ROBOTIC TABLE FOOTBALL

MMD900 Final Report

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Abstract

This report outlines the development of the Robotic Table Football system used as a demonstration for a competitive tender offer. The system needed to be able locate a player puck, opposition and table features in order to score 5 masked shots in 5 minutes (2 straight & 3 rebound) and demonstrate 5 un-masked shots.

The system was split into 3 areas of development; a kicker, manipulator and vision system. Initially, project management tools were used to ensure the project's completion within the specified time frame of 12 weeks and to identify potential risks to the project.

The vision system was developed using information obtained through research and testing. The final vision system used Local Threshold with background correction algorithms in order to mitigate the effects of ambient light. The pitch features, pucks and player were located using Geometric Matching and the edge of the pitch was located using Edge Detection algorithms. The system featured 1-click automated calibration with a re-designed A2 calibration sheet designed to national instruments specification. The shot was calculated using trigonometry and algebraic intersection with the selected path identified as the central one out of all the shot possibilities.

Performance testing determined that the vision system was able to measure to an accuracy of ±0.53mm in ambient light conditions ranging from 255 to 312 Lux with an overall operation time of 0.72 seconds.

The 3 sub-systems were integrated through a user friendly interface and testing of the integrated system determined that it was capable of taking 6 shots scoring 4 goals ± 1 during the 5 minute period.

Overall, the system was able to meet all of the customer requirements. There was a delay in kicker and manipulator manufacture, however this was due to the fact that the vision system could be developed outside of the allocated lab hours. Further work suggested for the vision system was improvement to shot power estimates and also further refinements in pitch detection algorithms.

Contents

1 Introduction

This report covers the final development of the Robotic Table Football. In order to meet the specification of the required contract, the system needed to be capable of identifying, locating and kicking a puck into a goal from multiple positions, whilst also having the capability to locate opposition pucks and be able to choose a suitable shot.

The system was split into 3 sub-systems (Vision, Manipulator & Kicker) which were developed by 3 engineers in order to fulfil the project requirements in the specified time. This report focuses on the vision system in more detail with its integration to a system as a whole.

In order to successfully achieve the project deliverable, the following objectives needed to be met:

- Development of a robust vision system that mitigates the effect of ambient light.
- Fully automated system including '1-click' calibration.
- Accurately identify the position of the pucks and features of the pitch.
- A user friendly interface to communicate data between the 3 sub-systems.
- Demonstrate shot learning capabilities.
- Testing and validation of the vision system to ensure customer confidence.

2 Project Management

Initially, the project requirements were reviewed in order to produce a project time plan that would meet all of the customer needs within the specified time frame. These key deliverables were translated into a work breakdown structure (WBS); from this a Gantt chart and risk register were created to ensure the project would be completed on time and with the minimum risk.

2.1 Planning & Divergence from the plan

The overall time given to this project was 12 weeks, the plan is detailed further in the Gantt chart (Appendix 1), this was designed to ensure that each of the sub-systems were developed in unison so that the integration of all the subsystems could be done at the specified date (28th April).

2.2 Risk management and mitigation

A risk register was developed (Appendix 2) with the purpose of identifying and mitigating potential risk areas of the project, the risks were rated in terms of their likelihood and overall effect on the project. Examples of the major risks of the project were:

- Camera communication – The camera had an out of date driver that often caused issues when communicating to Windows. In some cases it would cause the computer to crash and restart when running the LabVIEW software. This risk could not be removed completely, however regular saves of the software were done to minimise the effect of this risk.
- Loss/corruption of files – Whenever code was modified or changed it was saved as a new revision with modifications noted in a text file. This ensured that if new code did not function correctly a previous revision was readily available. Each revision was backed up on cloud storage and also a separate PC.

2.3 Reflective commentary on risk and planning

The project followed the time plan exceptionally well during the first half of the project. However, midway through the project there was a delay in the kicker manufacture and also the manipulator system; this was likely due to the fact that these systems could only be developed during scheduled Lab hours unlike the vision system. However, any delays in the sub-systems were within the team communicated early in the project to ensure that these risks could be mitigated in accordance to the risk register.

3 Vision System

3.1 Research & Development

Development of the vision sub-system can be broken down into the following stage:

Image Acquisition - Feb 8th to Feb 12th

Initially there were two lens options available, these were tested by acquiring images of the playing surface, it was found that the 12mm lens could not fit the entire pitch width in its field of view (FOV), therefore the 6mm lens was used.

