ROBOTIC TABLE FOOTBALL

Preliminary Design Review

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Contents

1 Introduction

This report covers the preliminary design review for the machine vision part of the Robotic Table football (RBTF) project; the report will cover background research and testing in order to develop a full understanding of the project. The success of the machine vision for this project will be determined by the accuracy in which the vision system can work to. According to National Instruments (1), the following steps are needed for machine vision success:

1. **Calculate the FOV** – choose a camera and lens that is able to fit the region of interest (ROI) in the field of view (FOV) and also inspect the smallest feature in the system.
2. **Calibrate** - Calibrate the lighting and camera system. Determine if the lighting in the field of view is homogeneous.
3. **Compensate and correct -** If it is not possible to create a consistent homogeneously illuminated scene, use software to correct for poor lighting.
4. **Identify fiducial elements -** Select a unique feature that is not a defect but is always present in the image. This unique feature will be used as a point of reference.
5. **Locate Features** - Select a feature-locating technique based on the features and speed requirements for your application.
6. **Automate -** Include lighting and camera calibration in the automated inspection system.

1.1 Product Design Specification

In order for the RBTF project to be successful the following specification points will need to be met for the vision system:

- The entire system must be built within the £100 budget.
- The vision system will use an IDS “micro-eye” USB camera.
- The lens will be either a Pentax 6mm or 12mm.
- The vision system must be immune to typical variations in ambient light.
- 5 valid masked and un-masked shot goals must be scored within 5 minutes.
- System must learn and autocorrect for missed shots.
- The puck must not collide with the opposition players.
- Over 50% of the puck’s diameter must cross the goal line.
- The entire system must operate off a single software implemented ‘Start’ button.
- The vision system must be made in application LabVIEW.
- Green lines indicate possible shots, Red indicating selected shots.
- The interface must show predicted and actual motion paths.
- The interface must show Kicker Power and pull back angle must be displayed.

1.2 System process

For the vision system the general process can be outlined as shown in Figure 1-1.

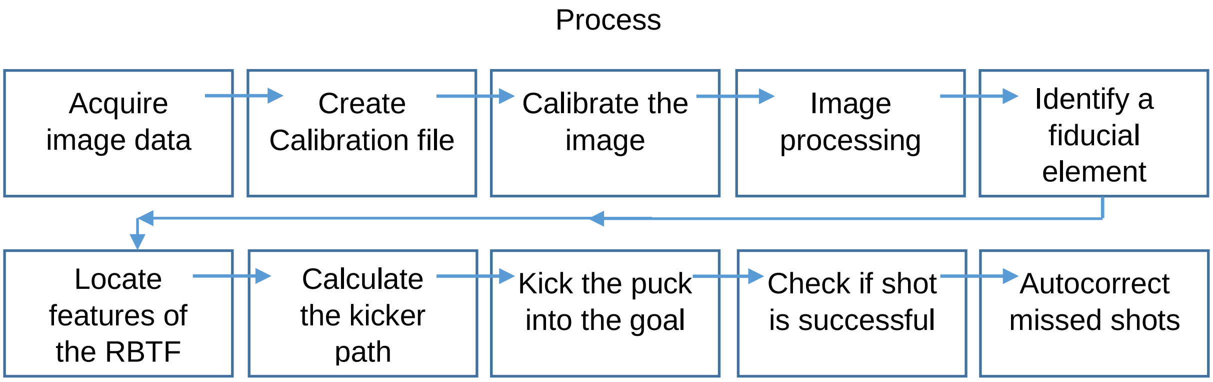


Figure 1-1 vision system process diagram.

There are 3 separate areas of this project (Vision, Manipulator and Kicker) in which data will need to be communicated from one to another. For the vision system the following data will need to be passed to the manipulator and kicker:

- Angle theta that the kicker must rotate.
- Position of the puck (X, Y) which will be used by the manipulator to position the kicker.
- The distance the puck must be 'kicked' and if there is a rebound.

2 Vision Research

The following vision research and testing is based on the 6 machine vision success principles outlined in the introduction.

2.1 Calculate the field of view

There are two camera lenses that can be used for this project; either 6mm or 12mm, each of which have their pro-s and cons:

- 6mm - wider field of view, more optical distortion than 12mm lens.
- 12mm - narrow field of view, less optical distortion than 6mm lens.

Initially, the camera's field of view was tested to ensure that the entire width of the RBTF rig (430mm) could be viewed with the vision system. The Pinhole camera model was used (Equation 1) in order to calculate the minimum distance needed for the camera to view the entire RBTF rig (2).

$$D = K.R_s + d \text{ (Eq.1)}$$

Where:
K = camera constant calculated as 1098.91 pixels.
R = spatial resolution.
d = distance to reference point on the camera 24.83mm (shown in Appendix 1).

It was found from this experimental data that with the 6mm lens, the camera would need to be roughly 520mm (including distance d) away from the RBTF shown in

Figure 2-1. It should be noted that the 12mm lens was not able to fully fit the RBTF rig with the camera mount provided.

