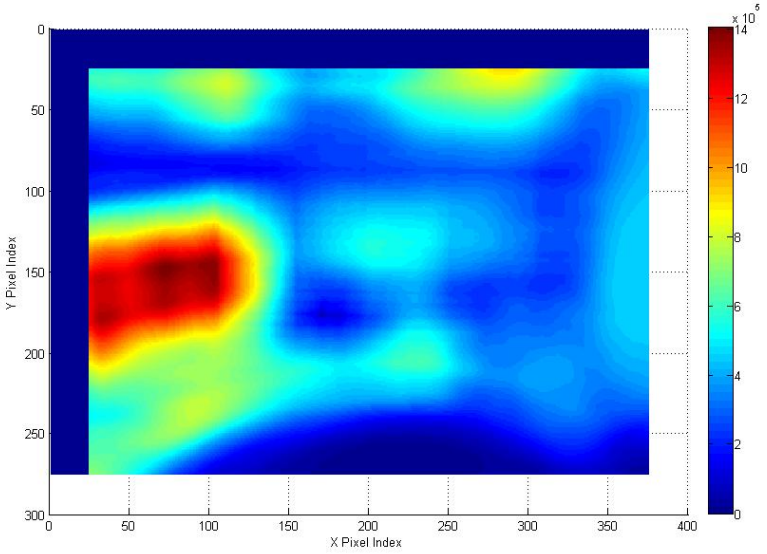
To compare these equations, a 50 by 50 image taken from the right picture was compared with the left image over the entire valid range. The coordinates on the graph give the centre pixel of the calculation.

Each of the graphs show the correct area being indentified 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 phone from the test figure. 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)).

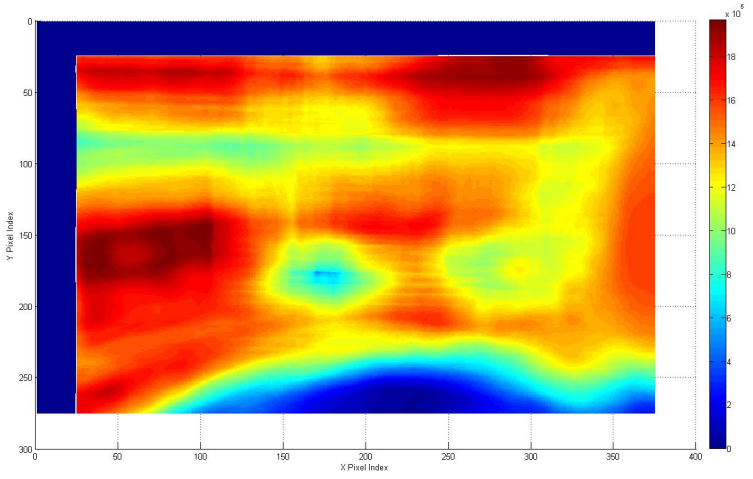
SAD results in figure 4.2(b) show large areas of matching. The actual match is at (170, 175) and a minimum does occur at this position as expected, of a value of 5.66×10^4. However, along the bottom of the image, where a dark area occurs in the lower part of figures 4.1 below the desk, the SAD algorithm 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 values 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 occurs at $(225, 274)$. This, again, is a false match and is a downfall of this algorithm.

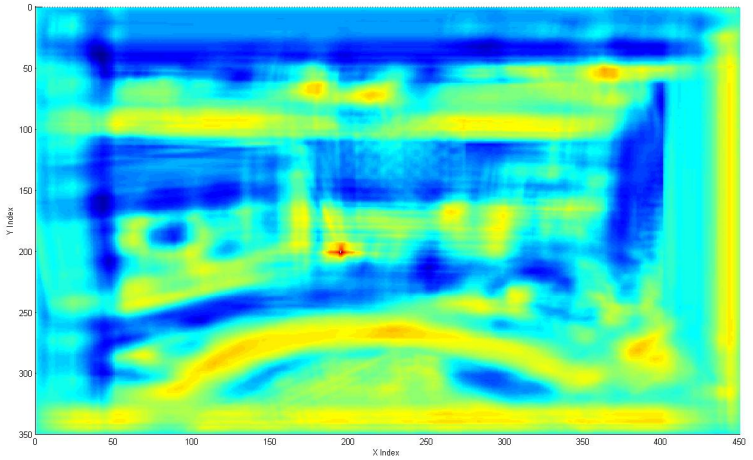
The NCC results are visible in figure 4.2(c). A match can be seen at coordinate $(195, 201)$ with a peak value of 0.9654. The coordinate is different to the previous results because the cross correlation works over the boundary of the image creating more results. The dimensions of the image are 300×400, but the NCC returns an data set of dimensions 350×450 when using a box size of 50×50. To get the actual match, half of the box size must be subtracted from the returned coordinate.



(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

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 difference, the range of an object can be found given some characteristics of the camera. The following is a derivation 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).

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

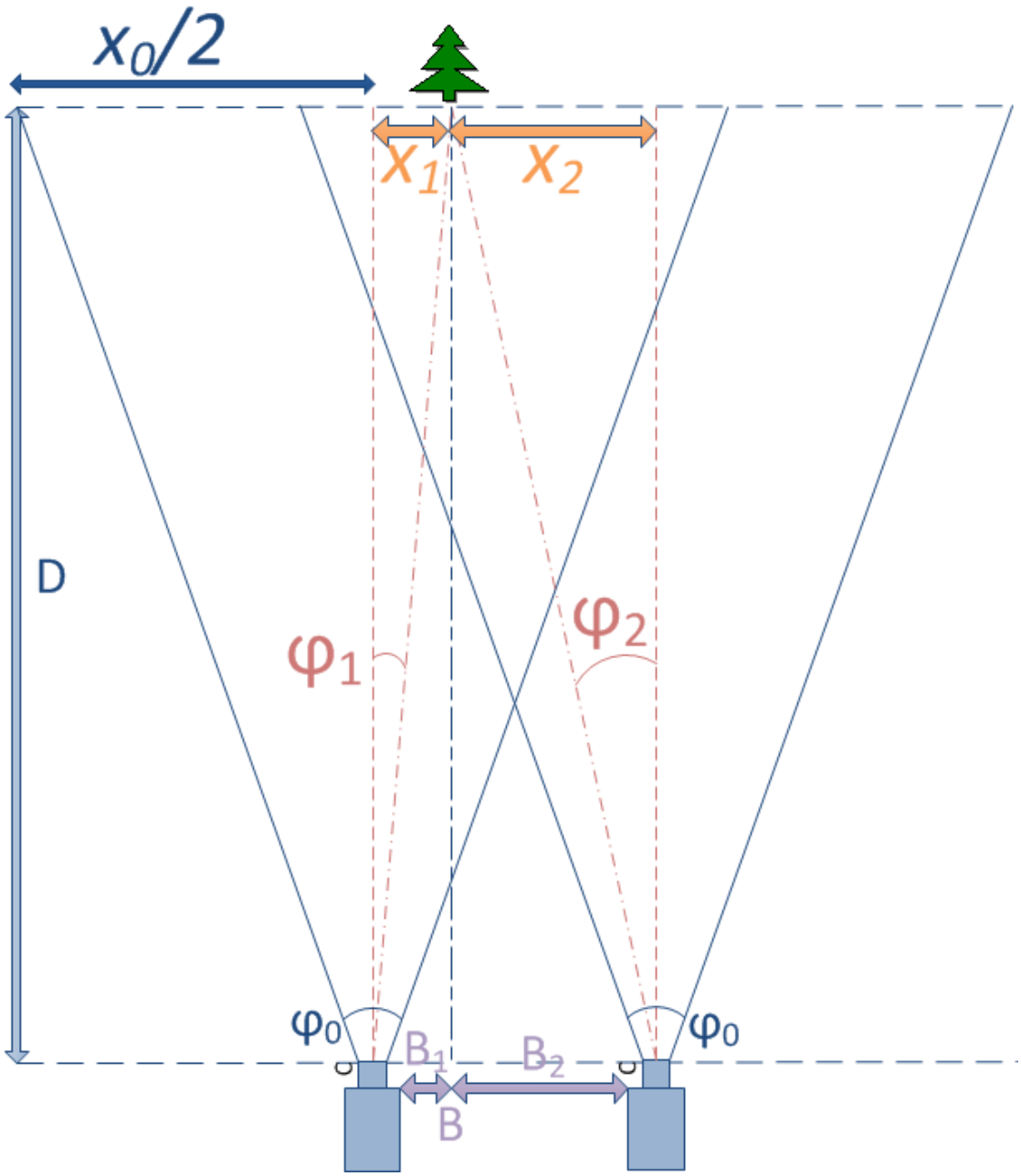


Figure 4.3: Problem 1 - Object is between the Cameras

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

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

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

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:

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

$$D.\tan(\frac{\varphi_1}{2}) = \frac{x_0}{2} \tag{4.13}$$

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

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

and similarly

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

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

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:

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

Where φ_2 can be found from equation 4.16.

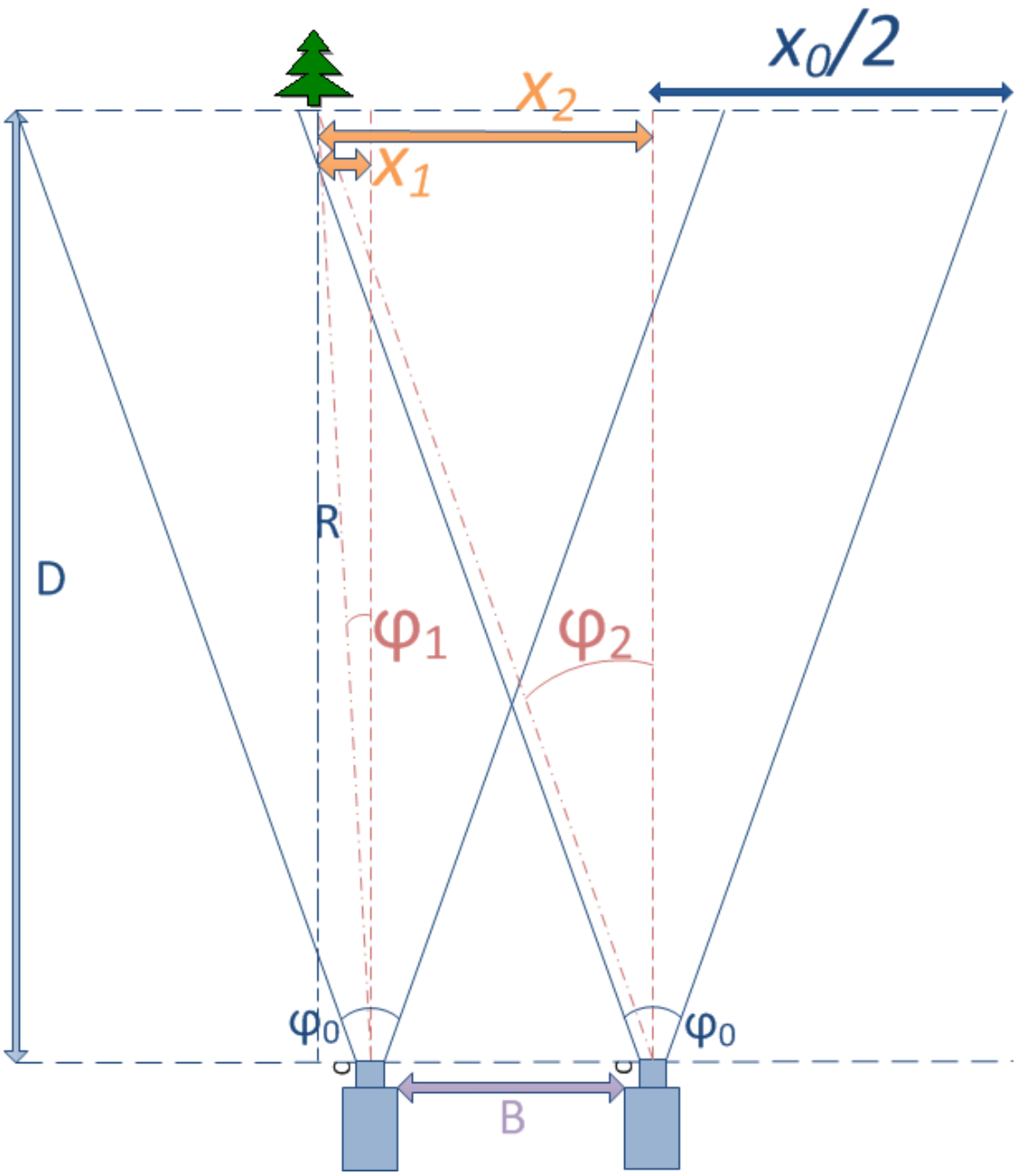


Figure 4.4: Problem 2 - Object is to the same side in both cameras

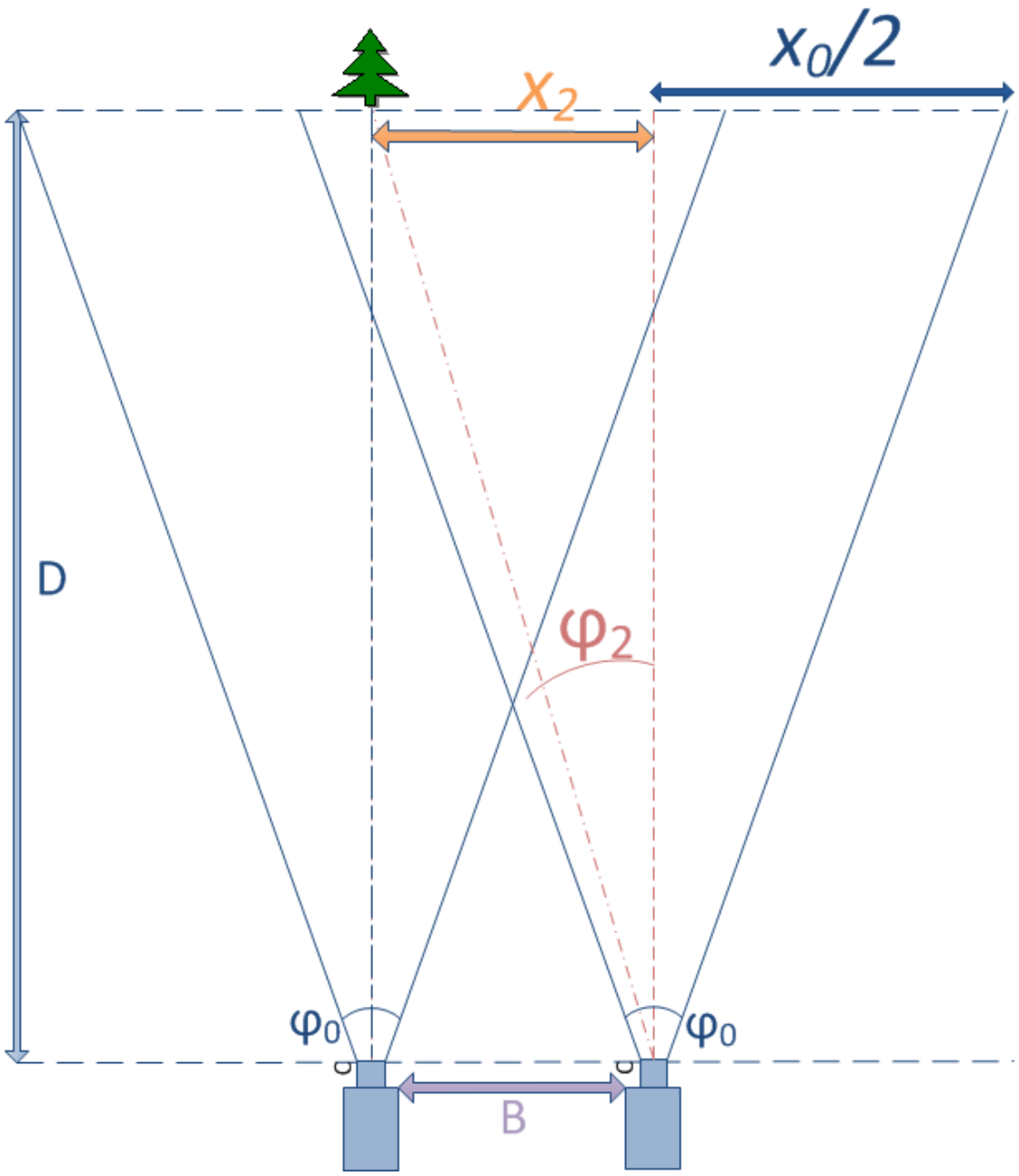


Figure 4.5: Problem 3 - Object is directly in front of a camera

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:

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

Object is directly in front of a camera:

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

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

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

Chapter 5

Conclusions and Further Work

So far, the project has addressed three aspects of the whole design: image acquisition, object matching a range finding. All these aspects have been developed separately on different platforms; on an ATMega644P or in MATLAB.