The maximum pixel resolution (with the required FOV) was then calculated using the Pinhole Camera model (1), this was found to be 2.20 pixels per mm at a height of 520mm. The camera relationship between height and pixel density was also tested (shown in Figure 3-1), it was discovered at the height of 520mm the relationship was near linear.

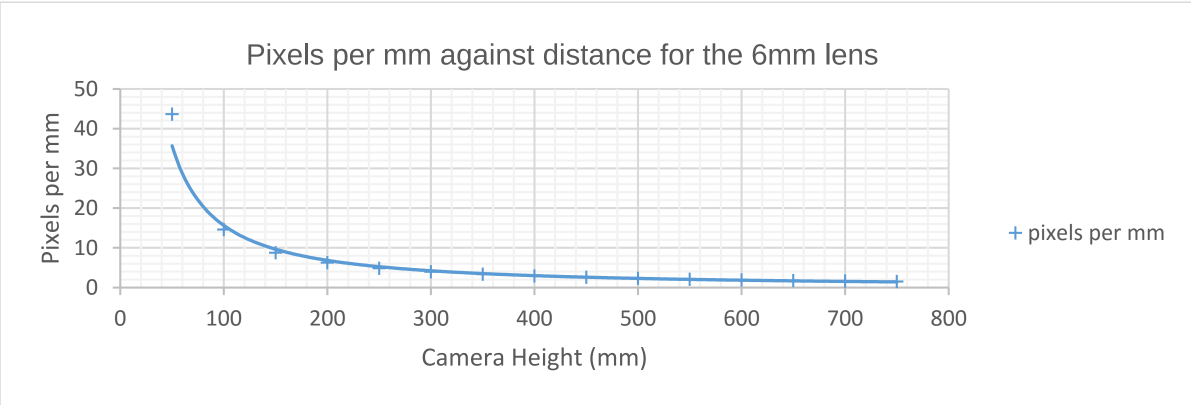

Figure 3-1 Relationship between pixels and camera height.

The camera sensor was then checked for its pixel accuracy by measuring a 30cm rule in both X and Y; this camera was found to have a ratio of 0.9998 (X: Y).

Ambient Light - Feb 12th to Feb 20th

The system needed to be robust against changes in ambient light, therefore thresholding methods were researched (2). This research suggested that an automatic or local threshold should be used to mitigate the lighting effects. The threshold methods were then tested in different ambient light scenarios simulated by desktop lamps and it was found that the Local Threshold with background correction proved to be the most robust (shown in Figure 3-2).

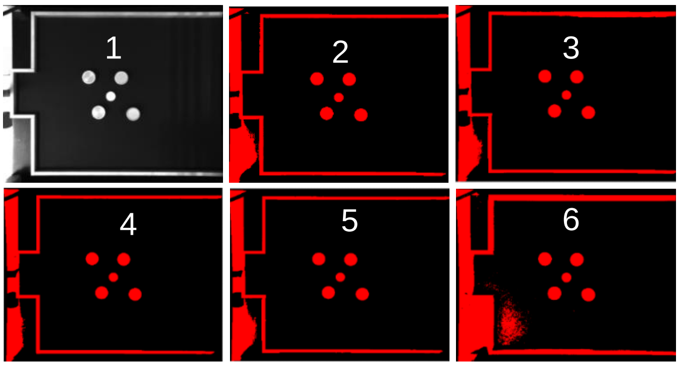

Figure 3-2 shows the results of different threshold methods 1-original image, 2-manual, 3-Local (Niblack), 4-Local (background correction), 5-Auto-Threshold (cluster), 6-Auto Threshold (entropy)

Calibration - Feb 20th to Feb 27th

Calibration was needed in order to remove any perspective and lens distortion in the image and to also get real world dimensions. National instruments have published a document specifying calibration sheet design (3), it was found from that the original calibration sheet was not within specification, hence a new A2 sheet was developed to cover the entire FOV. In order to create the automatic calibration template file, threshold methods along with particle filtering algorithms were used to ensure that only data from the calibration sheet (the dots) were used in the calibration (Figure 3-3), this was developed using literature research of perspective calibration (4).