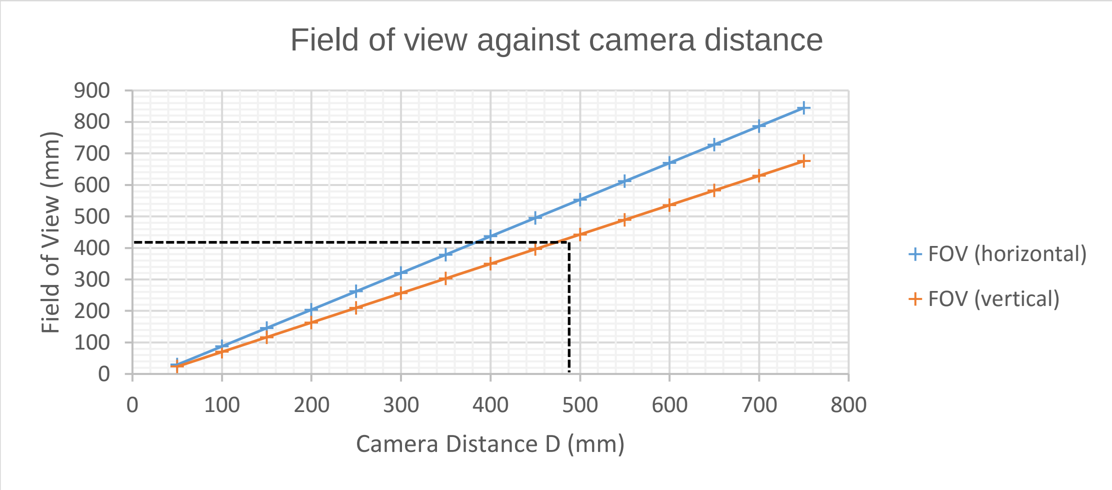


Figure 2-1 the camera distance for the required field of view.

Figure 2-2 below shows the relation between mm per pixel and camera height (reciprocal relation). The effect camera height has on accuracy becomes less as the distance increases from the playing field. To ensure the highest accuracy the camera should be mounted at the minimum height of 520mm, this estimates the camera will obtain around 2.2 pixels per mm.

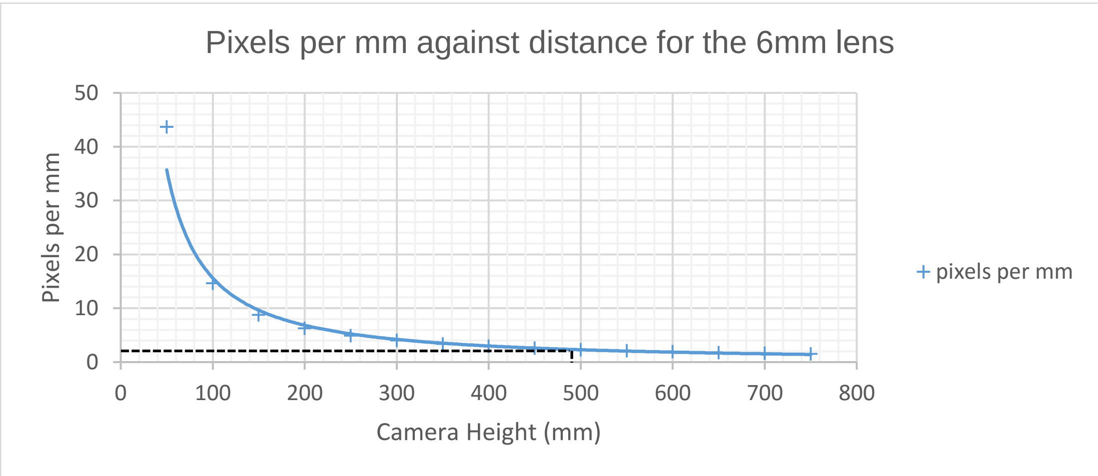


Figure 2-2 the relation between camera height and pixels per mm.

2.2 Calibration

The calibration of the camera was initially tested with the A4 calibration sheet provided. The sheet was initially moved 4 times during calibration (one in each corner) and the images were knitted together in order to calibrate the entire playing field. However, the calibrated image was extremely warped. The A4 calibration was repeated with 6 images of the A4 sheet which saw a large improvement as shown in Figure 2-3.

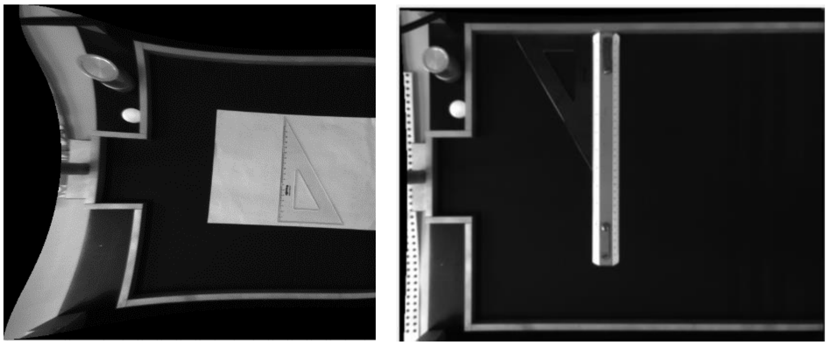


Figure 2-3 6mm lens calibration A4 sheet 4 images (left) A4 sheet 6 images (right).

According to National Instrument's IMAQ vision guide, the following set-up is recommended for a system calibration sheet (3):

- Displacement between dots in X & Y should be equal.
- The dots should cover the entire desired working area.
- The radius of the dots should acquire 6-10 pixels.
- Centre to centre distance between the dots should acquire 18-32 pixels.
- The dots should be separated by a minimum of 6 pixels.

Following the guidelines, the A4 calibration sheet was measured at the minimum camera distance (520mm), it was found that most of pixel dimensions were below the requirements. After this discovery, a new A3 calibration sheet was made with larger dots to cover the surface of interest; the sheet specifications are shown below in Table 2-1.

Sheet properties	**A4 sheet**	**New A3 sheet**
Centre to centre distance	12 pixels	23 pixels
Dot radius	2 pixels	6 pixels
Dot Radius	1.50mm	4mm
Dot separation	8 pixels	13 pixels
Real world centre distance	5mm	10mm

Table 2-1 calibration sheet properties.

The calibration sheets were next tested for their accuracy, this test was done by using the A4 and A3 calibration file to calibrate the same image of the A3 calibration sheet (Appendix 2). The 37 dots in this image were then measured across the field of view to compare the two calibration sheets.

The results from the calibration accuracy are shown below in Table 2-2.

Sheet properties	**A4 calibration**	**A3 calibration**
Mean measurement	9.94mm	9.96mm
Std. Deviation	0.08mm	0.04mm
95% CI	±0.16mm	±0.08mm
95% CI at 520mm	±0.35 pixels	±0.18 pixels

Table 2-2 calibration accuracy test of the A4 and A3 sheet set-up.