A full image can be read from a camera and stored on an SD card in a FAT32 filesystem. This gives the ability of removable memory that can be viewed on a computer to see any internal logs. Images are stored in QVGA format (320 by 240 pixels) as a bitmap image.

Multiple comparison algorithms have been investigated and compared using the same test image. It was clear that, although at a sacrifice of computations, the normalised cross correlation is the best with regard to overall reliability.

Range finding equations were then derived, which use the characteristics of the camera and the separation distance between them.

The next steps will be bringing the comparison and range equations together so as to be able to choose an object in a scene and find the range to said object. Object detection algorithms need to be looked into so that an object in view can be detected and correctly located.

Robot movement also needs development. An accurate method to move a distance will be implemented with a proportional or PID controller.

A printed circuit board will also be designed with an AVR32 as the microcontroller and all extra hardware on the board will be included. This will then mean all modules (image acquisition, comparison, range finding etc.) can be ported to the

AVR32 and the robot can be made mobile. Further parts can then be developed such as the occupancy map and search algorithms.

All modules will be tested before being implemented. The final hardware design and development is to be completed by 15th March 2013 and the project report hand-in date is 1st May 2013.

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Circuit Diagrams

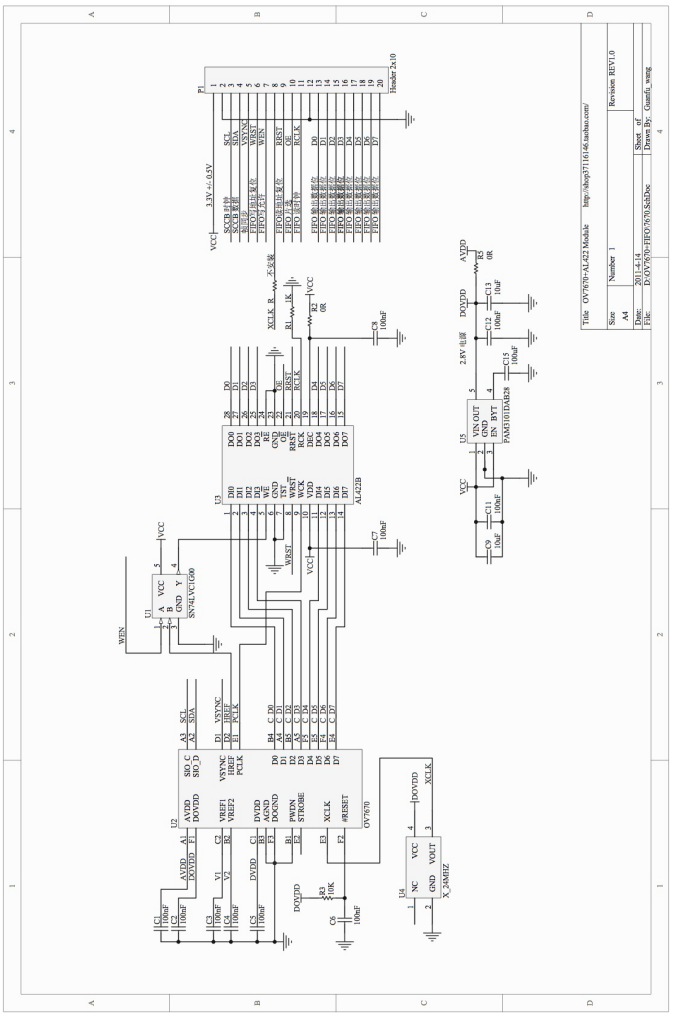

Figure 1: The circuit diagram for the OV7670 breakout board

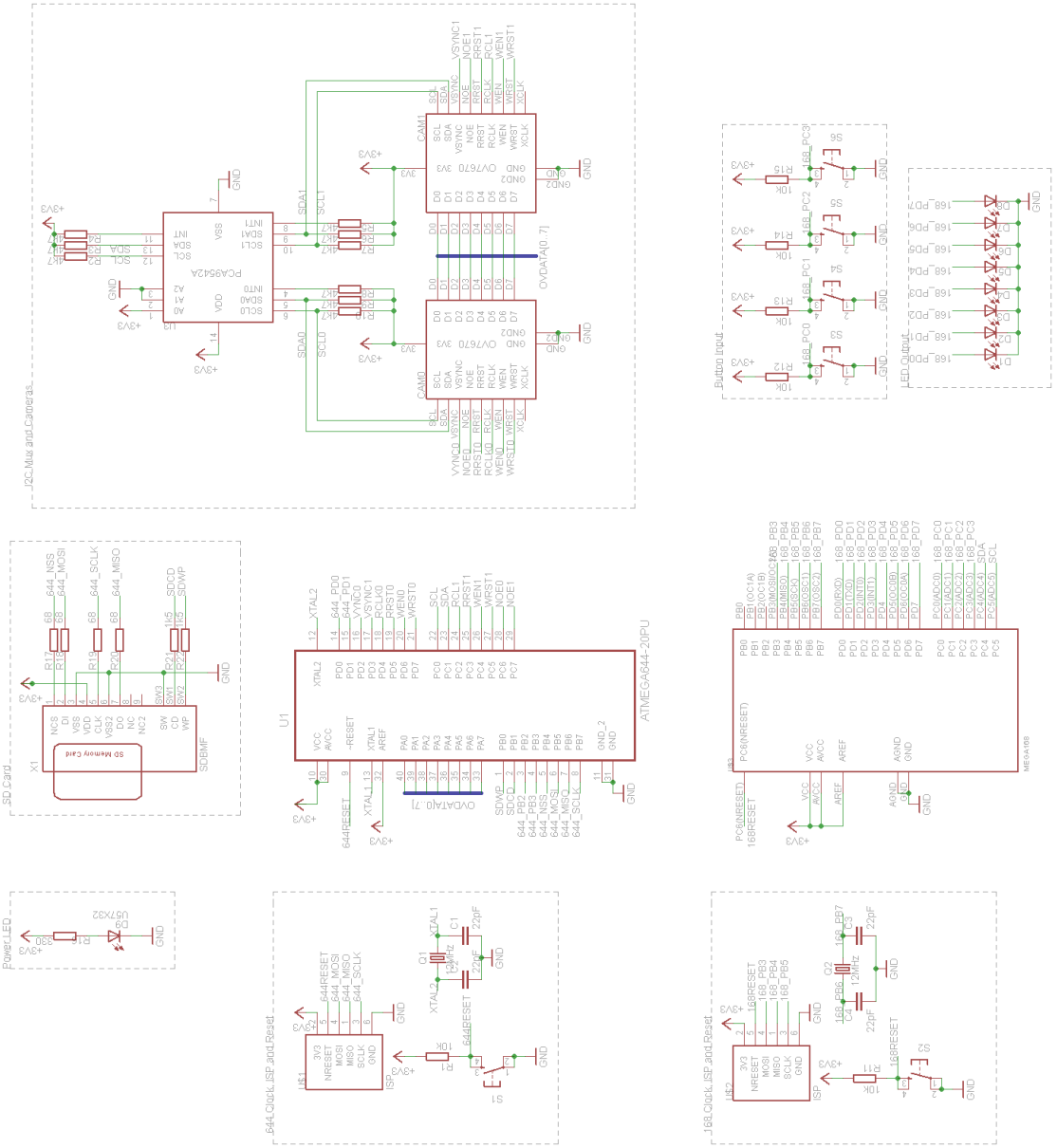

Figure 2: The circuit diagram for Dual Cameras using the Il Matto Board

Bitmap File Format

.1 Bitmap File Format

Table 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 Bitamp 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 Independant Bitmap) Header	Size	Size of the DIB Header (dictates the version)	4	7C000000
	Width	Width of the image (320 pixels)	4	40010000
	Height	Height of the image (240 pixels)	4	F0000000
	Planes	Number of colour planes	2	0100

Continued on next page

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

Table 1 – continued from previous page

Section	Field	Description	Size (Bytes)	Value (hex)
	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
	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

Continued on next page

Table 1 – continued from previous page

Section	Field	Description	Size (Bytes)	Value (hex)
	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

Source Code

.2 C Code for AVR

.2.1 Dual Camera Operation

.2.1.1 main.c

../Code/DualOV7670/main.c

```
/*
 * DualOV7670.c
 *
 * Created: 09/11/2012 11:43:13
 *  Author: hl13g10
 */
#include "Config.h"



//static FILE mystdout = FDEV_SETUP_STREAM(File_Write_Printf, NULL,
    _FDEV_SETUP_WRITE);
//FatFS Variables
FILINFO Finfo;
FATFS Fatfs[_VOLUMES];    /* File system object for each logical drive */
//FIL Files[2];       /* File object */
uint8_t StatusReg;
// char Line[100];         /* Console input buffer */
//char Buff[100];     /* Working buffer */
char ImageRName[20];
char ImageLName[20];
#define STATUS_OKAY     0x01
#define STATUS_SDOkay   0x02
#define STATUS_CAM0Okay   0x04
#define STATUS_CAM1Okay   0x08
#define STATUS_READY    0x10
#define STATUS_CAPTURING  0x20
#define STATUS_Exit_Bad   0x80

#define Button_Capture    0
#define Button_Exit     3
```

```
31 unsigned char UI_LEDs(uint8_t LED)
32 {
33   unsigned char mesbuf[TWI_BUFFER_SIZE];
34   mesbuf[0] = (0x15 << TWI_ADR_BITS) | (FALSE << TWI_READ_BIT);
35   mesbuf[1] = 0x10;
36   mesbuf[2] = LED;
37   TWI_Start_Transceiver_With_Data(mesbuf, 3);
38   while(TWI_Transceiver_Busy()) ;
39   return TWI_statusReg.lastTransOK;
40 }
41 unsigned char UI_Buttons()
42 {
43   unsigned char messageBuf[TWI_BUFFER_SIZE]; //Initialise a buffer
44   messageBuf[0] = (0x15<<TWI_ADR_BITS) | (FALSE<<TWI_READ_BIT); // The first
       byte must always consist of General Call code or the TWI slave address.
45   messageBuf[1] = 0x20;             // The first byte is used for the command
46   TWI_Start_Transceiver_With_Data( messageBuf, 2 );
47   _delay_us(250);
48   // Request/collect the data from the Slave
49   messageBuf[0] = (0x15<<TWI_ADR_BITS) | (TRUE<<TWI_READ_BIT); // The first
       byte must always consist of General Call code or the TWI slave address.
50   TWI_Start_Transceiver_With_Data( messageBuf, 2 );

52   // Get the received data from the transceiver buffer
53   TWI_Get_Data_From_Transceiver( messageBuf, 2 );
54   return messageBuf[1];
55 }
56 ISR(TIMER0_COMPA_vect)
57 {
58   disk_timerproc(); /* Drive timer procedure of low level disk I/O module */
59 //   if(!TWI_statusReg.lastTransOK) //if the last TWI transmission failed,
       reset the protocol
60 //     TWI_Start_Transceiver();
61 //   if(!TWI_Transceiver_Busy())
62 //     UI_LEDs(StatusReg);
63 }
64 int main(void)
65 {
66   unsigned long int a = 0;
67   uint8_t b = 0;
68   FRESULT fr;
69   uint8_t PhotoCount = 0;
70   TWI_Master_Initialise();
71   IO_Init();
72   sei();
73   PCA9542A_Init();

75   StatusReg = STATUS_OKAY;
76   UI_LEDs(StatusReg);


79   fr = f_mount(0, &Fatfs[0]);
80   if(fr != FR_OK)
81   {
82     StatusReg |= (STATUS_Exit_Bad);
83     StatusReg &= ~(STATUS_OKAY);
84     UI_LEDs(StatusReg);
85     return 0;
```

```
86    }
87    else
88      StatusReg |= STATUS_SDOkay;
89    UI_LEDs(StatusReg);

91    fr = f_open(&Files[0], "/log.txt", FA_WRITE|FA_CREATE_ALWAYS);
92    if(fr != FR_OK)
93    {
94      StatusReg |= (STATUS_Exit_Bad);
95      StatusReg &= ~(1<<STATUS_SDOkay) | (1<<STATUS_OKAY);
96      UI_LEDs(StatusReg);
97      return 0;
98    }
99    UI_LEDs(StatusReg);

101   f_close(&Files[0]);
102   f_open(&Files[0], "/log.txt", FA_WRITE);
103   //stdout = &mystdout;
104   b = MCUSR;
105   MCUSR = 0;
106   f_write(&Files[0],"Il Matto Dual Camera\n", sizeof("Il Matto Dual Camera\n")
        , &a);

108   /*f_write(&Files[0], "System Startup Complete.\n", 26, &a);*/

110   PCA9542A_SetChannel(CH1);
111   b = OV7670_init();
112   if(b == 0)
113     StatusReg |= STATUS_CAM1Okay;
114   PCA9542A_SetChannel(NO_SELECT);
115   UI_LEDs(StatusReg);
116   sprintf(Buff, "OV7670_1 Initialise result : %d\n", b);
117   f_write(&Files[0], &Buff, 33, &a);

119   PCA9542A_SetChannel(CH0);
120   b = OV7670_init();
121   if(b == 0)
122     StatusReg |= STATUS_CAM0Okay;
123   UI_LEDs(StatusReg);
124   PCA9542A_SetChannel(NO_SELECT);
125   sprintf(Buff, "OV7670_0 Initialise result : %d\n", b);
126   f_write(&Files[0], &Buff, 33, &a);
127   FIFO_init();

129   //f_close(&Files[0]);
130   StatusReg |= STATUS_READY;
131   UI_LEDs(StatusReg);
132   _delay_ms(250);
133   uint8_t Input;

135     while(1)
136     {
137     Input = (~UI_Buttons() & 0x0F);//Data is received negative
138     if(Input)//if a button has been pressed
139     {
140       _delay_ms(250);
141       sprintf(Buff, "Button Received : %d\n", Input);
142       f_write(&Files[0], Buff, 21, &a);
```

```
144         StatusReg&= ~(STATUS_READY);//no longer ready

146         switch(Input)
147         {
148           case (1<<Button_Capture):
149             StatusReg |= STATUS_CAPTURING;
150             UI_LEDs(StatusReg);
151             //Reset both buffers
152             FIFO_Reset(0);
153             FIFO_Reset(1);
154             f_write(&Files[0], "Capturing Images...\n", 20, &a);
155             LoadImagesToBuffer();//Load both images

157             //Create Bitmap for image 0
158             //PSTR("Image_r.bmp");

160             f_open(&Files[1], "Image_r.bmp", FA_CREATE_ALWAYS | FA_WRITE);
161             f_write(&Files[0], "Created image0 file.\n", 22, &a);
162             f_lseek(&Files[1], BMPFileSize);
163             f_lseek(&Files[1], 0);
164             f_close(&Files[1]);
165             f_write(&Files[0], "Extended image0 file.\n", 22, &a);

167             //Create Bitmap for image 1
168             f_open(&Files[1],"image_l.bmp", FA_CREATE_ALWAYS | FA_WRITE);
169             f_write(&Files[0], "Created image1 file.\n", 22, &a);
170             f_lseek(&Files[1], BMPFileSize);
171             f_lseek(&Files[1], 0);
172             f_close(&Files[1]);
173             f_write(&Files[0], "Extended image1 file.\n", 22, &a);
174             //Get image 0
175             f_open(&Files[1], "Image_r.bmp", FA_WRITE);
176             while (2 == GetImageIfAvailiable(&Files[1], 0)) ;
177             f_close(&Files[1]);
178             f_write(&Files[0], "Captured image0.\n", 17, &a);
179             //get image 1
180             f_open(&Files[1], "image_l.bmp", FA_WRITE);
181             while (2 == GetImageIfAvailiable(&Files[1], 1)) ;
182             f_close(&Files[1]);
183             f_write(&Files[0], "Captured image1.\n", 17, &a);
184             StatusReg |= STATUS_READY;
185             StatusReg &= ~STATUS_CAPTURING;
186             UI_LEDs(StatusReg);
187             break;//break case(1<<ButtonCapture)

189           case (1<<Button_Exit):
190             f_write(&Files[0], "\nSystem Exiting...\n",19 ,&a);
191             f_close(&Files[0]);//close log file

193             StatusReg = 0x41;
194             UI_LEDs(StatusReg);
195             return 0;//Q
196         }//End switch
197       }//End if(Input)
198       else
199       {
200         StatusReg |= STATUS_READY;
```

```
201         UI_LEDs(StatusReg);
202         _delay_ms(250);//wait
203       }//end else(Input)
204       }//End while(1)
205   }//End Main
```