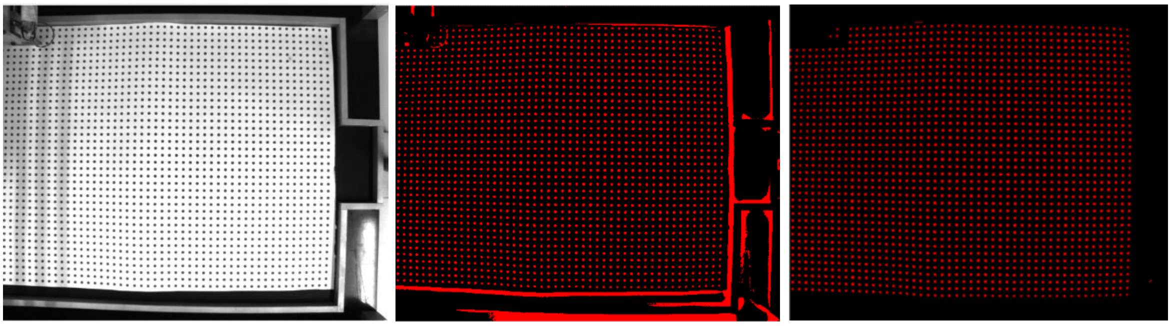

Figure 3-3 stages of calibration filtering (Left) - Original image, (Middle) – Threshold & (Right) - particle filtering.

Object location – Feb 27th to March 7th

LabVIEW offers many ways of object detection, these were all tested by measuring the distance between 3 opposition pucks aligned edge to edge and it was found that each provided near identical accuracies in detection. However, according to literature research (5) if an object is of a known size and orientation then the Geometric Matching method should be used; this also had further advantages as it could still detect the pucks when in contact with the pitch walls.

The walls edges of the pitch were detected using Edge detection algorithms and offset by the player pucks radius. These co-ordinates were then used for the shot calculation.

All of the objects to be located are above the calibration plane, hence the measurements will be incorrect. Methods to overcome this were researched and it was found that Horaud's Junction Orientation Technique could be used (6) in order to convert the measurement to one relative to the calibration plane.

Shot Calculation - March 7th to April 18th

The straight shot calculation functions by performing 200 loops (0.9 degree half steps totalling 180 degrees), each loop checks to see if the shot line intersects with the opposition pucks (using algebraic intersection of a line & circle (7)), it then checks to see if the shot intersects with the goal line. If these two cases are true the shot paths are plotted on the user interface. The rebound shot, in a near identical manor, however, this is repeated twice for each stage of the shot (pre & post rebound).

Shot selection needs to fill two criteria; most central shot in the goal and furthest away from the opposition pucks. Initially, a shot algorithm was developed which weighted the opposition and goal based on their algebraic intersection value or ‘collision value’ (7), the chosen shot would be the path with the lowest collision value. However, this method needed more development as some choices were illogical. Through further development the shot was eventually calculated by choosing the middle path out of the ones calculated, this method proved to be far more consistent in its logic when testing.

Shot learning capability was added so that after the shot an image would be taken in order to compare that predicted puck position to the actual shot. The two shot paths would then be compared in order to determine if the shot power should increase or decrease.

3.2 System

It was initially decided between the team members that each of the sub systems would operate from a global variable. Therefore, the vision system needed to communicate puck position, shot power and shot angle data to the other sub-systems in the agreed format; this allowed the team members to develop their software individually but still function from the data output by the vision system in a user friendly interface, hence making integration between software far simpler.

Once the sub-systems were complete, the project moved towards a more team based approach in which discussions, meetings and testing were carried out by all group members in order to ensure the successful integration of the sub-systems.

4 Performance/testing/analysis

For the vision sub-system and overall system the performance was determined by the following points:

4.1 Calibration Testing

Calibration has one of the highest influences in the overall system performance. In order to determine the accuracy of calibration, the calibration sheet was used in to measure the distance of each of the dots spaced 10mm apart (shown in Table 4-1). Each of the dots were then measured in order to produce calibration data for the entire field of view (58 columns and 40 rows of dots). This testing yielded an average measurement of 10.03 ± 0.26 mm at CI 95%.

(*Note: theoretical accuracy at 2.2 pixels per mm is 10.00 ±0.22 mm*)

Sheet properties	**A2 sheet**
Centre to centre distance	10mm (23 pixels)
Dot Radius	4mm (6 pixels)
Mean measurement	10.03mm
Std. Deviation	0.04mm
95% CI at 520mm	±0.26mm
95% CI at 520mm	±0.59 pixels

Table 4-1 calibration testing results using the A2 sheet.