It is clear to see that the A3 calibration sheet provides a higher resolution accuracy than the A4 calibration. The calibration using the A3 sheet is also quicker as only two images are used to generate the calibration file, whereas the A4 calibration requires 6 images in order to fill the working area. It should also be noted that the results could include a build-up of errors, as they depend on the accuracy in which the calibration sheet is printed and also the accuracy of the measurement software in LabVIEW. An example of the image calibration is shown below in Figure 2-4.

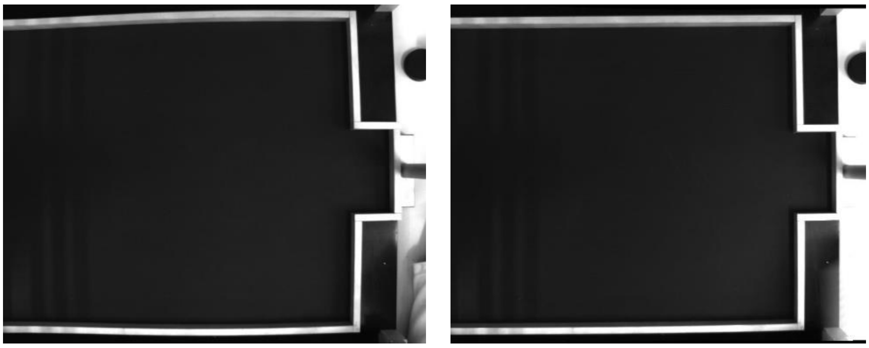


Figure 2-4 6mm lens pre calibration (left) post calibration (right) using the A3 sheet.

After calibration with the A3 sheet, the cameras pixels were measured to check if they were square. This was done by measuring the pixels over 10mm (using a ruler) in X and Y directions, these values were found to be X=43.0069 & Y=43.0152. These values yield an X to Y ratio of 0.9998 which is roughly equivalent to 1, therefore it is it is sensible to assume that the cameras pixels are square.

2.3 Compensating and correcting the image

Ideally an image should have homogeneous lighting throughout in order to achieve the best results. However the RBTF rig contains shadows from the manipulator which could cause inconstancy in the measurements taken.

In order to reduce the effects of lighting and shadows a threshold can be used to convert the image to binary. There are many types of threshold methods, 3 common methods found in LabVIEW are:

- **Manual Threshold**
  - Advantages of this method is that it is the least computationally demanding, however it will be affected by ambient light changes and may need to be manually adjusted.
- **Auto-Threshold** (Clustering, Entropy, Metric, Moments, Inter Variance)
  - Advantages of this method is that it is automated, therefore the software will determine the threshold value from sampling the image. This could be beneficial in the case of ambient light changes.
- **Local Threshold** (Niblack / Background correction)
  - This is the most computationally demanding method, however it is the best method if there are non-uniform areas of light in the image e.g. shadows. Local threshold methods works by taking a grey scale

sample from a region of interest and applying it over the whole image (4).

The different types of threshold methods were tested on the same image to see the effect of manual, auto and local thresholds (Shown below in Figure 2-5).

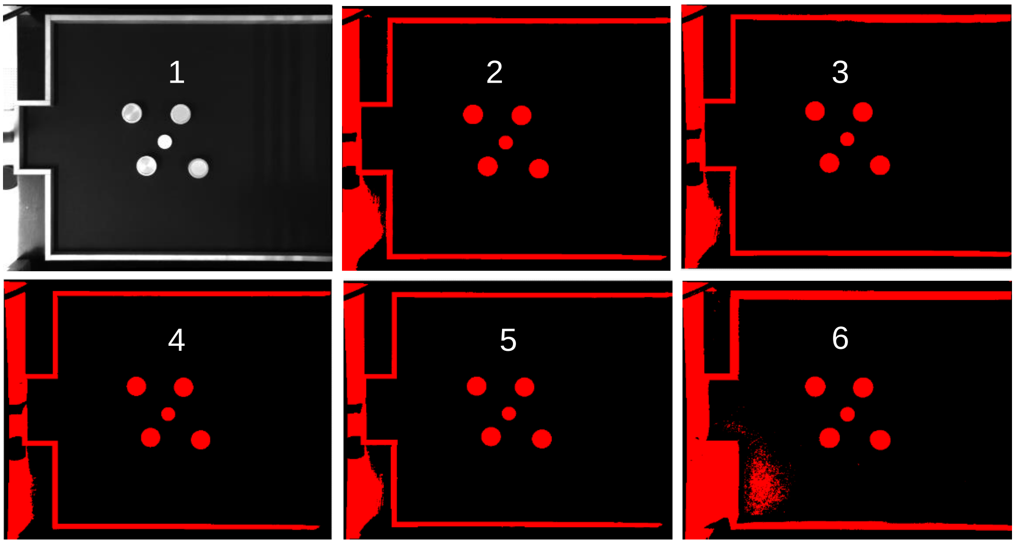


Figure 2-5 shows the results of different threshold methods 1-original image, 2-manual, 3-Local (Niblack), 4-Local (background correction), 5-Auto-Threshold (cluster), 6-Auto Threshold (entropy)

Each of the methods was test by simulating changes in light using a lamp; it was found that each threshold methods worked well. However the requirement of the customer is that the system should be immune to typical variation of light, which means that the manual threshold should not be used in the final system. The Local threshold (background correction) provided the best image in terms of shape definition, background noise removal and also robustness.

2.4 Location methods

The machine vision will need to be able to detect 3 things:

1. The Puck – diameter of 25.20mm and height of 6mm.
2. The opposition players – diameter of 34.98mm and of height 15mm.
3. The pitch (i.e. boundaries and goal location) of height 14.30mm.

There are multiple different ways in which the puck and opposition players can be located such as:

- Shape Detection (binary operation).
- Pattern Matching (looks for matching grey scale).
- Geometry Match (Looks for matching curve geometry)
- Find Circular edge.