.2.1.2 Bitmap.h

../Code/DualOV7670/Bitmap.h

```
1   /*
2    * Bitmap.h
3    *
4    * Created: 29/10/2012 11:31:11
5    *  Author: hslovett
6    */
7
8
9   #ifndef BITMAP_H_
10  #define BITMAP_H_
11
12  #define BMPHEADERSIZE 14
13  #define DIBHEADERSIZE 124 //v5
14  #define FILESIZE 153738
15
16  #include "ff.h"
17  #include "Config.h"
18
19
20  FRESULT WriteBMPHeader(FIL *File);
21  FRESULT WriteDIBHeader(FIL *File);
22
23
24  #endif /* BITMAP_H_ */
```

.2.1.3 Bitmap.c

../Code/DualOV7670/Bitmap.c

```
1   /*
2    * Bitmap.c
3    * Contains Methods to write the Bitmap and DIB Header. File must already be
       open.
4    * Created: 29/10/2012 11:30:58
5    *  Author: Henry Lovett (hl13g10@ecs.soton.ac.uk)
6    */
7   #include "Bitmap.h"
8
9   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
```

```
                    0x01, 0x00,       //Planes
                    0x10, 0x00,       //Bits per Pixel
                    0x03, 0x00, 0x00, 0x00, //Compression
                    0x00, 0x86, 0x25, 0x00, //Size of Raw Data
                    0x13, 0x0B, 0x00, 0x00, //Horizontal Resolution
                    0x13, 0x0B, 0x00, 0x00, //Vertical Resolution
                    0x00, 0x00, 0x00, 0x00, //Colours in Palette
                    0x00, 0x00, 0x00, 0x00, //Important Colours
                    0x00, 0xF8, 0x00, 0x00, //Red Mask
                    0xE0, 0x07, 0x00, 0x00, //Green Mask
                    0x1F, 0x00, 0x00, 0x00, //Blue Mask
                    0x00, 0x00, 0x00, 0x00, //Alpha Mask
                    0x01, 0x00, 0x00, 0x00, //Colour Space Type
                    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, //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

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



FRESULT WriteBMPHeader(FIL *File)
{
  uint32_t p;
  FRESULT f;

  f_lseek(File, 0);
  f = f_write(File, BMPHeader, BMPHEADERSIZE, &p);

  return f;
}

FRESULT WriteDIBHeader(FIL *File)
{
  uint32_t p;
  FRESULT f;

  f_lseek(File, BMPHEADERSIZE);//place just after the bitmap header
  f = f_write(File, DIBHead, DIBHEADERSIZE, &p);
  return f;
}
```

.2.1.4 Config.h

../Code/DualOV7670/Config.h

```
/*
 * Config.h
 *
 * Created: 25/10/2012 21:58:56
 *  Author: hslovett
 */
#define F_CPU 12000000UL
#include <avr/io.h>
#include <avr/interrupt.h>
#include <avr/pgmspace.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <util/delay.h>
#include "TWI_Master.h"
#include "ff.h"
#include "diskio.h"
#include "Bitmap.h"
#include "DualCameras.h"
#include "PCA9542A.h"
#ifndef CONFIG_H_
#define CONFIG_H_


void IO_Init(void);

#define TRUE 1
#define FALSE 0

FIL Files[2];
char Buff[1024];

#define BMPFileSize   153738
#define RGBFileSize   153600
////////////////////////////////////////////////////////////////////////
//  Port A
////////////////////////////////////////////////////////////////////////
#define FIFO_AVR_DPRT   DDRA
#define FIFO_AVR_PORT   PORTA
#define FIFO_AVR_PINP   PINA
////////////////////////////////////////////////////////////////////////
//  Port B
////////////////////////////////////////////////////////////////////////
#define SD_WP      PB0
#define SD_CD      PB1
//#define          PB2
//#define          PB3
#define SPI_nSS_SD    PB4
```

```
49 #define SPI_MOSI    PB5
50 #define SPI_MISO    PB6
51 #define SPI_SCK     PB7
52 ////////////////////////////////////////////////////////////////////////
53 //  Port C
54 ////////////////////////////////////////////////////////////////////////
55 #define TWI_SCL     PC0
56 #define TWI_SDA     PC1
57 #define FIFO_RCLK_1   PC2
58 #define FIFO_nRRST_1  PC3
59 #define FIFO_WEN_1    PC4
60 #define FIFO_WRST_1   PC5
61 #define FIFO_nOE_0    PC6
62 #define FIFO_nOE_1    PC7
63 ////////////////////////////////////////////////////////////////////////
64 //  Port D
65 ////////////////////////////////////////////////////////////////////////
66 #define USART0_RX   PD0
67 #define USART0_TX   PD1
68 #define OV7670_VSYNC_0  PD2 //MUST BE AN INTERRUPT PIN
69 #define OV7670_VSYNC_1  PD3 //MUST BE AN INTERRUPT PIN
70 #define FIFO_RCLK_0   PD4
71 #define FIFO_nRRST_0  PD5
72 #define FIFO_WEN_0    PD6
73 #define FIFO_WRST_0   PD7



77 #endif /* CONFIG_H_ */
```

.2.1.5 Config.c

../Code/DualOV7670/Config.c

```
1  /*
2   * Config.c
3   *
4   * Contains Global Methods and initialisations
5   *
6   * Created: 25/10/2012 21:59:06
7   *  Author: hslovett
8   */

10 #include "Config.h"
11 #include <avr/io.h>
12 void IO_Init(void)
13 {
14   //initialise timer 0 to interrupt every 10 ms
15   TIMSK0 |= (1 << OCIE0A);
16   TCCR0A |= (1 << WGM01);
17   OCR0A = 117; //10ms interrupt at 12MHz
18   TCCR0B |= (1 << CS02) | (1 << CS00);
```

```
21    DDRA = 0x00;
22    //PORTB = 0xBF;
23    DDRC = 0xFC;
24    DDRD = 0xF2;



28    //set int0 and int1 to trigger on falling edge
29    EIMSK = (1 << INT0) | (1 << INT1);        //Enable INT0 and INT1
30    EICRA = (1 << ISC01) | (1 << ISC11);      //Trigger INT0 and INT1 on the
        falling edge
31  }
```

.2.1.6 DualCameras.h

../Code/DualOV7670/DualCameras.h

```
1   /*
2    * DualCameras.h
3    *
4    * Created: 10/11/2012 15:19:52
5    *  Author: hslovett
6    */


9   #ifndef DUALCAMERAS_H_
10  #define DUALCAMERAS_H_

12  #include "Config.h"

14  ////////////////////////////////////////////////////////////////////////
15  //  Constants
16  ////////////////////////////////////////////////////////////////////////
17  #define HEIGHT        240
18  #define WIDTH       320
19  #define PIXELSIZE     2
20  #define SETTINGS_LENGTH   167
21  #define OV7670_ADDR     0x21
22  ////////////////////////////////////////////////////////////////////////
23  //  Globals
24  ////////////////////////////////////////////////////////////////////////
25  const char default_settings[SETTINGS_LENGTH][2];
26  volatile uint8_t VSYNC_0_Count;
27  volatile uint8_t VSYNC_1_Count;
28  ////////////////////////////////////////////////////////////////////////
29  //  Methods
30  ////////////////////////////////////////////////////////////////////////
31  unsigned char OV7670_init(void);              //Initialises Camera
32  void FIFO_init(void);         //Initialises Buffer
33  uint8_t GetImageIfAvailiable(FIL *File, uint8_t CameraID);
34  void LoadImagesToBuffer(void);
35  unsigned char rdOV7670Reg(unsigned char regID, unsigned char *regDat);
36  unsigned char OV7670_SCCB_init(void);
37  void FIFO_Reset(uint8_t CameraID);
```

```
38 ////////////////////////////////////////////////////////////////////////
39 //  Pins & Macros
40 ////////////////////////////////////////////////////////////////////////
41 #define FIFO_RCLK_1   PC2
42 #define FIFO_nRRST_1  PC3
43 #define FIFO_WEN_1    PC4
44 #define FIFO_WRST_1   PC5
45 #define FIFO_nOE_0    PC6
46 #define FIFO_nOE_1    PC7

48 #define FIFO_RCLK_1_SET   { PORTC |= (1 <<  FIFO_RCLK_1); }
49 #define FIFO_RCLK_1_CLR   { PORTC &= ~(1 << FIFO_RCLK_1); }
50 #define FIFO_nRRST_1_SET  { PORTC |= (1 <<  FIFO_nRRST_1);  }
51 #define FIFO_nRRST_1_CLR  { PORTC &= ~(1 << FIFO_nRRST_1);  }
52 #define FIFO_WEN_1_SET    { PORTC |= (1 <<  FIFO_WEN_1);  }
53 #define FIFO_WEN_1_CLR    { PORTC &= ~(1 << FIFO_WEN_1);  }
54 #define FIFO_WRST_1_SET   { PORTC |= (1 <<  FIFO_WRST_1); }
55 #define FIFO_WRST_1_CLR   { PORTC &= ~(1 << FIFO_WRST_1); }
56 #define FIFO_nOE_0_SET    { PORTC |= (1 << FIFO_nOE_0);   }
57 #define FIFO_nOE_0_CLR    { PORTC &= ~(1 << FIFO_nOE_0);  }
58 #define FIFO_nOE_1_SET    { PORTC |= (1 << FIFO_nOE_1);   }
59 #define FIFO_nOE_1_CLR    { PORTC &= ~(1 << FIFO_nOE_1);  }


62 #define FIFO_RCLK_0   PD4
63 #define FIFO_nRRST_0  PD5
64 #define FIFO_WEN_0    PD6
65 #define FIFO_WRST_0   PD7

67 #define FIFO_RCLK_0_SET   { PORTD |= (1 <<  FIFO_RCLK_0); }
68 #define FIFO_RCLK_0_CLR   { PORTD &= ~(1 << FIFO_RCLK_0); }
69 #define FIFO_nRRST_0_SET  { PORTD |= (1 <<  FIFO_nRRST_0);  }
70 #define FIFO_nRRST_0_CLR  { PORTD &= ~(1 << FIFO_nRRST_0);  }
71 #define FIFO_WEN_0_SET    { PORTD |= (1 <<  FIFO_WEN_0);  }
72 #define FIFO_WEN_0_CLR    { PORTD &= ~(1 << FIFO_WEN_0);  }
73 #define FIFO_WRST_0_SET   { PORTD |= (1 <<  FIFO_WRST_0); }
74 #define FIFO_WRST_0_CLR   { PORTD &= ~(1 << FIFO_WRST_0); }

76 ////////////////////////////////////////////////////////////////////////
77 //Camera Register Address definitions
78 ////////////////////////////////////////////////////////////////////////
79 #define OV_GAIN     0x00  //Gain Control Setting - ACG[7:0]
80 #define OV_BLUE     0x01  //Blue Channel Gain
81 #define OV_RED      0x02  //Red Channel Gain
82 #define OV_VREF     0x03  //Vertical Frame Control & ACG[9:8]
83 #define OV_COM1     0x04  //CCIR656 enable, AEC low bits (AECHH, AECH)
84 #define OV_BAVE     0x05  //U/B Average level - AUTO UPDATED
85 #define OV_GbAVE    0x06  //Y/Gb Average Level - AUTO UPDATED
86 #define OV_AECHH    0x07  //Exposure value [15:10] (AECH, COM1)
87 #define OV_RAVE     0x08  //V/R Average level - AUTO UPDATED
88 #define OV_COM2     0x09  //Soft Sleep, Output drive capability
89 #define OV_PID      0x0A  //Product ID MSB  Read only
90 #define OV_VER      0x0B  //Product ID LSB  Read Only
91 #define OV_COM3     0x0C  //Output data MSB/LSB swap + other stuff
92 #define OV_COM4     0x0D  //Average values - MUST BE SAME AS COM17
93 #define OV_COM5     0x0E  //RESERVED
94 #define OV_COM6     0x0F  //COM6
95 #define OV_AECH     0x10  //Exposure value [9:2] (see AECHH, COM1)
```

```
96  #define OV_CLKRC     0x11  //Internal Clock options
97  #define OV_COM7      0x12  //RESET, Output format
98  #define OV_COM8      0x13  //Common control 8
99  #define OV_COM9      0x14  //Automatic Gain Ceiling
100 #define OV_COM10     0x15  //PCLK, HREF and VSYNC options
101 #define OV_RSVD      0x16  //RESERVED
102 #define OV_HSTART    0x17  //Output format Horizontal Frame start
103 #define OV_HSTOP     0x18  //Output format Horizontal Frame end
104 #define OV_VSTRT     0x19  //Output format Vertical Frame start
105 #define OV_VSTOP     0x1A  //Output format Vertical Frame Stop
106 #define OV_PSHFT     0x1B  //Pixel Delay Select
107 #define OV_MIDH      0x1C  //Manufacturer ID MSB -   READ ONLY
108 #define OV_MIDL      0x1D  //Manufacturer ID LSB -   READ ONLY
109 #define OV_MVFP      0x1E  //Mirror / VFlip Enable
110 #define OV_LAEC      0x1F  //RESERVED
111 #define OV_ADCCTR0    0x20  //ADC Control
112 #define OV_ADCCTR1    0x21  //RESERVED
113 #define OV_ADCCTR2    0x22  //RESERVED
114 #define OV_ADCCTR3    0x23  //RESERVED
115 #define OV_AEW       0x24  //ACG/AEC Stable Operating Region Upper Limit
116 #define OV_AEB       0x25  //ACG/AEC Stable Operation Region Lower Limit
117 #define OV_VPT       0x26  //ACG/AEC Fast Mode Operation Region
118 #define OV_BBIAS     0x27  //B Channel Signal Output Bias
119 #define OV_GbBIAS    0x28  //Gb Channel Output Bias
120 #define OV_RSVD1     0x29  //RESERVED
121 #define OV_EXHCH     0x2A  //Dummy Pixel Insert MSB
122 #define OV_EXHCL     0x2B  //Dummy Pixel Insert LSB
123 #define OV_RBIAS     0x2C  //R Channel Signal Output Bias
124 #define OV_ADVFL     0x2D  //LSB of insert dummy line in vertical direction
125 #define OV_ADVFH     0x2E  //MSB of insert dummy line in vertical direction
126 #define OV_YAVE      0x2F  //Y/G Channel Average Value
127 #define OV_HSYST     0x30  //HSYNC Rising Edge Delay (low 8 bits)
128 #define OV_HSYEN     0x31  //HSYNCE Falling Edge Delay (low 8 bits)
129 #define OV_HREF      0x32  //HREF Control
130 #define OV_CHLF      0x33  //Array Current Control - RESERVED
131 #define OV_ARBLM     0x34  //Array Reference Control - RESERVED
132 #define OV_RSVD2     0x35  //RESERVED
133 #define OV_RSVD3     0x36  //RESERVED
134 #define OV_ADCCTRL    0x37  //ADC Control - RESERVED
135 #define OV_ACOM      0x38  //ADC and Analog Common Mode Control - RESERVED
136 #define OV_OFON      0x39  //ADC Offset Control
137 #define OV_TSLB      0x3A  //Line Buffer Test Option
138 #define OV_COM11     0x3B  //COM11
139 #define OV_COM12     0x3C  //COM12
140 #define OV_COM13     0x3D  //COM13
141 #define OV_COM14     0x3E  //COM14
142 #define OV_EDGE      0x3F  //Edge Detection Adjustment
143 #define OV_COM15     0x40  //COM15
144 #define OV_COM16     0x41  //COM16
145 #define OV_COM17     0x42  //COM17
146 #define OV_AWBC1     0x43
147 #define OV_AWBC2     0x44
148 #define OV_AWBC3     0x45
149 #define OV_AWBC4     0x46
150 #define OV_AWBC5     0x47
151 #define OV_AWBC6     0x48
152 #define OV_RSVD4     0x49
153 #define OV_RSVD5     0x40
```

```
154 #define OV_RSVD6    0x4A
155 #define OV_REG4B    0x4B
156 #define OV_DNSTH    0x4C
157 #define OV_RSVD7    0x4D
158 #define OV_RSVD8    0x4E
159 #define OV_MTX1     0x4F
160 #define OV_MTX2     0x50
161 #define OV_MTX3     0x51
162 #define OV_MTX4     0x52
163 #define OV_MTX5     0x53
164 #define OV_MTX6     0x54
165 #define OV_BRIGHT   0x55
166 #define OV_CONTRAS    0x56
167 #define OV_CONTRASCNTR  0x57
168 #define OV_MTXS     0x58
169 #define OV_RSVD9    0x59
170 #define OV_RSVD9_1    0x5A
171 #define OV_RSVD9_2    0x5B
172 #define OV_RSVD9_3    0x5C
173 #define OV_RSVD9_4    0x5D
174 #define OV_RSVD9_5    0x5E
175 #define OV_RSVD9_6    0x5F
176 #define OV_RSVD10   0x60
177 #define OV_RSVD11   0x61
178 #define OV_LCC1     0x62
179 #define OV_LCC2     0x63
180 #define OV_LCC3     0x64
181 #define OV_LCC4     0x65
182 #define OV_LCC5     0x66
183 #define OV_MANU     0x67
184 #define OV_MANV     0x68
185 #define OV_GFIX     0x69
186 #define OV_GGAIN    0x6A
187 #define OV_DBLV     0x6B
188 #define OV_AWBCTR3    0x6C
189 #define OV_AWBCTR2    0x6D
190 #define OV_AWBCTR1    0x6E
191 #define OV_AWBCTR0    0x6F
192 #define OV_SCALING_XSC  0x70
193 #define OV_SCALING_YSC  0x71
194 #define OV_SCALING_DCWCTR 0x72
195 #define OV_SCALING_PCLK_DIV 0x73
196 #define OV_REG74    0x74
197 #define OV_REG75    0x75
198 #define OV_REG76    0x76
199 #define OV_REG77    0x77
200 #define OV_RSVD12   0x78
201 #define OV_RSVD13   0x79
202 #define OV_GAM1     0x7A
203 #define OV_GAM2     0x7B
204 #define OV_GAM3     0x7C
205 #define OV_GAM4     0x7D
206 #define OV_GAM5     0x7E
207 #define OV_GAM6     0x7F
208 #define OV_GAM7     0x80
209 #define OV_GAM8     0x81
210 #define OV_GAM9     0x82
211 #define OV_GAM10    0x83
```

```
212 #define OV_GAM11    0x84
213 #define OV_GAM12    0x85
214 #define OV_GAM13    0x86
215 #define OV_GAM14    0x87
216 #define OV_GAM15    0x88
217 #define OV_GAM16    0x89
218 #define OV_RSVD14   0x8A
219 #define OV_RSVD15   0x8B
220 #define OV_RSVD16   0x8C
221 #define OV_RSVD17   0x8D
222 #define OV_RSVD18   0x8E
223 #define OV_RSVD19   0x8F
224 #define OV_RSVD20   0x90
225 #define OV_RSVD21   0x91
226 #define OV_DM_LNL   0x92
227 #define OV_DM_LNH   0x93
228 #define OV_LCC6     0x94
229 #define OV_LCC7     0x95
230 #define OV_RSVD22   0x96
231 #define OV_RSVD23   0x97
232 #define OV_RSVD24   0x98
233 #define OV_RSVD25   0x99
234 #define OV_RSVD26   0x9A
235 #define OV_RSVD27   0x9B
236 #define OV_RSVD28   0x9C
237 #define OV_BD50ST   0x9D
238 #define OV_BD60ST   0x9E
239 #define OV_HIST0    0x9F
240 #define OV_HIST1    0xA0
241 #define OV_HIST2    0xA1
242 #define OV_HIST3    0xA2
243 #define OV_HIST4    0xA3
244 #define OV_HIST5    0xA4
245 #define OV_HIST6    0xA5
246 #define OV_HIST7    0xA6
247 #define OV_HIST8    0xA7
248 #define OV_HIST9    0xA8
249 #define OV_HIST10   0xA9
250 #define OV_HIST11   0xAA
251 #define OV_HIST12   0xAB
252 #define OV_STR_OPT    0xAC
253 #define OV_STR_R    0xAD
254 #define OV_STR_G    0xAE
255 #define OV_STR_B    0xAF
256 #define OV_RSVD28_1   0xB0
257 #define OV_RSVD29   0xB1
258 #define OV_RSVD30   0xB2
259 #define OV_THL_ST   0xB3
260 #define OV_RSVD31   0xB4
261 #define OV_THL_DLT    0xB5
262 #define OV_RSVD32   0xB6
263 #define OV_RSVD33   0xB7
264 #define OV_RSVD34   0xB8
265 #define OV_RSVD35   0xB9
266 #define OV_RSVD36   0xBA
267 #define OV_RSVD37   0xBB
268 #define OV_RSVD38   0xBC
269 #define OV_RSVD39   0xBD
```

```
270 #define OV_AD_CHB   0xBE
271 #define OV_AD_CHR   0xBF
272 #define OV_AD_CHGb    0xC0
273 #define OV_AD_CHGr    0xC1
274 #define OV_RSVD40   0xC2
275 #define OV_RSVD41   0xC3
276 #define OV_RSVD42   0xC4
277 #define OV_RSVD43   0xC5
278 #define OV_RSVD44   0xC6
279 #define OV_RSVD45   0xC7
280 #define OV_RSVD46   0xC8
281 #define OV_SATCTR   0xC9

283 #endif /* DUALCAMERAS_H_ */
```