The calibration was also further verified during operation so that the user could get instant feedback. This was done by measuring the real world width of the goal (111.40 mm) using a set of callipers and comparing it to software measurements, the measured tolerance of the system was then used verify the calibration for the user and also prompt the user if the system was out of calibration. This was tested for 30 calibrations, in which the results determined that 93.33% of calibrations were within tolerance of the test data in Table 4-1.

4.2 Location of Elements Testing

The accuracy of feature location was tested by placing the pucks in known positions on the pitch at a set distance from the walls and goals (measured by callipers) and also the known centre distance between the 3 pucks (shown in Figure 4-1). This testing was repeated 10 times and the results suggested that the system was able to read to an accuracy of ±0.53mm. This was further tested with the manipulator system which proved to have near identical results when locating the puck.

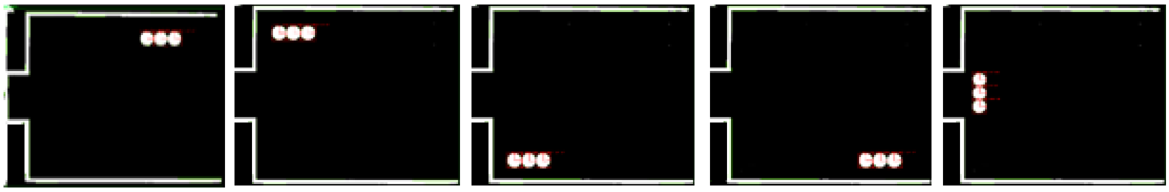

Figure 4-1 the testing positions of the pucks across the pitch surface.

4.3 Ambient Light Performance

The system needed to be resistant to changes in ambient lighting, in order to provide a numerical value to this the application Light Meter (Calibrated using Profession Illuminometer equipment) was used to take measurements in the lab over a period of 5 days. The Light Meter took measurements of Lux values for 30 seconds every hour. The results are shown below in Figure 4-2 and it was found that the vision system was able to function and identify all puck and pitch features in LUX values of 255 to 312 100% of the time.

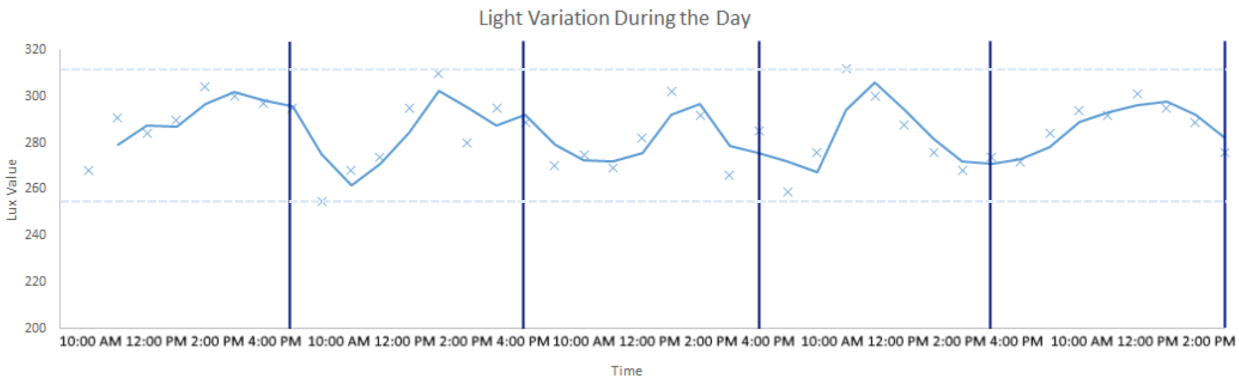

Figure 4-2 the variation in ambient light over a period of 5 days.

4.4 Speed of Vision System

The speed in which the system ran was analysed using the performance & memory tool available in LabVIEW, it was found the time taken to apply the calibration, locate features and plot shot paths was 1.20 seconds. By using parallelisable loops highlighted in the software analysis, the software functioned more efficiently and the operation time was decreased to 0.72 seconds (shown in Table 4-2).

Sub Vi operation	Time
Calibration	0.22 seconds
Pitch feature & Opposition Detection	0.21 seconds
Shot Path calculation	0.29 seconds

Table 4-2 breakdown of the Sub-VI times using the performance and memory analysis.