To test these different methods, 3 pucks were lined up edge to edge (shown in appendix 3). By aligning the pucks this way the real world distance between their centres can be calculated as 69.96mm (2x diameter). Each method was then measured using the different location methods and the measured distance was compared to the real distance as shown in Figure 2-3.

Location Method	Measured Diameter (mm)	Real Diameter (mm)	Measured Distance (mm)	Real Distance (mm)	Scale factor increase
Shape Detection	35.79	34.98	71.97	69.96	1.029
Pattern Match	N/A	N/A	71.70	69.96	1.025
Geometry Match	N/A	N/A	71.67	69.96	1.025
Find Circ. Edge	35.82	34.98	71.82	69.96	1.026

Table 2-3 the test results for puck location.

Each of the location methods tested measured the pucks larger than their actual size, this is due to the fact the pucks surface is 15mm above the calibrated surface. The measurements are on average a scale factor of 1.026 bigger than real world measurements. The width of the pitch was also measured using edge detection (with the top edge of the rail). The measurements gave an average width of 421.09mm; however the true width of the pitch is 410.80mm which gives a scale factor of 1.025.

To overcome this height error the following methods can be used:

- The measurements of pitch width and puck co-ordinates could be multiplied by a common scale factor (in this case 1.025) known as Horaud's Junction Orientation Technique (5). As shown previously in Figure 2-2, the relationship between mm and pixel is reciprocal however, as the camera height increases the relationship becomes near linear.
- The inside edge of the table football rig can be measured using a Sobel edge detection filter and the find straight edge function in LabVIEW, however this method has been found to be sensitive to light, there are methods of noise removal which will be further tested in order to improve the results of this method (6).
- Use geometry matching in order to find the inside edge of the RBTF rig. This method will be least prone to changes in light and the measurements will not require any multiplication factor.

According to National Instruments, if the part being measured is of a known size and orientation, grayscale pattern matching should be used or, if the feature is of a known shape and unknown size, use geometry shape matching (1).

2.5 Physical reference points

After the puck and wall positions have been defined in the software, the position of the kicker needs to be defined relative to an origin. For this system the top left corner will be used.

The issue in kicker location detection is that it is located above the calibration plane, which will lead to an error in position; therefore locating the position of the kicker accurately could be difficult. These are two methods in which the kicker can be calibrated:

- Attach a detachable reference point to the kicker (of a known length) which is at the height of the calibration plane in order to find the position of the kicker itself.
- Extrapolate the measured data using initial calibration data by Horaud's technique of back projection. However this method will most likely not provide accurate data as at the motor height the relation between camera height and pixel resolution is reciprocal (Figure 2-2).

2.6 Automate

As part of the specification the system should have built in calibration, therefore when selected the user should be able to calibrate the system at the click of a button. For calibration, the user will insert a calibration sheet that fits the RBTF playing surface using the dot dimensions as tested on the A3 sheet.

3 Conclusion

In conclusion, the initial testing of vision system has given data to suggest that the system is able to read to an accuracy of ±0.53mm. This tolerance will have to be taken into account when specifying the puck's shot tolerance. For example, the power required to hit the puck and the path collision with the opposition pucks.

Currently the vision system is able to do the following with the majority of operations currently using vision assistant. (Note: software shown in Appendix 7)

- Calibrate the playing surface using an A3 sheet and 2 images.
- Detect the co-ordinates of the RBTF pitch edges, using the top left as the origin. The vision software currently uses geometry matching; however further testing will be conducted for positional accuracy.
- Detect the puck locations and identify the player and opposition pucks separately.
- Identify the goal line and its position relative to the puck.
- The system currently uses a local threshold (background correction) to ensure maximum system robustness when subject to changes in ambient light, this has been used for 2 weeks with changes in ambient light and no issues have arisen so far.

The code will be developed and tested further following the plan of work in Appendix 4 in order to meet all of the customer requirements for this project.

4 References

1. **Instruments, National.** Using Edge Detection in Machine Vision Gauging Applications . [Online] 28th Feb 2013. http://www.ni.com/white-paper/4536/en/.

2. **Press, NTS.** NI Vision: Camera Setup Principles. [Online] 29th July 2015. https://www.youtube.com/watch?v=ul5sme31cMo.

3. **National Instruments.** *IMAQ Vision for LabVIEW USer Manual.* s.l. : National Instruments Corporation, 2004.

4. Thresholding Techniques. [book auth.] E.R.Davies. *Machine Vision Threory.* s.l. : Elsevier, 2005.

5. **E.R.Davie.** Three Dimensional World. [book auth.] E.R.Davies. *Machine Vision Theory.* s.l. : Elsevier Inc, 2005.

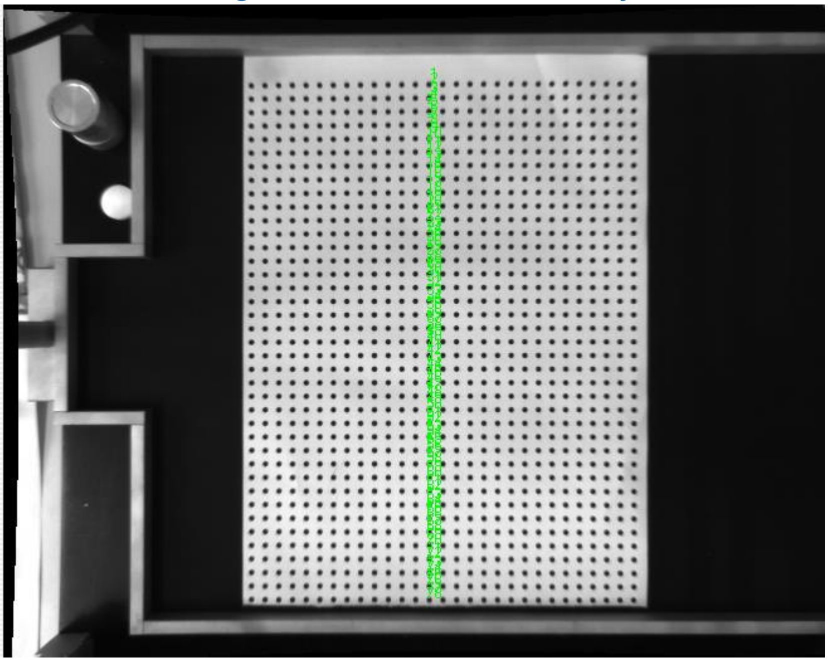
6. **C.Gonzalez, Rafael.** Edge Detection. *Digital Image Processing.* 2001.