.2.1.7 DualCameras.c

../Code/DualOV7670/DualCameras.c

```
1  /*
2   * DualCameras.c
3   *
4   * Created: 10/11/2012 15:20:03
5   *  Author: hl13g10
6   */

8  #include "DualCameras.h"

10 const char default_settings[SETTINGS_LENGTH][2]=
11 {
12 {OV_TSLB, 0x04},
13 {OV_COM15, 0xd0},//RGB565 / RGB555
14 {OV_COM7, 0x14},
15 {OV_HREF, 0x80},
16 {OV_HSTART, 0x16},
17 {OV_HSTOP, 0x04},
18 {OV_VSTRT, 0x02},
19 {OV_VSTOP, 0x7b},//0x7a,
20 {OV_VREF, 0x06},//0x0a,
21 {OV_COM3, 0x00},
22 {OV_COM14, 0x00},//
23 {OV_SCALING_XSC, 0x00},
24 {OV_SCALING_YSC, 0x00},
25 {OV_SCALING_DCWCTR, 0x11},
26 {OV_SCALING_PCLK_DIV, 0x00},//
27 {0xa2, 0x02},
28 {OV_CLKRC, 0x01},
29 {OV_GAM1, 0x20},
30 {OV_GAM2, 0x1c},
31 {OV_GAM3, 0x28},
32 {OV_GAM4, 0x3c},
33 {OV_GAM5, 0x55},
34 {OV_GAM6, 0x68},
35 {OV_GAM7, 0x76},
```

```
36  {OV_GAM8, 0x80},
37  {OV_GAM9, 0x88},
38  {OV_GAM10, 0x8f},
39  {OV_GAM11, 0x96},
40  {OV_GAM12, 0xa3},
41  {OV_GAM13, 0xaf},
42  {OV_GAM14, 0xc4},
43  {OV_GAM15, 0xd7},
44  {OV_GAM16, 0xe8},
45  {OV_COM8, 0xe0},
46  {OV_GAIN, 0x00},//AGC
47  {OV_AECH, 0x00},
48  {OV_COM4, 0x00},
49  {OV_COM9, 0x20},//0x38, limit the max gain
50  {OV_HIST6, 0x05},
51  {OV_HIST12, 0x07},
52  {OV_AEW, 0x75},
53  {OV_AEB, 0x63},
54  {OV_VPT, 0xA5},
55  {OV_HIST0, 0x78},
56  {OV_HIST1, 0x68},
57  {OV_HIST2, 0x03},//0x0b,
58  {OV_HIST7, 0xdf},//0xd8,
59  {OV_HIST8, 0xdf},//0xd8,
60  {OV_HIST9, 0xf0},
61  {OV_HIST10, 0x90},
62  {OV_HIST11, 0x94},
63  {OV_COM8, 0xe5},
64  {OV_COM5, 0x61},
65  {OV_COM6, 0x4b},
66  {0x16, 0x02},
67  {OV_MVFP, 0x27},//0x37,
68  {0x21, 0x02},
69  {0x22, 0x91},
70  {0x29, 0x07},
71  {0x33, 0x0b},
72  {0x35, 0x0b},
73  {0x37, 0x1d},
74  {0x38, 0x71},
75  {OV_OFON, 0x2a},//
76  {OV_COM12, 0x78},
77  {0x4d, 0x40},
78  {0x4e, 0x20},
79  {OV_GFIX, 0x0c},//////////////////////
80  {OV_DBLV, 0x60},//PLL
81  {OV_REG74, 0x19},
82  {0x8d, 0x4f},
83  {0x8e, 0x00},
84  {0x8f, 0x00},
85  {0x90, 0x00},
86  {0x91, 0x00},
87  {OV_DM_LNL, 0x00},//0x19,//0x66
88  {0x96, 0x00},
89  {0x9a, 0x80},
90  {0xb0, 0x84},
91  {0xb1, 0x0c},
92  {0xb2, 0x0e},
93  {OV_THL_ST, 0x82},
```

```
94  {0xb8, 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

180 };



184 //ISR for controlling WEN.
185 ISR(INT0_vect)
186 {
187   //printf("ISR INT0 Entered\n");
188   if (VSYNC_0_Count==1)//start a frame read
189   {
190     FIFO_WEN_0_SET;
191     VSYNC_0_Count++;
192   }
193   else if (VSYNC_0_Count==2)//end a frame read
194   {
195     FIFO_WEN_0_CLR;
196     VSYNC_0_Count++;
197   }
198   else if(VSYNC_0_Count == 3)
199   {
200     FIFO_WEN_0_CLR;
201   }
202   else
203   {
204     FIFO_WEN_0_CLR
205     VSYNC_0_Count = 0;//wait for a read to be started
206   }
207 }
208 //ISR for controlling WEN.
209 ISR(INT1_vect)
```

```
210 {
211   //printf("ISR INT1 Entered\n");
212   if (VSYNC_1_Count==1)//start a frame read
213   {
214     FIFO_WEN_1_SET;
215     VSYNC_1_Count++;
216   }
217   else if (VSYNC_1_Count==2)//end a frame read
218   {
219     FIFO_WEN_1_CLR;
220     VSYNC_1_Count++;
221   }
222   else if(VSYNC_1_Count == 3)
223   {
224     FIFO_WEN_1_CLR;
225   }
226   else
227   {
228     FIFO_WEN_1_CLR
229     VSYNC_1_Count = 0;//wait for a read to be started
230   }
231 }

233 //Write Register Method
234 unsigned char wrOV7670Reg(unsigned char regID, unsigned char regDat)
235 {
236   /*  I2C Traffic Generated:
237    *  S | OV_7670 + W | A | RegID | A | Data | A | P |
238    */
239   //I2C Interface
240   unsigned char messageBuf[TWI_BUFFER_SIZE];
241   messageBuf[0] = (OV7670_ADDR  <<TWI_ADR_BITS) | (FALSE<<TWI_READ_BIT); //
        The first byte must always consit of General Call code or the TWI slave
        address.
242   messageBuf[1] = regID;             // The first byte is used for commands.
243   messageBuf[2] = regDat;                          // The second byte is used
        for the data.
244   TWI_Start_Transceiver_With_Data( messageBuf, 3 );

246   while(TWI_Transceiver_Busy()) ; //Wait for transceiver to clear

248   return TWI_statusReg.lastTransOK;
249 }

251 //Read Register Method
252 unsigned char rdOV7670Reg(unsigned char regID, unsigned char *regDat)
253 {
254   /*  I2C Traffic Generated:
255    *  S | OV_ADDR + W | A | RegID | A | P |
256    *  S | OV_ADDR + R | A | Data  |~A | P |
257    */
258   //I2C Interface
259   unsigned char messageBuf[TWI_BUFFER_SIZE]; //Initialise a buffer
260   messageBuf[0] = (OV7670_ADDR<<TWI_ADR_BITS) | (FALSE<<TWI_READ_BIT); // The
        first byte must always consist of General Call code or the TWI slave
        address.
261   messageBuf[1] = regID;             // The first byte is used for Address
        Pointer.
```

```
262   TWI_Start_Transceiver_With_Data( messageBuf, 2 );

264   // Request/collect the data from the Slave
265   messageBuf[0] = (OV7670_ADDR<<TWI_ADR_BITS) | (TRUE<<TWI_READ_BIT); // The
        first byte must always consist of General Call code or the TWI slave
        address.
266   TWI_Start_Transceiver_With_Data( messageBuf, 2 );

268   // Get the received data from the transceiver buffer
269   TWI_Get_Data_From_Transceiver( messageBuf, 2 );
270   *regDat = messageBuf[1];
271   return TWI_statusReg.lastTransOK;
272 }


275 unsigned char OV7670_init()
276 {
277   uint8_t i = 0;
278   if(0==wrOV7670Reg(OV_COM7, 0x80)) //Reset Camera
279   {
280     return 1;
281   }
282   _delay_ms(10);
283   for(i=0; i<SETTINGS_LENGTH; i++)
284   {
285     if( 0==wrOV7670Reg(default_settings[i][0], default_settings[i][1] ))
286     {
287       return 1;
288     }
289     _delay_ms(1);
290   }

292   return 0;
293 }

295 void FIFO_init( void )
296 {
297   //disable both outputs
298   FIFO_nOE_0_SET;
299   FIFO_nOE_1_SET;
300   //Reset Buffer 0
301   FIFO_WRST_0_CLR;
302   FIFO_RCLK_0_CLR;
303   //FIFO_nOE_0_CLR;
304   FIFO_nRRST_0_SET;
305   FIFO_WEN_0_CLR;
306   _delay_us(10);
307   FIFO_RCLK_0_SET;
308   _delay_us(10);
309   FIFO_RCLK_0_CLR;
310   FIFO_nRRST_0_CLR;
311   _delay_us(10);
312   FIFO_RCLK_0_SET;
313   _delay_us(10);
314   FIFO_RCLK_0_CLR;
315   FIFO_nRRST_0_SET;
316   _delay_us(10);
317   FIFO_WRST_0_SET;
```

```
319   //Reset Buffer 1
320   FIFO_WRST_1_CLR;
321   FIFO_RCLK_1_CLR;
322   //FIFO_nOE_1_CLR;
323   FIFO_nRRST_1_SET;
324   FIFO_WEN_1_CLR;
325   _delay_us(10);
326   FIFO_RCLK_1_SET;
327   _delay_us(10);
328   FIFO_RCLK_1_CLR;
329   FIFO_nRRST_1_CLR;
330   _delay_us(10);
331   FIFO_RCLK_1_SET;
332   _delay_us(10);
333   FIFO_RCLK_1_CLR;
334   FIFO_nRRST_1_SET;
335   _delay_us(10);
336   FIFO_WRST_1_SET;

338 }

340 //Write one pixel in AVR
341 uint16_t FIFO_TO_AVR(uint8_t ID)
342 {
343   uint16_t data = 0;

345   DDRA = 0;
346   if(ID == 1)
347   {
348     FIFO_RCLK_1_SET;
349     data = PINA;
350     FIFO_RCLK_1_CLR;
351     data <<= 8;
352     FIFO_RCLK_1_SET;
353     data |= PINA;
354     FIFO_RCLK_1_CLR;
355   }
356   else
357   {
358     FIFO_RCLK_0_SET;
359     data = PINA;
360     FIFO_RCLK_0_CLR;
361     data <<= 8;
362     FIFO_RCLK_0_SET;
363     data |= PINA;
364     FIFO_RCLK_0_CLR;
365   }
366   return(data);
367 }


370 //Resets both pointers
371 void FIFO_Reset(uint8_t CameraID)
372 {
373   FIFO_nOE_0_SET;
374   FIFO_nOE_1_SET;
375   if(CameraID == 0)
```

```
376     {
377       FIFO_WRST_0_CLR;
378       FIFO_nRRST_0_CLR;
379       FIFO_RCLK_0_SET;
380       FIFO_RCLK_0_CLR;
381       FIFO_nRRST_0_SET;
382       FIFO_WRST_0_SET;
383     }
384     else
385     {
386       FIFO_WRST_1_CLR;
387       FIFO_nRRST_1_CLR;
388       FIFO_RCLK_1_SET;
389       FIFO_RCLK_1_CLR;
390       FIFO_nRRST_1_SET;
391       FIFO_WRST_1_SET;
392     }

394   }
395   void LoadImagesToBuffer()
396   {
397     VSYNC_0_Count = 0;
398     VSYNC_1_Count = 0;
399     FIFO_Reset(0);
400     FIFO_Reset(1);
401     VSYNC_0_Count = 1;
402     VSYNC_1_Count = 1;

404   }
405   uint8_t GetImageIfAvailiable(FIL *File, uint8_t CameraID)
406   {

408     if( ((CameraID == 0) && (VSYNC_0_Count == 3)) ||
409       ((CameraID == 1) && (VSYNC_1_Count == 3)) )
410     {

412       //Write Bitmap Headers
413       WriteBMPHeader(File);
414       WriteDIBHeader(File);
415       if (CameraID == 0)
416       {
417         //Enable output of Camera 0
418         FIFO_nOE_0_CLR;
419         //Reset Read Pointer
420         FIFO_nRRST_0_CLR;
421         FIFO_RCLK_0_SET;
422         FIFO_RCLK_0_CLR;
423         FIFO_nRRST_0_SET;
424       }
425       else
426       {
427         //Enable output of Camera 0
428         FIFO_nOE_1_CLR;
429         //Reset Read Pointer
430         FIFO_nRRST_1_CLR;
431         FIFO_RCLK_1_SET;
432         FIFO_RCLK_1_CLR;
433         FIFO_nRRST_1_SET;
```

```
434       }
435       int i, j;
436       uint32_t pointer;
437       uint16_t Temp;
438       uint32_t p;
439       FRESULT fr;
440       //for(j = HEIGHT; j>0; j--)
441       for(j = 0; j < HEIGHT; j++)
442       {
443         pointer = 0;
444         for(i = 0; i < WIDTH; i++)
445         {
446           Temp = FIFO_TO_AVR(CameraID);
447           //USART0_Senduint16(Temp);
449           Buff[pointer++] = (uint8_t)(Temp >> 8);
450           Buff[pointer++] = (uint8_t)Temp;
451         }
452         pointer = (uint32_t)j * (uint32_t)WIDTH * 2 + BMPHEADERSIZE +
      DIBHEADERSIZE;
453         f_lseek(File, pointer);
454         fr = f_write(File, Buff, WIDTH * 2, &p);
455         if(fr != FR_OK)
456         {
457           //printf("Write Fail.\n");
458           VSYNC_0_Count = 0;
459           VSYNC_1_Count = 0;
460           FIFO_Reset(CameraID);
461           FIFO_nOE_0_SET;
462           FIFO_nOE_1_SET;
463           return 1;
464         }
465       }
466       FIFO_Reset(CameraID);
467       //fr = f_close(File);
468       FIFO_nOE_0_SET;
469       FIFO_nOE_1_SET;
470       return 0;
471     }
472     else
473     {
474       return 2;
475     }
476   }
```