4.5 System Performance

Once the system was integrated with a user interface (Figure 4-3), shots were tested 62 times, with adjustments made in the software in terms of angle of rebound and co-efficient of restitution to continuously improve the system performance. This testing yielded a success rate of 71.40% for straight shots and 34.20% for the rebound. It should be noted due to the continuous improvements over the simulated runs the system became far more reliable and consistent (shown below in Figure 4-3). The testing results suggested that the system was able to take 6 shots and score 4 ± 1 goals during the 5 minute period.

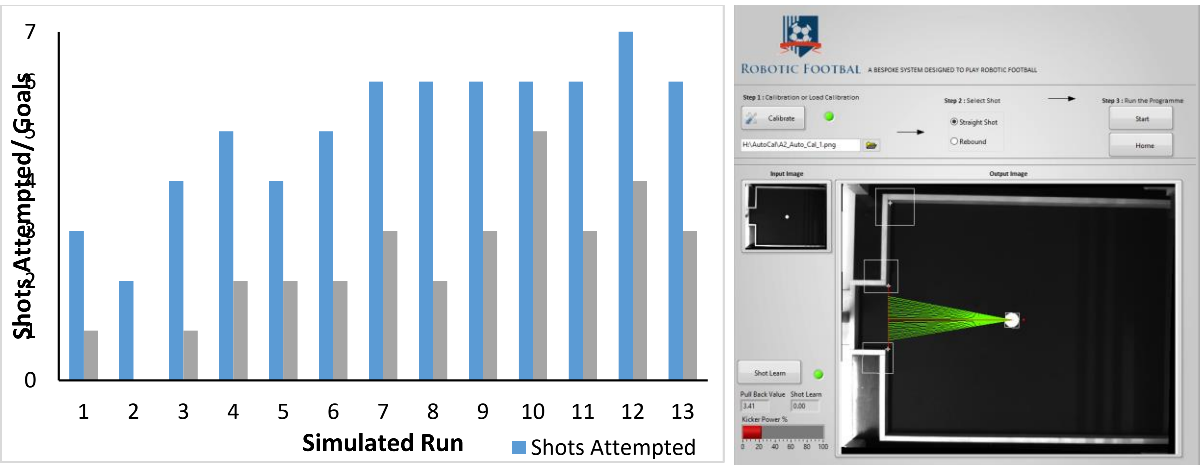

Figure 4-3 CDR timed testing results (Left) and the final user interface (Right).

During testing it was observed that the inaccuracies in the straight shot were mainly due to the pitch surface variation, in some cases shots from the same position and same power would either have too little power (not reaching the goal) or have too much causing the puck to rebound out of the goal.

The variation in the rebound shot was partly due to the surface variation, however there was also variation in the restitution values along the pitch wall; this variation sometimes caused the rebound angle to be far different than the predicted and the initial angle of the shot taken by the kicker.

The total time taken for the system to start moving once the start button was pressed was around 3.21 seconds; this can be broken down further into 0.72 seconds for vision and 2.49 seconds for manipulator and kicker (Totalling 16.05 second of system calculation when taking 5 shots).

5 Reflections

Throughout the 12 week period of this project my skills as an engineer have been thoroughly tested and developed. Initially, I had no previous experience with machine vision and there are many alternate methods that could have been used to achieve the required outcome; hence a vast amount of background research and reading was required to fully gain an understanding of machine vision fundamentals.

Although machine vision was a large part of this project, I also further developed my software and coding skills. The shot calculation proved to be fairly challenging especially for the rebound shot, development of this required many complex array calculations which were refined through testing and research.

Providing confidence to the customer was one of the main deliverables of this project, hence thoroughly tested data was required in order to back up any of the system specification claims. This required many hours of testing in which I learnt efficient ways to get the test data needed.

From a team perspective I found co-ordination and communication was crucial to the overall project's success. There were many scenarios in which team members would openly discuss the possible methods of programming the shot paths and the manipulator movement. There were also periods in the event of delayed project deliverables in which the team had to collaborate with each other's sub-system to ensure that the project deliverables would be met on time.

The use of a client throughout the project was a far different experience than presenting work to a lecturer in which we had to work as a professional team in order to present. I found this greatly developed my professional and organisational skills as an engineer.