5 Appendix

5.1 Appendix 1 – Camera lens reference point

Camera Distance (mm)	mm per pixel	pixels per mm	FOV (horizontal)	FOV (vertical)
50	0.022904514	43.6595153	29.32	23.45
100	0.068404146	14.61899694	87.56	70.05
150	0.113903777	8.779340097	145.80	116.64
200	0.159403409	6.273391562	204.04	163.23
250	0.20490304	4.880357064	262.28	209.82
300	0.250402672	3.993567613	320.52	256.41
350	0.295902303	3.379493803	378.75	303.00
400	0.341401935	2.929098809	436.99	349.60
450	0.386901566	2.584636734	495.23	396.19
500	0.432401198	2.312667045	553.47	442.78
550	0.477900829	2.092484338	611.71	489.37
600	0.52340046	1.910582958	669.95	535.96
650	0.568900092	1.757777884	728.19	582.55
700	0.614399723	1.6276049	786.43	629.15
750	0.659899355	1.5153826	844.67	675.74

5.2 Appendix 2 – Test image for calibration accuracy.

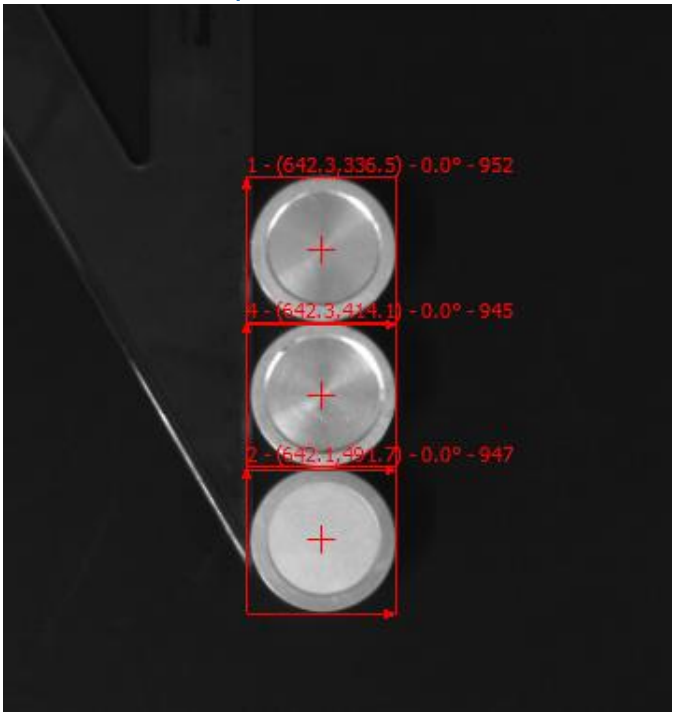


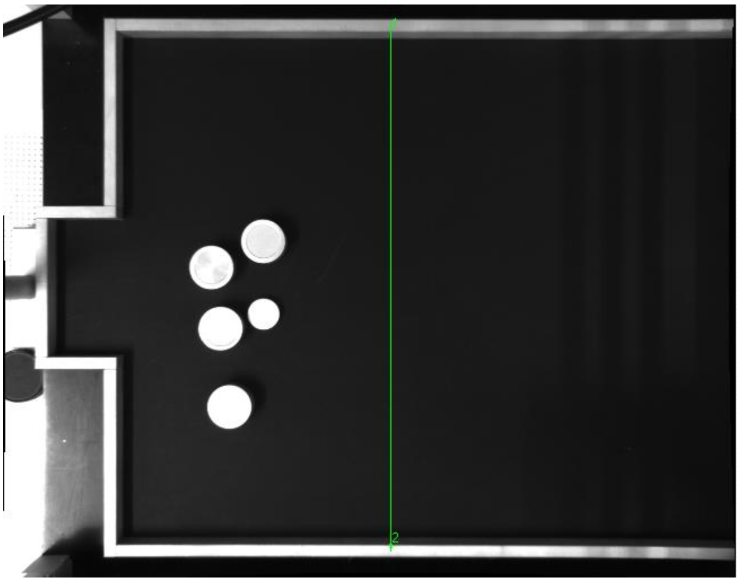
A3 2 sheet	mm		std dev	mean	A4 6 sheet	mm		std dev	mean
1	9.90	0.10	0.040231	9.96	1	9.80	0.20	0.075603	9.94
2	9.89	0.11		0.05	2	9.91	0.09		0.07
3	9.83	0.17			3	9.76	0.24		
4	9.90	0.10	95 ci	9.946758	4	9.96	0.04		
5	10.00	0.00		9.979558	5	9.92	0.08		
6	9.90	0.10			6	9.96	0.04		
7	9.97	0.03		0.032799	7	9.92	0.08		
8	9.96	0.04			8	10.02	0.02		
9	9.98	0.02			9	9.98	0.02		
10	10.04	0.04			10	10.01	0.01		
11	9.98	0.02			11	9.95	0.05		
12	9.89	0.11			12	9.95	0.05		
13	9.94	0.06			13	9.97	0.03		
14	9.95	0.05			14	10.06	0.06		
15	10.03	0.03			15	9.99	0.01		
16	9.93	0.07			16	9.97	0.03		
17	9.99	0.01			17	9.99	0.01		
18	10.01	0.01			18	10.01	0.01		
19	9.93	0.07			19	9.98	0.02		
20	10.04	0.04			20	10.01	0.01		
21	9.95	0.05			21	10.00	0.00		
22	10.05	0.05			22	10.02	0.02		
23	9.93	0.07			23	9.98	0.02		
24	10.01	0.01			24	9.97	0.03		
25	9.89	0.11			25	9.92	0.08		
26	10.03	0.03			26	9.99	0.01		
27	9.90	0.10			27	9.93	0.07		
28	9.99	0.01			28	9.84	0.16		
29	10.00	0.00			29	9.98	0.02		
30	10.03	0.03			30	10.00	0.00		