.2.1.8 PCA9542A.h

../Code/DualOV7670/PCA9542A.h

```
1  /*
2   * PCA9542A.h
3   *
4   * Created: 13/11/2012 23:24:48
5   *  Author: hslovett
```

```
 */


#ifndef PCA9542A_H_
#define PCA9542A_H_
#include "Config.h"

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

#define NO_SELECT 0x00
#define CH0     0x04
#define CH1     0x05

unsigned char PCA9542A_Init();
unsigned char PCA9542A_SetChannel(uint8_t Channel);

#endif /* PCA9542A_H_ */
```

.2.1.9 PCA9542A.c

../Code/DualOV7670/PCA9542A.c

```
/*
 * PCA9542A.c
 *
 * Created: 13/11/2012 23:24:40
 *  Author: hslovett
 */
#include "PCA9542A.h"


unsigned char PCA9542A_Init()
{
  unsigned char messageBuf[TWI_BUFFER_SIZE];
  messageBuf[0] = (PCA9542A_ADDR  <<TWI_ADR_BITS) | (FALSE<<TWI_READ_BIT); //
    The first byte must always consit of General Call code or the TWI slave
    address.
  messageBuf[1] = NO_SELECT;             // The first byte is used for
    commands.
  // The second byte is used for the data.
  TWI_Start_Transceiver_With_Data( messageBuf, 2 );

  while(TWI_Transceiver_Busy()) ; //Wait for transceiver to clear

  return TWI_statusReg.lastTransOK;
}

unsigned char PCA9542A_SetChannel( uint8_t Channel )
{
  unsigned char messageBuf[TWI_BUFFER_SIZE];
```

```
26    messageBuf[0] = (PCA9542A_ADDR  <<TWI_ADR_BITS) | (FALSE<<TWI_READ_BIT); //
        The first byte must always consit of General Call code or the TWI slave
        address.
27    messageBuf[1] = Channel;             // The first byte is used for commands.
28                          // The second byte is used for the data.
29    TWI_Start_Transceiver_With_Data( messageBuf, 2 );

31    while(TWI_Transceiver_Busy()) ; //Wait for transceiver to clear

33    return TWI_statusReg.lastTransOK;
34  }

36  unsigned char PCA9542A_ReadChannel()
37  {
38    unsigned char messageBuf[TWI_BUFFER_SIZE];
39    messageBuf[0] = (PCA9542A_ADDR  <<TWI_ADR_BITS) | (TRUE<<TWI_READ_BIT); //
        The first byte must always consit of General Call code or the TWI slave
        address.

41    TWI_Start_Transceiver_With_Data( messageBuf, 1 );

43    while(TWI_Transceiver_Busy()) ; //Wait for transceiver to clear
44    // Get the received data from the transceiver buffer
45    TWI_Get_Data_From_Transceiver( messageBuf, 2 );
46    return TWI_statusReg.lastTransOK;
47  }
```

.2.1.10 TWI_Master.h

../Code/DualOV7670/TWI_Master.h

```
1  /****************************************************************************
2  *
3  * Atmel Corporation
4  *
5  * File              : TWI_Master.h
6  * Compiler          : IAR EWAAVR 2.28a/3.10c
7  * Revision          : Revision: 1.13
8  * Date              : Date: 24. mai 2004 11:31:22
9  * Updated by        : Author: ltwa
10 *
11 * Support mail      : avr@atmel.com
12 *
13 * Supported devices : All devices with a TWI module can be used.
14 *                     The example is written for the ATmega16
15 *
16 * AppNote           : AVR315 - TWI Master Implementation
17 *
18 * Description       : Header file for TWI_Master.c
19 *                     Include this file in the application.
20 *
21 ****************************************************************************/
```

```
23 /*  Modified by Henry Lovett (hl13g10@ecs.soton.ac.uk) to allow SCL frequency
       to be specified and TWBR calculated
24  *  Also allows AVR internal pull up resistors to be used.
25  */
26 #ifndef _TWI_MASTER_H
27 #define _TWI_MASTER_H
28 #include <avr/io.h>
29 #include <avr/interrupt.h>
30 #include "Config.h"
31 /************************************************************************
32   TWI Status/Control register definitions
33 ************************************************************************/

35 #define INTERNAL_PULLUPS 0

37 #define TWI_BUFFER_SIZE 4   // Set this to the largest message size that will
       be sent including address byte.

39 #define SCL_Freq    100000    //SCL Frequency in Hertz
40 #define TWI_TWBR    (char)(F_CPU / 2 / SCL_Freq - 8) //Equation to calculate
       TWBR Based on SCL Frequency and Clock Frequency

42 //#define TWI_TWBR            0x0C //400KHz       // TWI Bit rate Register
       setting.
43 //#define TWI_TWBR        0x34 //100KHz                                    //
        Se Application note for detailed
44                                        // information on setting this value.
45 // Not used defines!
46 //#define TWI_TWPS          0x00        // This driver presumes prescaler = 00

48 /************************************************************************
49   Global definitions
50 ************************************************************************/

52 union TWI_statusReg                       // Status byte holding flags.
53 {
54     unsigned char all;
55     struct
56     {
57         unsigned char lastTransOK:1;
58         unsigned char unusedBits:7;
59     };
60 };

62 extern union TWI_statusReg TWI_statusReg;

64 /************************************************************************
65   Function definitions
66 ************************************************************************/
67 void TWI_Master_Initialise( void );
68 unsigned char TWI_Transceiver_Busy( void );
69 unsigned char TWI_Get_State_Info( void );
70 void TWI_Start_Transceiver_With_Data( unsigned char * , unsigned char );
71 void TWI_Start_Transceiver( void );
72 unsigned char TWI_Get_Data_From_Transceiver( unsigned char *, unsigned char );

74 /************************************************************************
75   Bit and byte definitions
```

```
76 ************************************************************************/
77 #define TWI_READ_BIT  0       // Bit position for R/W bit in "address byte".
78 #define TWI_ADR_BITS  1       // Bit position for LSB of the slave address
       bits in the init byte.

80 #define TRUE          1
81 #define FALSE         0

83 /************************************************************************
84   TWI State codes
85 ************************************************************************/
86 // General TWI Master staus codes
87 #define TWI_START                  0x08  // START has been transmitted
88 #define TWI_REP_START              0x10  // Repeated START has been
       transmitted
89 #define TWI_ARB_LOST               0x38  // Arbitration lost

91 // TWI Master Transmitter staus codes
92 #define TWI_MTX_ADR_ACK            0x18  // SLA+W has been tramsmitted and ACK
        received
93 #define TWI_MTX_ADR_NACK           0x20  // SLA+W has been tramsmitted and
       NACK received
94 #define TWI_MTX_DATA_ACK           0x28  // Data byte has been tramsmitted and
        ACK received
95 #define TWI_MTX_DATA_NACK          0x30  // Data byte has been tramsmitted and
        NACK received

97 // TWI Master Receiver staus codes
98 #define TWI_MRX_ADR_ACK            0x40  // SLA+R has been tramsmitted and ACK
        received
99 #define TWI_MRX_ADR_NACK           0x48  // SLA+R has been tramsmitted and
       NACK received
100 #define TWI_MRX_DATA_ACK           0x50  // Data byte has been received and
       ACK tramsmitted
101 #define TWI_MRX_DATA_NACK          0x58  // Data byte has been received and
       NACK tramsmitted

103 // TWI Slave Transmitter staus codes
104 #define TWI_STX_ADR_ACK            0xA8  // Own SLA+R has been received; ACK
       has been returned
105 #define TWI_STX_ADR_ACK_M_ARB_LOST 0xB0  // Arbitration lost in SLA+R/W as
       Master; own SLA+R has been received; ACK has been returned
106 #define TWI_STX_DATA_ACK           0xB8  // Data byte in TWDR has been
       transmitted; ACK has been received
107 #define TWI_STX_DATA_NACK          0xC0  // Data byte in TWDR has been
       transmitted; NOT ACK has been received
108 #define TWI_STX_DATA_ACK_LAST_BYTE 0xC8  // Last data byte in TWDR has been
       transmitted (TWEA =  0 ); ACK has been received

110 // TWI Slave Receiver staus codes
111 #define TWI_SRX_ADR_ACK            0x60  // Own SLA+W has been received ACK
       has been returned
112 #define TWI_SRX_ADR_ACK_M_ARB_LOST 0x68  // Arbitration lost in SLA+R/W as
       Master; own SLA+W has been received; ACK has been returned
113 #define TWI_SRX_GEN_ACK            0x70  // General call address has been
       received; ACK has been returned
114 #define TWI_SRX_GEN_ACK_M_ARB_LOST 0x78  // Arbitration lost in SLA+R/W as
       Master; General call address has been received; ACK has been returned
```

```
115 #define TWI_SRX_ADR_DATA_ACK       0x80  // Previously addressed with own SLA+
        W; data has been received; ACK has been returned
116 #define TWI_SRX_ADR_DATA_NACK      0x88  // Previously addressed with own SLA+
        W; data has been received; NOT ACK has been returned
117 #define TWI_SRX_GEN_DATA_ACK       0x90  // Previously addressed with general
        call; data has been received; ACK has been returned
118 #define TWI_SRX_GEN_DATA_NACK      0x98  // Previously addressed with general
        call; data has been received; NOT ACK has been returned
119 #define TWI_SRX_STOP_RESTART       0xA0  // A STOP condition or repeated START
         condition has been received while still addressed as Slave

121 // TWI Miscellaneous status codes
122 #define TWI_NO_STATE               0xF8  // No relevant state information
        available; TWINT =  0
123 #define TWI_BUS_ERROR              0x00  // Bus error due to an illegal START
        or STOP condition

125 #endif
```