6 Conclusion

The aim of this project was to produce a system capable of identifying, locating and kicking a puck into a goal from multiple positions within a 5 minute period. During the customer acceptance demonstration 6 shots were taken and 4 goals were scored within the allocated time period; this is exactly what the group had predicted in the client presentation. The initial requirements were to score 5 goals in this time period, the system was able to take 6 shots however, due to variations outside of the groups controls such as pitch surface and wall restitution consistency in goal accuracy was difficult to achieve.

Through successful development, the vision system was able to mitigate the effects of ambient light, detect all of the pitch features, choose logical shot paths and demonstrate learning capabilities. This system met all of the customer requirements and when integrated into the system performed as the test data had predicted to an accuracy of ±0.53mm.

Overall the project was successful, each of the specification points were met due to the teams collaboration which ensured the project's completion.

7 Further work

Further refinements to the vision systems feature detection could still be made, for example, if the goal was occluded when the software was run, the vision system may not detect all the features causing a software error. Therefore, the programme could be further refined to ensure that all of the points of the pitch were found before the system would run.

Further testing and refinement of rebound shot would be beneficial as this was more inconsistent than the straight shot due to the variation in the pitch surface and the restitution values of the pitch edge.

The manipulator system gradually moved forward over time when not in use due to the software design, this caused issues in puck location and had to be re-adjusted multiple times in order to get valid test data.

The kicker systems design caused on some occasions a premature kick, thus kicking the puck with less than the required force. However, this could be simply improved in a future revision by increasing the thickness of the kicker plate.

Overall, there are some refinements that could be made to the system to further improve its consistency when performing the 5 minute shot demonstration.

8 References

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

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

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

4. —. Perspective Calibration Example. [Online] Dec 2015. http://www.ni.com/example/30631/en/.

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

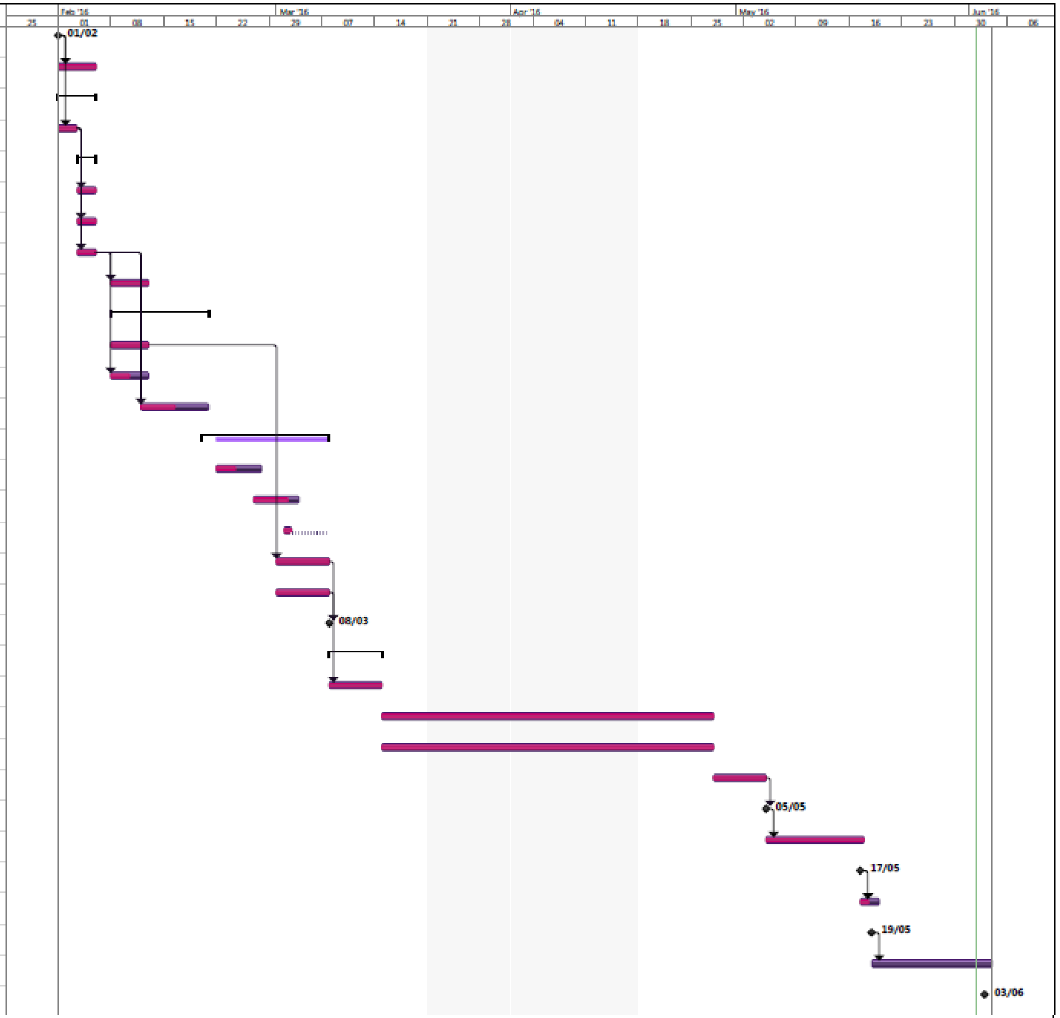
7. Plymouth University. Finding the points of intersection of a circle and a straight line. [Online] http://www.cimt.plymouth.ac.uk/projects/mepres/allgcse/add_10.12b.pdf.