31	10.03	0.03
32	9.96	0.04
33	10.00	0.00
34	9.97	0.03
35	10.01	0.01
36	9.95	0.05
37	9.96	0.04
38	9.88	0.12

31	9.97	0.03
32	9.94	0.06
33	9.87	0.13
34	9.93	0.07
35	9.87	0.13
36	9.89	0.11
37	9.77	0.23
38	9.73	0.27

5.3 Appendix 3 – The test set up for location methods





5.4 Appendix 4 -Further Plan of Work Machine Vision

Week 6:

- Continue the software development, including overlaying shot paths and also the kicker unit location method.
- Investigate dimension conversion due to height further.

Week 7:

- Continue to develop software to overlay shot paths and start communication between the vision system, manipulator and kicker. Test the accuracy of the location methods of the pucks and kickers.
- Develop the software in lower level IMAQ operations

Week 8:

- Start testing in readiness for the CDR demonstration to ensure the system is able to identify the location of the puck and the manipulator and pass the relevant information to the manipulator and kicker.

Week 9:

- Further testing of the accuracy of the kicker in relation to real world position
- CDR final preparations ready to deliver flyer and demonstration to customer.

Week 10:

- Continue normal development of software and integration between the manipulator and kicker.
- Test the rig to ensure repeatability of results, analyse these results to provide accuracy confidence to the customer.

Week 11:

- Test Readiness review. Ensure that the system is performing to full potential.
- Calculate all results to ensure confidence in measurement

Week 12:

- Customer acceptance meeting

Week 13:

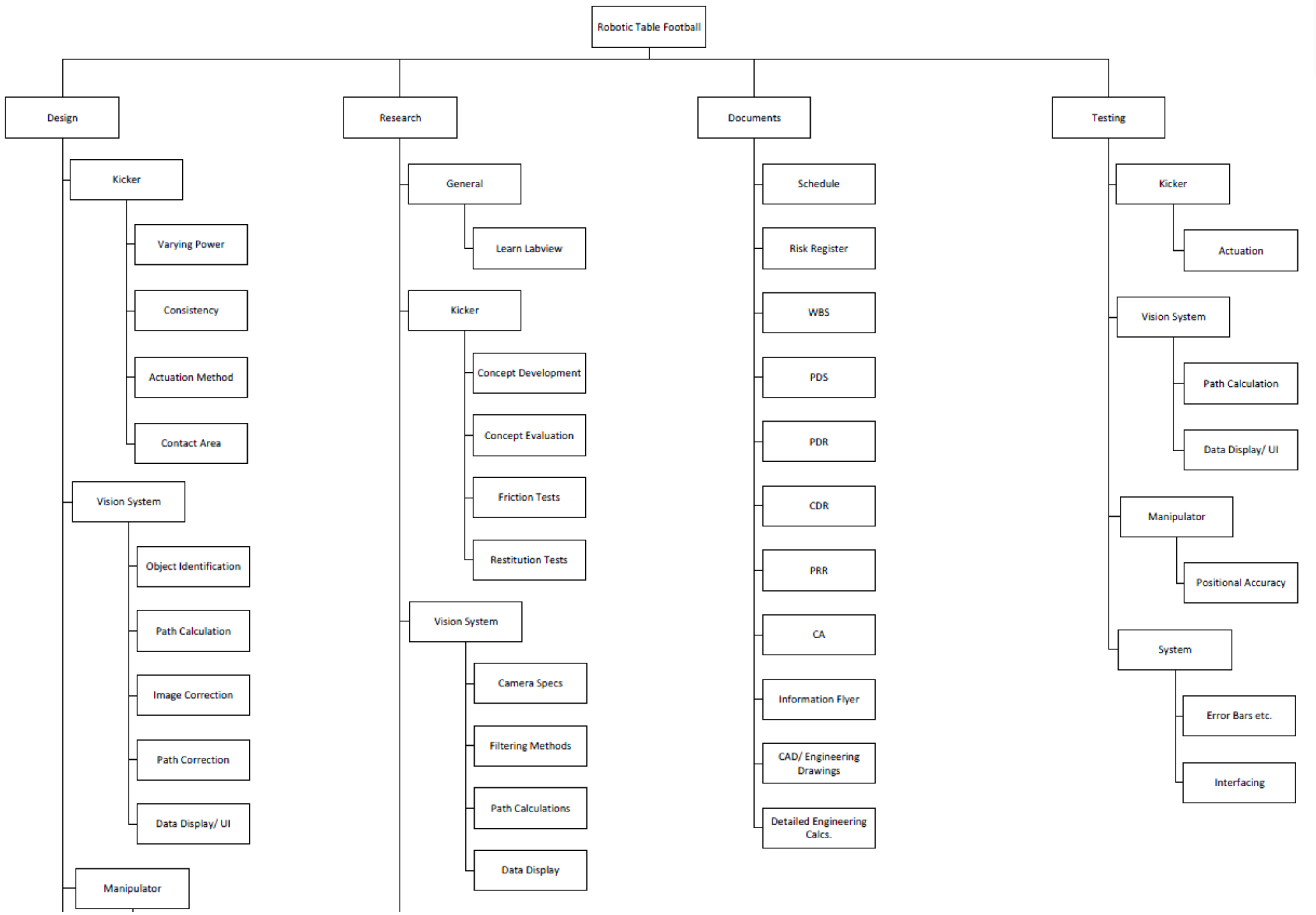
- Submission of individual project reports.