.2.1.11 TWI_Master.c

../Code/DualOV7670/TWI_Master.c

```
1  /*****************************************************************************
2  *
3  * Atmel Corporation
4  *
5  * File              : TWI_Master.c
6  * Compiler          : IAR EWAAVR 2.28a/3.10c
7  * Revision          : Revision: 1.13
8  * Date              : Date: 24. mai 2004 11:31:20
9  * Updated by        : Author: ltwa
10 *
11 * Support mail      : avr@atmel.com
12 *
13 * Supported devices : All devices with a TWI module can be used.
14 *                     The example is written for the ATmega16
15 *
16 * AppNote           : AVR315 - TWI Master Implementation
17 *
18 * Description       : This is a sample driver for the TWI hardware modules.
19 *                     It is interrupt driveren. All functionality is
       controlled through
20 *                     passing information to and from functions. Se main.c for
        samples
21 *                     of how to use the driver.
22 *
23 *
24 *****************************************************************************/


27 #include "TWI_Master.h"

29 static unsigned char TWI_buf[ TWI_BUFFER_SIZE ];    // Transceiver buffer
```

```
30 static unsigned char TWI_msgSize;                    // Number of bytes to be
       transmitted.
31 static unsigned char TWI_state = TWI_NO_STATE;       // State byte. Default set
        to TWI_NO_STATE.

33 union TWI_statusReg TWI_statusReg = {0};             // TWI_statusReg is
       defined in TWI_Master.h

35 /****************************************************************************
36 Call this function to set up the TWI master to its initial standby state.
37 Remember to enable interrupts from the main application after initializing the
        TWI.
38 ****************************************************************************/
39 void TWI_Master_Initialise(void)
40 {
41   #if INTERNAL_PULLUPS == 1//enable built in pullups for I2C Lines
42     DDRC = 0x00;
43     PORTC = (1 << PC0) | (1 << PC1);
44   #else
45     #pragma message("External I2C Pull Ups Required.")
46   #endif
47   TWBR = TWI_TWBR;                                  // Set bit rate register (
       Baudrate). Defined in header file.
48   // TWSR = TWI_TWPS;                                  // Not used. Driver
       presumes prescaler to be 00.
49   TWDR = 0xFF;                                      // Default content = SDA
       released.
50   TWCR =  (1<<TWEN)|                                 // Enable TWI-interface
       and release TWI pins.
51     (0<<TWIE)|(0<<TWINT)|                         // Disable Interupt.
52     (0<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|              // No Signal requests.
53     (0<<TWWC);                                    //
54 }

56 /****************************************************************************
57 Call this function to test if the TWI_ISR is busy transmitting.
58 ****************************************************************************/
59 unsigned char TWI_Transceiver_Busy( void )
60 {
61   return ( TWCR & (1<<TWIE) );                  // IF TWI Interrupt is enabled
        then the Transceiver is busy
62 }

64 /****************************************************************************
65 Call this function to fetch the state information of the previous operation.
       The function will hold execution (loop)
66 until the TWI_ISR has completed with the previous operation. If there was an
       error, then the function
67 will return the TWI State code.
68 ****************************************************************************/
69 unsigned char TWI_Get_State_Info( void )
70 {
71   while ( TWI_Transceiver_Busy() );             // Wait until TWI has
       completed the transmission.
72   return ( TWI_state );                         // Return error state.
73 }

75 /****************************************************************************
```

```
76  Call this function to send a prepared message. The first byte must contain the
        slave address and the
77  read/write bit. Consecutive bytes contain the data to be sent, or empty
        locations for data to be read
78  from the slave. Also include how many bytes that should be sent/read including
        the address byte.
79  The function will hold execution (loop) until the TWI_ISR has completed with
        the previous operation,
80  then initialize the next operation and return.
81  ****************************************************************************/
82  void TWI_Start_Transceiver_With_Data( unsigned char *msg, unsigned char
        msgSize )
83  {
84    unsigned char temp;

86    while ( TWI_Transceiver_Busy() );             // Wait until TWI is ready for
         next transmission.

88    TWI_msgSize = msgSize;                        // Number of data to transmit.
89    TWI_buf[0]  = msg[0];                         // Store slave address with R/
        W setting.
90    if (!( msg[0] & (TRUE<<TWI_READ_BIT) ))       // If it is a write operation,
         then also copy data.
91    {
92      for ( temp = 1; temp < msgSize; temp++ )
93        TWI_buf[ temp ] = msg[ temp ];
94    }
95    TWI_statusReg.all = 0;
96    TWI_state         = TWI_NO_STATE ;
97    TWCR = (1<<TWEN)|                             // TWI Interface enabled.
98           (1<<TWIE)|(1<<TWINT)|                  // Enable TWI Interupt and
        clear the flag.
99           (0<<TWEA)|(1<<TWSTA)|(0<<TWSTO)|       // Initiate a START condition.
100          (0<<TWWC);                             //
101 }

103 /****************************************************************************
104 Call this function to resend the last message. The driver will reuse the data
        previously put in the transceiver buffers.
105 The function will hold execution (loop) until the TWI_ISR has completed with
        the previous operation,
106 then initialize the next operation and return.
107 ****************************************************************************/
108 void TWI_Start_Transceiver( void )
109 {
110   while ( TWI_Transceiver_Busy() );             // Wait until TWI is ready for
         next transmission.
111   TWI_statusReg.all = 0;
112   TWI_state         = TWI_NO_STATE ;
113   TWCR = (1<<TWEN)|                             // TWI Interface enabled.
114          (1<<TWIE)|(1<<TWINT)|                  // Enable TWI Interupt and
        clear the flag.
115          (0<<TWEA)|(1<<TWSTA)|(0<<TWSTO)|       // Initiate a START condition.
116          (0<<TWWC);                             //
117 }

119 /****************************************************************************
```

```
120 Call this function to read out the requested data from the TWI transceiver
        buffer. I.e. first call
121 TWI_Start_Transceiver to send a request for data to the slave. Then Run this
        function to collect the
122 data when they have arrived. Include a pointer to where to place the data and
        the number of bytes
123 requested (including the address field) in the function call. The function
        will hold execution (loop)
124 until the TWI_ISR has completed with the previous operation, before reading
        out the data and returning.
125 If there was an error in the previous transmission the function will return
        the TWI error code.
126 ************************************************************************/
127 unsigned char TWI_Get_Data_From_Transceiver( unsigned char *msg, unsigned char
         msgSize )
128 {
129   unsigned char i;
131   while ( TWI_Transceiver_Busy() );             // Wait until TWI is ready for
       next transmission.
133   if( TWI_statusReg.lastTransOK )               // Last transmission competed
      successfully.
134   {
135     for ( i=0; i<msgSize; i++ )                 // Copy data from Transceiver
      buffer.
136     {
137       msg[ i ] = TWI_buf[ i ];
138     }
139   }
140   return( TWI_statusReg.lastTransOK );
141 }
143 // ********** Interrupt Handlers ********** //
144 /************************************************************************
145 This function is the Interrupt Service Routine (ISR), and called when the TWI
        interrupt is triggered;
146 that is whenever a TWI event has occurred. This function should not be called
        directly from the main
147 application.
148 ************************************************************************/
150 ISR(TWI_vect)
151 {
152   static unsigned char TWI_bufPtr;
154   switch (TWSR)
155   {
156     case TWI_START:             // START has been transmitted
157     case TWI_REP_START:         // Repeated START has been transmitted
158       TWI_bufPtr = 0;                                     // Set buffer
      pointer to the TWI Address location
159     case TWI_MTX_ADR_ACK:       // SLA+W has been tramsmitted and ACK received
160     case TWI_MTX_DATA_ACK:      // Data byte has been tramsmitted and ACK
      received
161       if (TWI_bufPtr < TWI_msgSize)
162       {
163         TWDR = TWI_buf[TWI_bufPtr++];
```

```
164         TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
165                (1<<TWIE)|(1<<TWINT)|                      // Enable TWI
    Interupt and clear the flag to send byte
166                (0<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           //
167                (0<<TWWC);                                 //
168       }else                    // Send STOP after last byte
169       {
170         TWI_statusReg.lastTransOK = TRUE;                 // Set status bits
    to completed successfully.
171         TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
172                (0<<TWIE)|(1<<TWINT)|                      // Disable TWI
    Interrupt and clear the flag
173                (0<<TWEA)|(0<<TWSTA)|(1<<TWSTO)|           // Initiate a STOP
    condition.
174                (0<<TWWC);                                 //
175       }
176       break;
177     case TWI_MRX_DATA_ACK:      // Data byte has been received and ACK
    tramsmitted
178       TWI_buf[TWI_bufPtr++] = TWDR;
179     case TWI_MRX_ADR_ACK:       // SLA+R has been tramsmitted and ACK received
180       if (TWI_bufPtr < (TWI_msgSize-1) )                  // Detect the last
    byte to NACK it.
181       {
182         TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
183                (1<<TWIE)|(1<<TWINT)|                      // Enable TWI
    Interupt and clear the flag to read next byte
184                (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Send ACK after
    reception
185                (0<<TWWC);                                 //
186       }else                    // Send NACK after next reception
187       {
188         TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
189                (1<<TWIE)|(1<<TWINT)|                      // Enable TWI
    Interupt and clear the flag to read next byte
190                (0<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Send NACK after
    reception
191                (0<<TWWC);                                 //
192       }
193       break;
194     case TWI_MRX_DATA_NACK:     // Data byte has been received and NACK
    tramsmitted
195       TWI_buf[TWI_bufPtr] = TWDR;
196       TWI_statusReg.lastTransOK = TRUE;                 // Set status bits to
    completed successfully.
197       TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
198              (0<<TWIE)|(1<<TWINT)|                      // Disable TWI
    Interrupt and clear the flag
199              (0<<TWEA)|(0<<TWSTA)|(1<<TWSTO)|           // Initiate a STOP
    condition.
200              (0<<TWWC);                                 //
201       break;
202     case TWI_ARB_LOST:          // Arbitration lost
```

```
203         TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
204                 (1<<TWIE)|(1<<TWINT)|                     // Enable TWI Interupt
     and clear the flag
205                 (0<<TWEA)|(1<<TWSTA)|(0<<TWSTO)|          // Initiate a (RE)
    START condition.
206                 (0<<TWWC);                                //
207         break;
208       case TWI_MTX_ADR_NACK:      // SLA+W has been tramsmitted and NACK
    received
209       case TWI_MRX_ADR_NACK:      // SLA+R has been tramsmitted and NACK
    received
210       case TWI_MTX_DATA_NACK:     // Data byte has been tramsmitted and NACK
    received
211 //      case TWI_NO_STATE              // No relevant state information
    available; TWINT =  0
212       case TWI_BUS_ERROR:         // Bus error due to an illegal START or STOP
    condition
213       default:
214         TWI_state = TWSR;                                 // Store TWSR and
    automatically sets clears noErrors bit.
215                                                           // Reset TWI Interface
216         TWCR = (1<<TWEN)|                                 // Enable TWI-
    interface and release TWI pins
217                 (0<<TWIE)|(0<<TWINT)|                     // Disable Interupt
218                 (0<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|          // No Signal requests
219                 (0<<TWWC);                                //
220     }
221 }
```

.2.1.12 Usart.h

../Code/DualOV7670/Usart.h

```
1  /*
2   * Usart.h
3   *
4   * Created: 25/10/2012 22:25:14
5   *  Author: hslovett
6   */
7
8
9  #ifndef USART_H_
10 #define USART_H_
11
12 #include "Config.h"
13 #include <stdio.h>
14 #include <avr/io.h>
15 #define USART0_BITRATE 57600
16 #define UBBR F_CPU/16/USART0_BITRATE-1
17
18 void USART0_Init ();
19 void Usart_SendChar(char data);
20 unsigned char Usart_Receive( void );
```

```
21 int Usart_printf(char var, FILE *stream);
22 void Usart_get_line (char *buff, int len);
23 void USART0_Senduint16 (uint16_t Data);
24 // void USART0_SendChar( unsigned char data );
25 // unsigned char USART0_Receive( void );
26 // void USART0_SendString(char str[]);

28 #endif /* USART_H_ */
```

.2.1.13 Usart.c

../Code/DualOV7670/Usart.c

```
1  /*
2   * Usart.c
3   *
4   * Created: 25/10/2012 22:25:04
5   *  Author: hl13g10@ecs.soton.ac.uk
6   */


9  #include "Usart.h"


12 void USART0_Init()
13 {
14   uint16_t ubrr = UBBR;
15   //Set baud rate
16   UBRR0H = (unsigned char)(ubrr >>8);
17   UBRR0L = (unsigned char)ubrr ;
18   //Enable receiver and transmitter
19   UCSR0B = (1<<RXEN0)|(1<<TXEN0);

21   UCSR0C = 0x06; //set asynchronous, no parity, one stop bit, 8 bit transfer.

23   //UCSR0B |= (1 << RXCIE0) | (1 << TXCIE0); //set RX and TX interrupt on
24 }
25 void Usart_SendChar(char data)
26 {
27     // Wait for empty transmit buffer
28     while ( !(UCSR0A & (1 << UDRE0)) );
29     // Start transmission
30     UDR0 = data;
31 }
32 unsigned char Usart_Receive( void )
33 {
34   /* Wait for data to be received */
35   while ( !(UCSR0A & (1<<RXC0)) )
36   ;
37   /* Get and return received data from buffer */
38   //Usart_SendChar(UDR0);
39   return UDR0;
40 }
```

```
42 //to use this copy the following as a global-
43 //    static FILE mystdout = FDEV_SETUP_STREAM(Usart_printf, NULL,
       _FDEV_SETUP_WRITE);
44 // and add this line at the beginning of main:
45 //    stdout = &mystdout;
46 //  stdio.h must be used.
47 int Usart_printf(char var, FILE *stream) {
48     // translate \n to \r for br@y++ terminal
49     if (var == '\n') Usart_SendChar('\r');
50     Usart_SendChar(var);
51     return 0;
52 }

54 void Usart_get_line (char *buff, int len)
55 {
56   cli();
57   char c;
58   int i = 0;


61   for (;;) {
62     c = Usart_Receive();
63     if (c == '\r') break;
64     if ((c == '\b') && i) {
65       i--;
66       Usart_SendChar(c);
67       continue;
68     }
69     if (c >= ' ' && i < len - 1) {  /* Visible chars */
70       buff[i++] = c;
71       Usart_SendChar(c);
72     }
73   }
74   buff[i] = 0;
75   Usart_SendChar('\n');
76   sei();
77 }
78 void USART0_Senduint16 (uint16_t Data)
79 {
80   Usart_SendChar(Data >> 8);
81   Usart_SendChar(Data & 0xFF);
82 }
```

.2.2 Dual Camera User Interface

.2.2.1 DualCamera_UI.c

../Code/DualCamera_UI/DualCamera_UI.c

```
1 /*
2  * DualCamera_UI.c
3  *
4  * Created: 12/11/2012 08:32:27
```

```
 *  Author: hslovett
 */


#include <avr/io.h>
#include <avr/interrupt.h>
#include "TWI_slave.h"

#define ButtonMask  0x0F

#define TWI_CMD_MASTER_WRITE 0x10
#define TWI_CMD_MASTER_READ  0x20

// When there has been an error, this function is run and takes care of it
unsigned char TWI_Act_On_Failure_In_Last_Transmission ( unsigned char
    TWIerrorMsg );

int main(void)
{

  char ButtonStatus = 0xFF;
  unsigned char TWI_slaveAddress;
  unsigned char messageBuff[TWI_BUFFER_SIZE];
  DDRD = 0xFF;// Port D is the LED output
  DDRC = 0x00; //PortC is the switch input
  //PORTC = 0xFF;
  TWI_slaveAddress = 0x15;
  TWI_Slave_Initialise( (unsigned char)((TWI_slaveAddress<<TWI_ADR_BITS) | (
    TRUE<<TWI_GEN_BIT) ));
  sei();
  TWI_Start_Transceiver();
    while(1)
    {

    ButtonStatus = (ButtonStatus & PINC) & ButtonMask;
    //PORTD = ButtonStatus;
        // Check if the TWI Transceiver has completed an operation.
        if ( ! TWI_Transceiver_Busy() )
        {
          // Check if the last operation was successful
          if ( TWI_statusReg.lastTransOK )
          {
            // Check if the last operation was a reception
            if ( TWI_statusReg.RxDataInBuf )
            {
              TWI_Get_Data_From_Transceiver(messageBuff, 2);
              // Check if the last operation was a reception as General Call
              if ( TWI_statusReg.genAddressCall )
              {
                // Put data received out to PORTB as an example.
                PORTB = messageBuff[0];
              }
              else // Ends up here if the last operation was a reception as
    Slave Address Match
              {
                // Example of how to interpret a command and respond.

                // TWI_CMD_MASTER_WRITE stores the data to PORTB
```

```
60                  if (messageBuff[0] == TWI_CMD_MASTER_WRITE)
61                  {
62                    PORTD = messageBuff[1];
63                  }
64                  // TWI_CMD_MASTER_READ prepares the data from PINB in the
    transceiver buffer for the TWI master to fetch.
65                  if (messageBuff[0] == TWI_CMD_MASTER_READ)
66                  {
67                    messageBuff[0] = ButtonStatus;
68                    TWI_Start_Transceiver_With_Data( messageBuff, 1 );
69                ButtonStatus = ButtonMask; //clear all logged button presses
70                  }
71                }
72              }
73              else // Ends up here if the last operation was a transmission
74              {
75                //__no_operation(); // Put own code here.
76              }
77              // Check if the TWI Transceiver has already been started.
78              // If not then restart it to prepare it for new receptions.
79              if ( ! TWI_Transceiver_Busy() )
80              {
81                TWI_Start_Transceiver();
82              }
83            }
84            else // Ends up here if the last operation completed unsuccessfully
85            {
86              //TWI_Act_On_Failure_In_Last_Transmission( TWI_Get_State_Info() );
87            }
88      }
89      }
90  }

92  unsigned char TWI_Act_On_Failure_In_Last_Transmission ( unsigned char
        TWIerrorMsg )
93  {
94    // A failure has occurred, use TWIerrorMsg to determine the nature of the
        failure
95    // and take appropriate actions.
96    // Se header file for a list of possible failures messages.

98    // This very simple example puts the error code on PORTB and restarts the
        transceiver with
99    // all the same data in the transmission buffers.
100   //PORTB = TWIerrorMsg;
101   TWI_Start_Transceiver();

103   return TWIerrorMsg;
104 }
```

.2.2.2 TWI_slave.h

../Code/DualCamera_UI/TWI_slave.h

```
/*****************************************************************************
*
* Atmel Corporation
*
* File              : TWI_Slave.h
* Compiler          : IAR EWAAVR 2.28a/3.10c
* Revision          : Revision: 2475
* Date              : Date: 2007-09-20 12:00:43 +0200 (to, 20 sep 2007)
* Updated by        : Author: mlarsson

* Support mail      : avr@atmel.com
*
* Supported devices : All devices with a TWI module can be used.
*                     The example is written for the ATmega16
*
* AppNote           : AVR311 - TWI Slave Implementation
*
* Description       : Header file for TWI_slave.c
*                     Include this file in the application.
*
*****************************************************************************/
/*! \page MISRA
 *
 * General disabling of MISRA rules:
 * * (MISRA C rule 1) compiler is configured to allow extensions
 * * (MISRA C rule 111) bit fields shall only be defined to be of type
    unsigned int or signed int
 * * (MISRA C rule 37) bitwise operations shall not be performed on signed
    integer types
 * As it does not work well with 8bit architecture and/or IAR

 * Other disabled MISRA rules
 * * (MISRA C rule 109) use of union - overlapping storage shall not be used
 * * (MISRA C rule 61) every non-empty case clause in a switch statement shall
     be terminated with a break statement
*/

/*****************************************************************************
  TWI Status/Control register definitions
*****************************************************************************/

#define TWI_BUFFER_SIZE 4      // Reserves memory for the drivers transceiver
    buffer.
                               // Set this to the largest message size that
    will be sent including address byte.

/*****************************************************************************
  Global definitions
*****************************************************************************/

union TWI_statusReg_t                       // Status byte holding flags.
{
    unsigned char all;
    struct
    {
        unsigned char lastTransOK:1;
        unsigned char RxDataInBuf:1;
```

```
53          unsigned char genAddressCall:1;                         // TRUE =
        General call, FALSE = TWI Address;
54          unsigned char unusedBits:5;
55      };
56  };

58  extern union TWI_statusReg_t TWI_statusReg;

60  //static unsigned char dont_sleep = 0;

62  /****************************************************************************
63    Function definitions
64  ****************************************************************************/
65  void TWI_Slave_Initialise( unsigned char );
66  unsigned char TWI_Transceiver_Busy( void );
67  unsigned char TWI_Get_State_Info( void );
68  void TWI_Start_Transceiver_With_Data( unsigned char * , unsigned char );
69  void TWI_Start_Transceiver( void );
70  unsigned char TWI_Get_Data_From_Transceiver( unsigned char *, unsigned char );

72  ISR( TWI_vect );

74  /****************************************************************************
75    Bit and byte definitions
76  ****************************************************************************/
77  #define TWI_READ_BIT  0   // Bit position for R/W bit in "address byte".
78  #define TWI_ADR_BITS  1   // Bit position for LSB of the slave address bits in
         the init byte.
79  #define TWI_GEN_BIT   0   // Bit position for LSB of the general call bit in
        the init byte.

81  #define TRUE          1
82  #define FALSE         0

84  /****************************************************************************
85    TWI State codes
86  ****************************************************************************/
87  // General TWI Master staus codes
88  #define TWI_START                  0x08  // START has been transmitted
89  #define TWI_REP_START              0x10  // Repeated START has been
        transmitted
90  #define TWI_ARB_LOST               0x38  // Arbitration lost

92  // TWI Master Transmitter staus codes
93  #define TWI_MTX_ADR_ACK            0x18  // SLA+W has been tramsmitted and ACK
         received
94  #define TWI_MTX_ADR_NACK           0x20  // SLA+W has been tramsmitted and
        NACK received
95  #define TWI_MTX_DATA_ACK           0x28  // Data byte has been tramsmitted and
         ACK received
96  #define TWI_MTX_DATA_NACK          0x30  // Data byte has been tramsmitted and
         NACK received

98  // TWI Master Receiver staus codes
99  #define TWI_MRX_ADR_ACK            0x40  // SLA+R has been tramsmitted and ACK
         received
100 #define TWI_MRX_ADR_NACK           0x48  // SLA+R has been tramsmitted and
        NACK received
```

```
101 #define TWI_MRX_DATA_ACK           0x50  // Data byte has been received and
        ACK tramsmitted
102 #define TWI_MRX_DATA_NACK          0x58  // Data byte has been received and
        NACK tramsmitted

104 // TWI Slave Transmitter staus codes
105 #define TWI_STX_ADR_ACK            0xA8  // Own SLA+R has been received; ACK
        has been returned
106 #define TWI_STX_ADR_ACK_M_ARB_LOST 0xB0  // Arbitration lost in SLA+R/W as
        Master; own SLA+R has been received; ACK has been returned
107 #define TWI_STX_DATA_ACK           0xB8  // Data byte in TWDR has been
        transmitted; ACK has been received
108 #define TWI_STX_DATA_NACK          0xC0  // Data byte in TWDR has been
        transmitted; NOT ACK has been received
109 #define TWI_STX_DATA_ACK_LAST_BYTE 0xC8  // Last data byte in TWDR has been
        transmitted (TWEA =  0 ); ACK has been received

111 // TWI Slave Receiver staus codes
112 #define TWI_SRX_ADR_ACK            0x60  // Own SLA+W has been received ACK
        has been returned
113 #define TWI_SRX_ADR_ACK_M_ARB_LOST 0x68  // Arbitration lost in SLA+R/W as
        Master; own SLA+W has been received; ACK has been returned
114 #define TWI_SRX_GEN_ACK            0x70  // General call address has been
        received; ACK has been returned
115 #define TWI_SRX_GEN_ACK_M_ARB_LOST 0x78  // Arbitration lost in SLA+R/W as
        Master; General call address has been received; ACK has been returned
116 #define TWI_SRX_ADR_DATA_ACK       0x80  // Previously addressed with own SLA+
        W; data has been received; ACK has been returned
117 #define TWI_SRX_ADR_DATA_NACK      0x88  // Previously addressed with own SLA+
        W; data has been received; NOT ACK has been returned
118 #define TWI_SRX_GEN_DATA_ACK       0x90  // Previously addressed with general
        call; data has been received; ACK has been returned
119 #define TWI_SRX_GEN_DATA_NACK      0x98  // Previously addressed with general
        call; data has been received; NOT ACK has been returned
120 #define TWI_SRX_STOP_RESTART       0xA0  // A STOP condition or repeated START
         condition has been received while still addressed as Slave

122 // TWI Miscellaneous status codes
123 #define TWI_NO_STATE               0xF8  // No relevant state information
        available; TWINT =  0
124 #define TWI_BUS_ERROR              0x00  // Bus error due to an illegal START
        or STOP condition
```

.2.2.3 TWI_slave.c

../Code/DualCamera_UI/TWI_slave.c

```
1 /****************************************************************************
2 *
3 * Atmel Corporation
4 *
5 * File              : TWI_Slave.c
6 * Compiler          : IAR EWAAVR 2.28a/3.10c
7 * Revision          : Revision: 2475
```

```
8  * Date               : Date: 2007-09-20 12:00:43 +0200 (to, 20 sep 2007)
9  * Updated by         : Author: mlarsson
10 *
11 * Support mail       : avr@atmel.com
12 *
13 * Supported devices  : All devices with a TWI module can be used.
14 *                      The example is written for the ATmega16
15 *
16 * AppNote            : AVR311 - TWI Slave Implementation
17 *
18 * Description        : This is sample driver to AVRs TWI module.
19 *                      It is interupt driveren. All functionality is controlled
       through
20 *                      passing information to and from functions. Se main.c for
       samples
21 *                      of how to use the driver.
22 *
23 ****************************************************************************/
24 /*! \page MISRA
25  *
26  * General disabling of MISRA rules:
27  * * (MISRA C rule 1) compiler is configured to allow extensions
28  * * (MISRA C rule 111) bit fields shall only be defined to be of type
       unsigned int or signed int
29  * * (MISRA C rule 37) bitwise operations shall not be performed on signed
       integer types
30  * As it does not work well with 8bit architecture and/or IAR

32  * Other disabled MISRA rules
33  * * (MISRA C rule 109) use of union - overlapping storage shall not be used
34  * * (MISRA C rule 61) every non-empty case clause in a switch statement shall
       be terminated with a break statement
35 */

37 #include <avr/io.h>
38 #include <avr/interrupt.h>
39 #include "TWI_slave.h"

41 static unsigned char TWI_buf[TWI_BUFFER_SIZE];     // Transceiver buffer. Set
       the size in the header file
42 static unsigned char TWI_msgSize  = 0;             // Number of bytes to be
       transmitted.
43 static unsigned char TWI_state    = TWI_NO_STATE;  // State byte. Default set
       to TWI_NO_STATE.

45 // This is true when the TWI is in the middle of a transfer
46 // and set to false when all bytes have been transmitted/received
47 // Also used to determine how deep we can sleep.
48 static unsigned char TWI_busy = 0;

50 union TWI_statusReg_t TWI_statusReg = {0};           // TWI_statusReg is
       defined in TWI_Slave.h

52 /****************************************************************************
53 Call this function to set up the TWI slave to its initial standby state.
54 Remember to enable interrupts from the main application after initializing the
       TWI.
```

```
55 Pass both the slave address and the requrements for triggering on a general
       call in the
56 same byte. Use e.g. this notation when calling this function:
57 TWI_Slave_Initialise( (TWI_slaveAddress<<TWI_ADR_BITS) | (TRUE<<TWI_GEN_BIT) )
       ;
58 The TWI module is configured to NACK on any requests. Use a
       TWI_Start_Transceiver function to
59 start the TWI.
60 ****************************************************************************/
61 void TWI_Slave_Initialise( unsigned char TWI_ownAddress )
62 {
63   TWAR = TWI_ownAddress;                             // Set own TWI slave
       address. Accept TWI General Calls.
64   TWCR = (1<<TWEN)|                                  // Enable TWI-interface
       and release TWI pins.
65          (0<<TWIE)|(0<<TWINT)|                       // Disable TWI Interupt.
66          (0<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|            // Do not ACK on any
       requests, yet.
67          (0<<TWWC);                                  //
68   TWI_busy = 0;
69 }

71 ****************************************************************************
72 Call this function to test if the TWI_ISR is busy transmitting.
73 ****************************************************************************/
74 unsigned char TWI_Transceiver_Busy( void )
75 {
76   return TWI_busy;
77 }

79 ****************************************************************************
80 Call this function to fetch the state information of the previous operation.
       The function will hold execution (loop)
81 until the TWI_ISR has completed with the previous operation. If there was an
       error, then the function
82 will return the TWI State code.
83 ****************************************************************************/
84 unsigned char TWI_Get_State_Info( void )
85 {
86   while ( TWI_Transceiver_Busy() ) {}             // Wait until TWI has
       completed the transmission.
87   return ( TWI_state );                          // Return error state.
88 }

90 ****************************************************************************
91 Call this function to send a prepared message, or start the Transceiver for
       reception. Include
92 a pointer to the data to be sent if a SLA+W is received. The data will be
       copied to the TWI buffer.
93 Also include how many bytes that should be sent. Note that unlike the similar
       Master function, the
94 Address byte is not included in the message buffers.
95 The function will hold execution (loop) until the TWI_ISR has completed with
       the previous operation,
96 then initialize the next operation and return.
97 ****************************************************************************/
98 void TWI_Start_Transceiver_With_Data( unsigned char *msg, unsigned char
       msgSize )
```

```
99  {
100   unsigned char temp;

102   while ( TWI_Transceiver_Busy() ) {}              // Wait until TWI is ready
        for next transmission.

104   TWI_msgSize = msgSize;                          // Number of data to transmit.
105   for ( temp = 0; temp < msgSize; temp++ )        // Copy data that may be
        transmitted if the TWI Master requests data.
106   {
107     TWI_buf[ temp ] = msg[ temp ];
108   }
109   TWI_statusReg.all = 0;
110   TWI_state         = TWI_NO_STATE ;
111   TWCR = (1<<TWEN)|                               // TWI Interface enabled.
112          (1<<TWIE)|(1<<TWINT)|                    // Enable TWI Interupt and
        clear the flag.
113          (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|         // Prepare to ACK next time
        the Slave is addressed.
114          (0<<TWWC);                               //
115   TWI_busy = 1;
116 }

118 /****************************************************************************
119 Call this function to start the Transceiver without specifing new transmission
        data. Useful for restarting
120 a transmission, or just starting the transceiver for reception. The driver
        will reuse the data previously put
121 in the transceiver buffers. The function will hold execution (loop) until the
        TWI_ISR has completed with the
122 previous operation, then initialize the next operation and return.
123 ****************************************************************************/
124 void TWI_Start_Transceiver( void )
125 {
126   while ( TWI_Transceiver_Busy() ) {}              // Wait until TWI is ready
        for next transmission.
127   TWI_statusReg.all = 0;
128   TWI_state         = TWI_NO_STATE ;
129   TWCR = (1<<TWEN)|                               // TWI Interface enabled.
130          (1<<TWIE)|(1<<TWINT)|                    // Enable TWI Interupt and
        clear the flag.
131          (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|         // Prepare to ACK next time
        the Slave is addressed.
132          (0<<TWWC);                               //
133   TWI_busy = 0;
134 }
135 /****************************************************************************
136 Call this function to read out the received data from the TWI transceiver
        buffer. I.e. first call
137 TWI_Start_Transceiver to get the TWI Transceiver to fetch data. Then Run this
        function to collect the
138 data when they have arrived. Include a pointer to where to place the data and
        the number of bytes
139 to fetch in the function call. The function will hold execution (loop) until
        the TWI_ISR has completed
140 with the previous operation, before reading out the data and returning.
141 If there was an error in the previous transmission the function will return
        the TWI State code.
```

```
142 ************************************************************************/
143 unsigned char TWI_Get_Data_From_Transceiver( unsigned char *msg, unsigned char
        msgSize )
144 {
145   unsigned char i;
147   while ( TWI_Transceiver_Busy() ) {}             // Wait until TWI is ready
      for next transmission.
149   if( TWI_statusReg.lastTransOK )                // Last transmission completed
       successfully.
150   {
151     for ( i=0; i<msgSize; i++ )                  // Copy data from Transceiver
      buffer.
152     {
153       msg[ i ] = TWI_buf[ i ];
154     }
155     TWI_statusReg.RxDataInBuf = FALSE;           // Slave Receive data has been
       read from buffer.
156   }
157   return( TWI_statusReg.lastTransOK );
158 }
161 // ********** Interrupt Handlers ********** //
162 /************************************************************************
163 This function is the Interrupt Service Routine (ISR), and called when the TWI
      interrupt is triggered;
164 that is whenever a TWI event has occurred. This function should not be called
      directly from the main
165 application.
166 ************************************************************************/
167 ISR(TWI_vect)
168 {
169   static unsigned char TWI_bufPtr;
171   switch (TWSR)
172   {
173     case TWI_STX_ADR_ACK:            // Own SLA+R has been received; ACK has
      been returned
174 //    case TWI_STX_ADR_ACK_M_ARB_LOST: // Arbitration lost in SLA+R/W as
      Master; own SLA+R has been received; ACK has been returned
175       TWI_bufPtr   = 0;                                  // Set buffer pointer
      to first data location
176     case TWI_STX_DATA_ACK:           // Data byte in TWDR has been transmitted
      ; ACK has been received
177       TWDR = TWI_buf[TWI_bufPtr++];
178       TWCR = (1<<TWEN)|                                  // TWI Interface
      enabled
179              (1<<TWIE)|(1<<TWINT)|                       // Enable TWI Interupt
       and clear the flag to send byte
180              (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|            //
181              (0<<TWWC);                                  //
182       TWI_busy = 1;
183       break;
184     case TWI_STX_DATA_NACK:          // Data byte in TWDR has been transmitted
      ; NACK has been received.
```

```
185                                     // I.e. this could be the end of the
    transmission.
186       if (TWI_bufPtr == TWI_msgSize) // Have we transceived all expected data?
187       {
188         TWI_statusReg.lastTransOK = TRUE;               // Set status bits to
    completed successfully.
189       }
190       else                          // Master has sent a NACK before all data
    where sent.
191       {
192         TWI_state = TWSR;                               // Store TWI State as
    errormessage.
193       }
194
195       TWCR = (1<<TWEN)|                                 // Enable TWI-
    interface and release TWI pins
196              (1<<TWIE)|(1<<TWINT)|                      // Keep interrupt
    enabled and clear the flag
197              (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Answer on next
    address match
198              (0<<TWWC);                                 //
199
200       TWI_busy = 0;   // Transmit is finished, we are not busy anymore
201       break;
202     case TWI_SRX_GEN_ACK:           // General call address has been received
    ; ACK has been returned
203 //    case TWI_SRX_GEN_ACK_M_ARB_LOST: // Arbitration lost in SLA+R/W as
    Master; General call address has been received; ACK has been returned
204       TWI_statusReg.genAddressCall = TRUE;
205     case TWI_SRX_ADR_ACK:           // Own SLA+W has been received ACK has
    been returned
206 //    case TWI_SRX_ADR_ACK_M_ARB_LOST: // Arbitration lost in SLA+R/W as
    Master; own SLA+W has been received; ACK has been returned
207                                                         // Dont need to clear
    TWI_S_statusRegister.generalAddressCall due to that it is the default
    state.
208       TWI_statusReg.RxDataInBuf = TRUE;
209       TWI_bufPtr   = 0;                                 // Set buffer pointer
    to first data location
210
211                                                         // Reset the TWI
    Interupt to wait for a new event.
212       TWCR = (1<<TWEN)|                                 // TWI Interface
    enabled
213              (1<<TWIE)|(1<<TWINT)|                      // Enable TWI Interupt
     and clear the flag to send byte
214              (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Expect ACK on this
    transmission
215              (0<<TWWC);
216       TWI_busy = 1;
217
218       break;
219     case TWI_SRX_ADR_DATA_ACK:      // Previously addressed with own SLA+W;
    data has been received; ACK has been returned
220     case TWI_SRX_GEN_DATA_ACK:      // Previously addressed with general call
    ; data has been received; ACK has been returned
221       TWI_buf[TWI_bufPtr++]     = TWDR;
```

```
222         TWI_statusReg.lastTransOK = TRUE;                 // Set flag
      transmission successfull.
223                                                           // Reset the TWI
      Interupt to wait for a new event.
224         TWCR = (1<<TWEN)|                                 // TWI Interface
      enabled
225                (1<<TWIE)|(1<<TWINT)|                      // Enable TWI Interupt
       and clear the flag to send byte
226                (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Send ACK after next
       reception
227                (0<<TWWC);                                 //
228         TWI_busy = 1;
229         break;
230       case TWI_SRX_STOP_RESTART:       // A STOP condition or repeated START
      condition has been received while still addressed as Slave
231                                                           // Enter not addressed
       mode and listen to address match
232         TWCR = (1<<TWEN)|                                 // Enable TWI-
      interface and release TWI pins
233                (1<<TWIE)|(1<<TWINT)|                      // Enable interrupt
      and clear the flag
234                (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Wait for new
      address match
235                (0<<TWWC);                                 //

237         TWI_busy = 0;  // We are waiting for a new address match, so we are not
      busy

239         break;
240       case TWI_SRX_ADR_DATA_NACK:      // Previously addressed with own SLA+W;
      data has been received; NOT ACK has been returned
241       case TWI_SRX_GEN_DATA_NACK:      // Previously addressed with general call
      ; data has been received; NOT ACK has been returned
242       case TWI_STX_DATA_ACK_LAST_BYTE: // Last data byte in TWDR has been
      transmitted (TWEA =  0 ); ACK has been received
243   //    case TWI_NO_STATE              // No relevant state information
      available; TWINT =  0
244       case TWI_BUS_ERROR:         // Bus error due to an illegal START or STOP
      condition
245         TWI_state = TWSR;                 //Store TWI State as errormessage,
      operation also clears noErrors bit
246         TWCR =   (1<<TWSTO)|(1<<TWINT);   //Recover from TWI_BUS_ERROR, this
      will release the SDA and SCL pins thus enabling other devices to use the
      bus
247         break;
248       default:
249         TWI_state = TWSR;                                 // Store TWI State as
      errormessage, operation also clears the Success bit.
250         TWCR = (1<<TWEN)|                                 // Enable TWI-
      interface and release TWI pins
251                (1<<TWIE)|(1<<TWINT)|                      // Keep interrupt
      enabled and clear the flag
252                (1<<TWEA)|(0<<TWSTA)|(0<<TWSTO)|           // Acknowledge on any
      new requests.
253                (0<<TWWC);                                 //

255         TWI_busy = 0; // Unknown status, so we wait for a new address match that
       might be something we can handle
```

```
256     }
257 }
```