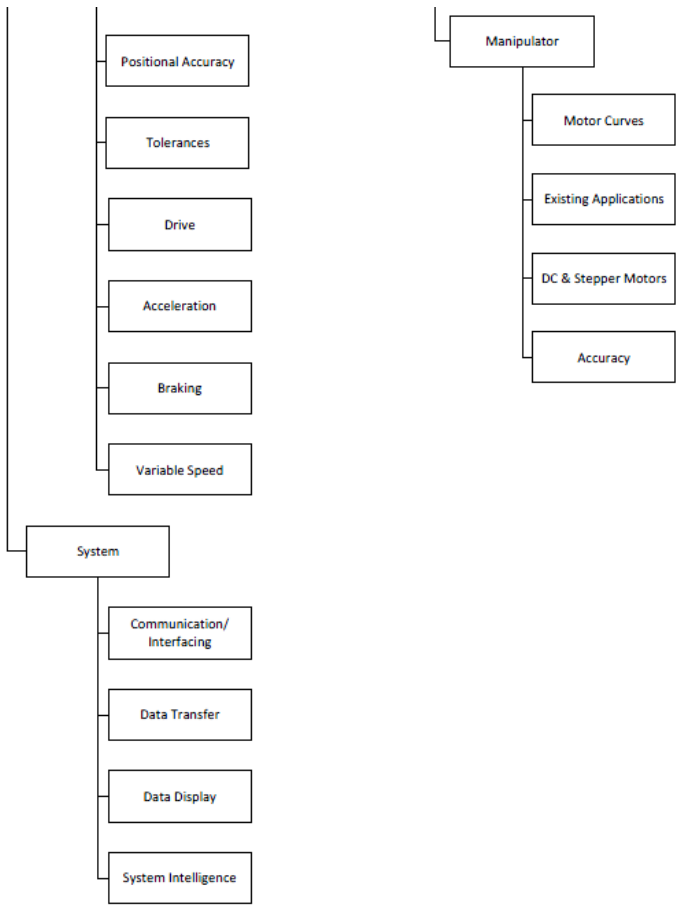
5.5 Appendix 5 - Risk Register

Risk ID	Risk (Description)	Owner	Date Raised	Probability	Impact	Severity	Mitigation	Trigger Date	Status
1	Software failure on demonstration day.	ALL	08/02/2016	2	4	8	Revert to last know working version.	On Going	Open
2	Delay of kicker Manufacture.	S.M.	08/02/2016	2	5	10	Ensure drawings are signed off and all files/ drawings are delivered to workshop on time.		Open
3	Team member no longer able to contribute to project.	ALL	08/02/2016	1	5	5	Ensure all files are kept on a communal networked drive. Maintain regular meetings to update all parties involved.		Open
4	Software files become corrupt or lost.	ALL	08/02/2016	3	4	12	Maintain working log of software version, along with version details i.e. working with manipulation ver. X.XX.		Open
5	Lab is out of action during project.	ALL	08/02/2016	1	3	3	Ensure all files are available outside of labs.		Open
6	Behind schedule for review	ALL	08/02/2016	2	4	8	Maintain regular progress meetings and continually review progress on schedule.		Open
7	Camera is dislodged during manufacture/ assembly.	H.T.	08/02/2016	2	5	10	Ensure valid calibration routine is established early on.		Open
8	Malfunction of sub system.	ALL	08/02/2016	3	5	15	Ensure all sub systems are thoroughly tested throughout project.		Open

9	Sub systems not communicating correctly.	ALL	08/02/2016	3	5	15	Ensure sub systems are tested together early on. Maintain details on which software versions work correctly together.		Open
10	Electric board failure.	ALL	08/02/2016	1	5	5	Ensure spare boards are available if required. Ensure suitable tools are available for testing.		Open
11	Changing pitch/puck surface properties effecting dynamic parameters.	S.M.	08/02/2016	2	4	8	Clean board before initial testing, ensure board is regularly cleaned.		Open
12	Power loss during demonstration.	ALL	08/02/2016	1	5	5	Ensure adequate time is provided to allow demenstration to be carried out later in the day.		Open
13	Parts wear out during testing, adversely effecting performance.	S.M.	08/02/2016	2	4	8	Ensure all moving parts are designed adequately for expected life. Maintain parts suitably.		Open
14	Kicker is not adequately manufacturing, displaying poor performance.	S.M.	08/02/2016	3	5	15	Ensure design is robust, and thoroughly reviewed before manufacture.		Open
15	Deliverables are not inline with customer requirements.	ALL	08/02/2016	3	3	9	Develop thorough PDS and reference this PDS throughout project.		Open
16	Ordered parts don't arrive on time or are unavaliable.	ALL	09/03/2016	2	3	6	Ensure stock before ordering and order early.		Open