.3 MATLAB Code for Image Algorithm Prototyping

.3.1 Image Matching Algorithms

.3.1.1 loadimages.m

../MATLAB/loadimages.m

```
1  left = imread('viprectification_deskLeft.png');
2  right = imread('viprectification_deskRight.png');
3
4  % left = imread('battery_left.bmp');
5  % right = imread('battery_right.bmp');
6
7  % left = imread('square_left.bmp');
8  % right = imread('square_right.bmp');
9
10 % left = imread('fiftycm_left.bmp');
11 % right = imread('fiftycm_right.bmp');
12
13 % left = imread('2objs_left.bmp');
14 % right = imread('2objs_right.bmp');
```

.3.1.2 GetSubImage.m

../MATLAB/GetSubImage.m

```
1  function [ SubImage ] = GetSubImage( Image, BoxSize, StartCoordinates)
2  %GETSUBIMAGE Returns a sub section of the image according to the other
3  %inputs
4  %   Image - The image of which a subimage is to be taken from
5  %   BoxSize - A 2x1 matrix containing the size of the subImage
6  %   StartCoordinates - A 2x1 matrix with the start point of the image
7  %   Dimensions - How many planes - 3 for colour, 1 for grey scale
8
9  XLow = StartCoordinates(1)-(BoxSize(1)/2);
10 YLow = StartCoordinates(2)-(BoxSize(2)/2);
11 if(XLow<1)
12     XLow = 1;
13 end
```

```
15  if(YLow < 1)
16      YLow = 1;
17  end

19  XHigh = XLow + BoxSize(1);
20  YHigh = YLow + BoxSize(2);
21  [~, ~, LZ] = size(Image);

23  %SubImage = zeros(BoxSize);
24  for i = XLow:XHigh
25      for j = YLow:YHigh
26          if LZ == 3
27              for z = 1:3
28                  SubImage(i-XLow+1,j-YLow+1,z) = Image(i,j,z);
29              end
30          elseif LZ == 1
31              SubImage(i-XLow+1,j-YLow+1) = Image(i,j);
32          else
33              error('Number of Dimensions "%d" are not supported', LZ);
34          end
35      end
36  end

38  end
```

.3.1.3 SADAll.m

../MATLAB/SADAll.m

```
1   %function [ Results ] = SADAll( Left, Right )
2   %SADALL Function to compute all SADs of an image
3   %   The sum of absolute differences is calculated and returned on a mesh
4   %   graph to show how well matched the sub image is to the image. A box out
5   %   of the right image is taken and compared with the left image.
6   loadimages;
7   BoxSize = [50,50];
8   [~,~,C] = size(right);
9   [I,J,D] = size(left);
10  if C ~= D
11      error('Images have different number of colour planes');
12  end

14  RightSub = GetSubImage(right, BoxSize, [190,190]);

16  for i = 25:(I-25)
17      for j = 25:(J-25)
18          LeftSub = GetSubImage(left, BoxSize, [i, j]);
19          Diff = LeftSub - RightSub;

21          Results(i,j) = sum(Diff(:));
22      end
23  end

25  %Display
```

```
26 figure;
27 subplot(2,2,1);
28 imshow(left);
29 title('Left Image');

31 subplot(2,2,2);
32 imshow(right);
33 title('Right Image');

35 subplot(2,2,3);
36 imshow(RightSub);
37 title('Right Sub');

39 figure;
40 surf(Results);
41 shading flat;
42 %end
```

.3.1.4 SSDAll.m

../MATLAB/SSDAll.m

```
1  %function [ Results ] = SADAll( Left, Right )
2  %SADALL Function to compute all SADs of an image
3  %   The sum of absolute differences is calculated and returned on a mesh
4  %   graph to show how well matched the sub image is to the image. A box out
5  %   of the right image is taken and compared with the left image.
6  loadimages;
7  BoxSize = [50,50];
8  [~,~,C] = size(right);
9  [I,J,D] = size(left);
10 if C ~= D
11     error('Images have different number of colour planes');
12 end

14 RightSub = GetSubImage(right, BoxSize, [190,190]);

16 for i = 25:(I-25)
17     for j = 25:(J-25)
18         LeftSub = GetSubImage(left, BoxSize, [i, j]);
19         Diff = LeftSub - RightSub;
20         Diff = Diff.^2;
21         Results(i,j) = sum(Diff(:));
22     end
23 end

25 %Display
26 figure;
27 subplot(2,2,1);
28 imshow(left);
29 title('Left Image');

31 subplot(2,2,2);
32 imshow(right);
```

```
33 title('Right Image');

35 subplot(2,2,3);
36 imshow(RightSub);
37 title('Right Sub');

39 figure;
40 surf(Results);
41 shading flat;
42 %end
```

.3.1.5 NCC.m

../MATLAB/NCC.m

```


2  loadimages;
3  show;
4  BoxSize = [50,50];
5  MaxConfMatches = 20;
6  %SubCoord = [145, 300];
7  figure(1);
8  %[rightSub, rect_Sub] = imcrop(right);
9  figure(2);
10 imshow(right);
11 rSubCoord = ginput(1);
12 rSubCoord = [190,190]; [rSubCoord(2), rSubCoord(1)];
13 rSubCoord = round(rSubCoord);
14 close;
15 tic;
16 rightSub = GetSubImage(right, BoxSize, rSubCoord);
17 %imshow(rightSub);
18 rightSubGray = rgb2gray(rightSub);
19 leftGray = rgb2gray(left);
20 rightGray = rgb2gray(right);
21 cL = normxcorr2(rightSubGray(:,:), leftGray(:,:));
22 figure(2);
23 % subplot(1,2,1);
24 surf(cL), shading flat;
25 title('Normalised Cross Correlation of Right Sub and Left Image');
26 toc;
27 % cR = normxcorr2(rightSubGray(:,:), rightGray(:,:));
28 % subplot(1,2,2);
29 % surf(cR), shading flat;
30 % title('Normalised Cross Correlation of Right Sub and Right Image');

32 % cD = cL - cR;
33 %
34 % figure;
35 % surf(cD), shading flat;
36 % title('Differences of the Normalised Cross Correlation of Right and Left');

38 %Find coordintes of best match.
39 [Y,X] = size(cL);
```

```
40 maxValue = 0;
41 LeftMatchCoord = [0,0];
42 NumConfidentMatches = 0;

44 for i = 1:X
45    for j = 1:Y
46        Val = cL(j,i);
47        if Val > 0.9
48            NumConfidentMatches = NumConfidentMatches + 1;
49        end
50        if Val > maxValue
51           maxValue = Val;
52           LeftMatchCoord = [j-(BoxSize(1) / 2 ), i-(BoxSize(2) / 2 )];
53        end
54    end
55 end

57 Result = [maxValue, LeftMatchCoord];
58 figure(1);
59 if NumConfidentMatches >= 1 && NumConfidentMatches < MaxConfMatches
60     left(LeftMatchCoord(1)-(BoxSize(1)/2):LeftMatchCoord(1)+(BoxSize(1)/2),
       LeftMatchCoord(2)-(BoxSize(2))/2)=255;
61     left(LeftMatchCoord(1)-(BoxSize(1)/2):LeftMatchCoord(1)+(BoxSize(1)/2),
       LeftMatchCoord(2)+(BoxSize(2))/2)=255;
62     left(LeftMatchCoord(1)-(BoxSize(1)/2),LeftMatchCoord(2)-(BoxSize(2)/2):
       LeftMatchCoord(2)+(BoxSize(2))/2)=255;
63     left(LeftMatchCoord(1)+(BoxSize(1)/2),LeftMatchCoord(2)-(BoxSize(2)/2):
       LeftMatchCoord(2)+(BoxSize(2)/2))=255;

65     right(rSubCoord(1)-(BoxSize(1)/2):rSubCoord(1)+(BoxSize(1)/2),rSubCoord(2)
       -(BoxSize(2)/2))=255;
66     right(rSubCoord(1)-(BoxSize(1)/2):rSubCoord(1)+(BoxSize(1)/2),rSubCoord(2)
       +(BoxSize(2)/2))=255;
67     right(rSubCoord(1)-(BoxSize(1)/2),rSubCoord(2)-(BoxSize(2)/2):rSubCoord(2)
       +(BoxSize(2)/2))=255;
68     right(rSubCoord(1)+(BoxSize(1)/2),rSubCoord(2)-(BoxSize(2)/2):rSubCoord(2)
       +(BoxSize(2)/2))=255;

70     subplot(1,2,1);
71     imshow(left);
72     subplot(1,2,2);
73     imshow(right);
74 %      LeftMatchCoord
75 %      rSubCoord
76 %      NumConfidentMatches
77     Distance = Range(rSubCoord(2), LeftMatchCoord(2));
78     sprintf('Distance to Object = %d metres', Distance)
79 elseif NumConfidentMatches >= MaxConfMatches
80     title(sprintf('Too many matches found : %d', NumConfidentMatches));
81 else
82     title(sprintf('No Reliable Match Found'));

84 end
```