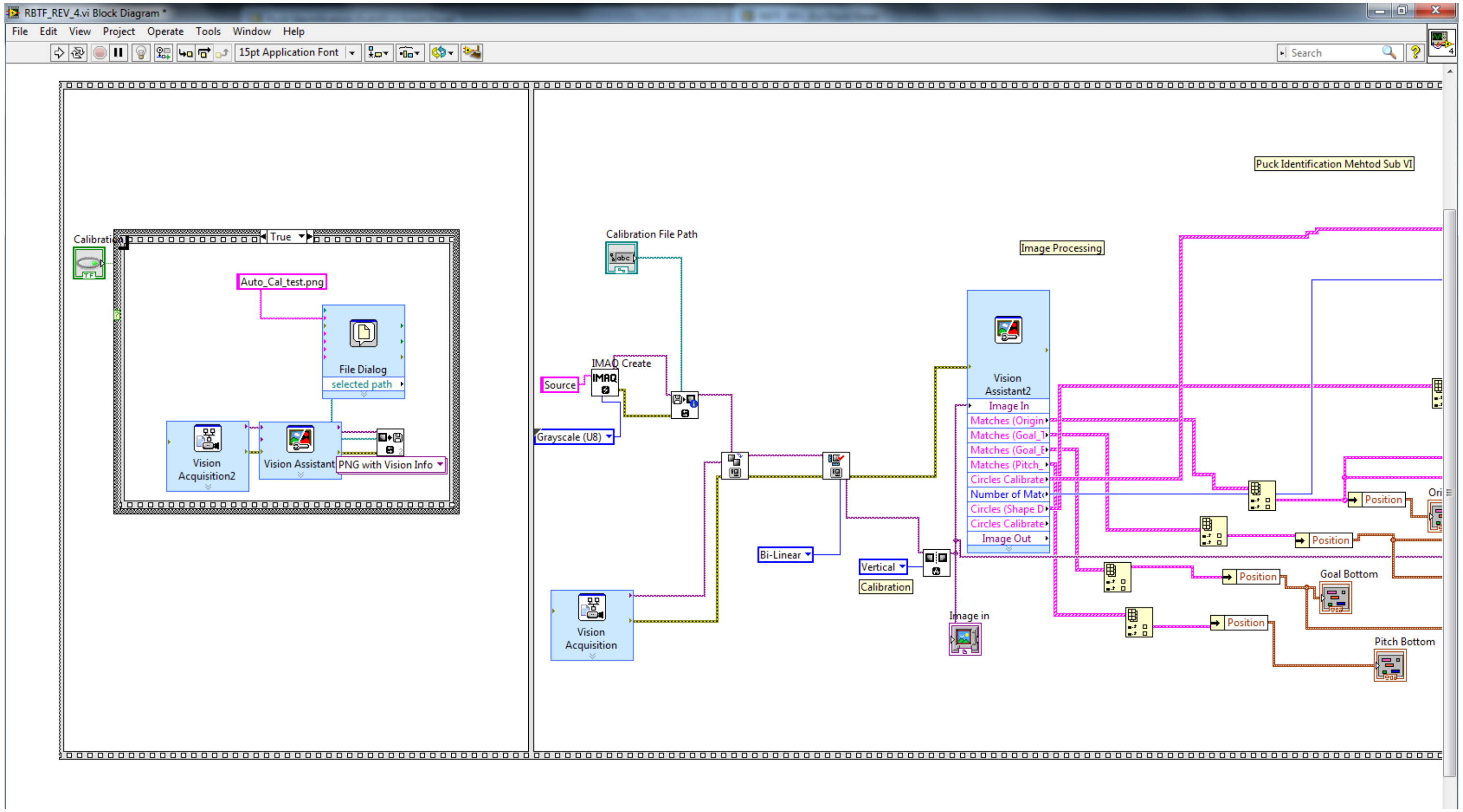
5.6 Appendix 6 - Work Breakdown Structure

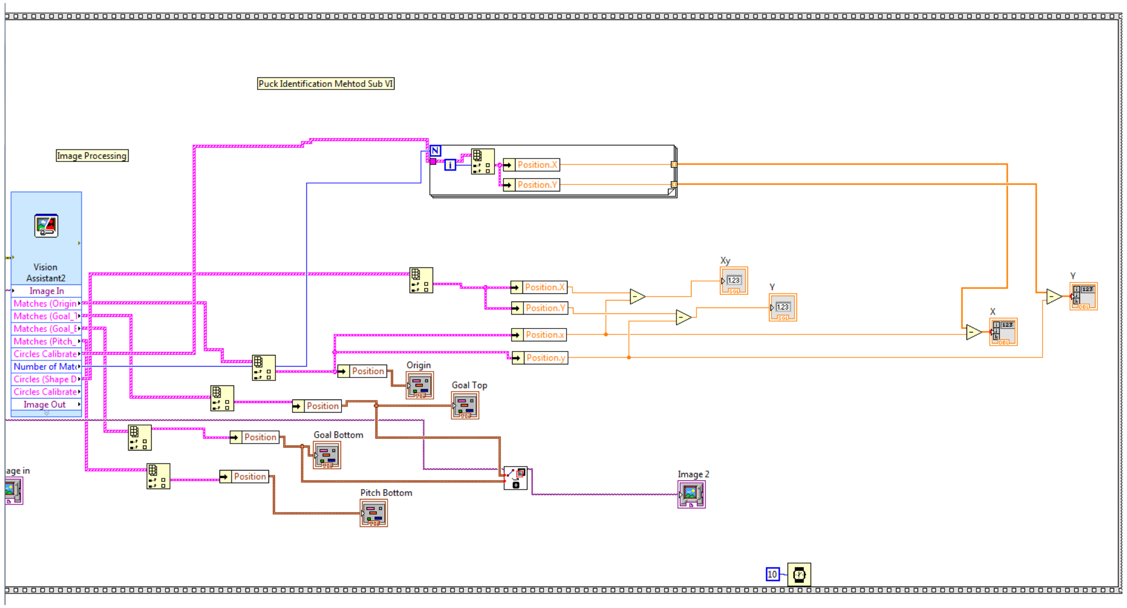




Positional Accuracy
Tolerances
Drive
Acceleration
Braking
Variable Speed
System
Communication/ Interfacing
Data Transfer
Data Display
System Intelligence
Manipulator
Motor Curves
Existing Applications
DC & Stepper Motors
Accuracy

5.7 Appendix 7 – Software Revision 4 as of 9-3-2106




Puck Identification Mehtod Sub VI
Image Processing
Vision Assistant2
Origin
Goal Top
Goal Bottom
Pitch Bottom
Image 2


ROBOTIC TABLE FOOTBALL
Calibration
Calibration File Path
Puck Position
Opposition Position
Pitch Dimensions
Origin
Goal Top
Goal Bottom
Pitch Bottom
Image in
Image 2