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

9 Appendix

9.1 Appendix 1 – Project Gantt Chart

ID	Task Name	Duration	Start	Finish
1	Project KickOff	0 wks	Mon 01/02/16	Mon 01/02/16
2	Complete Core 1 Online Training	1 wk	Mon 01/02/16	Fri 05/02/16
3	**Project Setup**	**1 wk**	**Mon 01/02/16**	**Fri 05/02/16**
4	Determine Group Roles	0.5 wks	Mon 01/02/16	Wed 03/02/16
5	**Create planning and management documents**	**0.5 wks**	**Wed 03/02/16**	**Fri 05/02/16**
6	Develop WBS	0.5 wks	Wed 03/02/16	Fri 05/02/16
7	Develop Initial Schedule	0.5 wks	Wed 03/02/16	Fri 05/02/16
8	Develop Risk Register	0.5 wks	Wed 03/02/16	Fri 05/02/16
9	Complete Core 2 Online Training	1 wk	Mon 08/02/16	Fri 12/02/16
10	**Initial Research**	**2 wks**	**Mon 08/02/16**	**Sat 20/02/16**
11	Work through machine vision exercises	1 wk	Mon 08/02/16	Fri 12/02/16
12	Image Acquisition Research & Testing	1 wk	Mon 08/02/16	Fri 12/02/16
13	Ambient Light Research & Testing	1.2 wks	Fri 12/02/16	Sat 20/02/16
14	**Develop Vision System**	**2.4 wks**	**Sat 20/02/16**	**Mon 07/03/16**
15	Calibration Development & Testing	1 wk	Mon 22/02/16	Sat 27/02/16
16	Object Location Development & Testing	0.8 wks	Sat 27/02/16	Thu 03/03/16
17	Shot Calculation Development & Testing	0.2 wks	Wed 02/03/16	Mon 07/03/16
18	Preliminary Design Review Meetings	1 wk	Tue 01/03/16	Mon 07/03/16
19	Develop PDR Report	1 wk	Tue 01/03/16	Mon 07/03/16
20	Submit PDR Report	0 wks	Tue 08/03/16	Tue 08/03/16
21	**Finalise Vision System**	**1 wk**	**Tue 08/03/16**	**Mon 14/03/16**
22	Generate test Data	1 wk	Tue 08/03/16	Mon 14/03/16
23	Intergrate Machine Vision and Manipulator system	2 wks	Tue 15/03/16	Wed 27/04/16
24	Intergrate Machine Vision and Kicker system	2 wks	Tue 15/03/16	Wed 27/04/16
25	Prepare System for CDR	1 wk	Thu 28/04/16	Wed 04/05/16
26	Critical Design Review	0 wks	Thu 05/05/16	Thu 05/05/16
27	Develop System and Prepare for CA	1.8 wks	Thu 05/05/16	Tue 17/05/16
28	Deliver CA Presentation	0 wks	Tue 17/05/16	Tue 17/05/16
29	Prepare for CA Demonstration	0.5 wks	Tue 17/05/16	Thu 19/05/16
30	Deliver CA Demonstration	0 wks	Thu 19/05/16	Thu 19/05/16
31	Prepare for Final Report	2.4 wks	Thu 19/05/16	Fri 03/06/16
32	Submit Final Report	0 wks	Fri 03/06/16	Fri 03/06/16



Project: Project Time Plan - Me
Date: Thu 02/06/16

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Baseline, Baseline Milestone, Baseline Summary, Progress, Manual Progress

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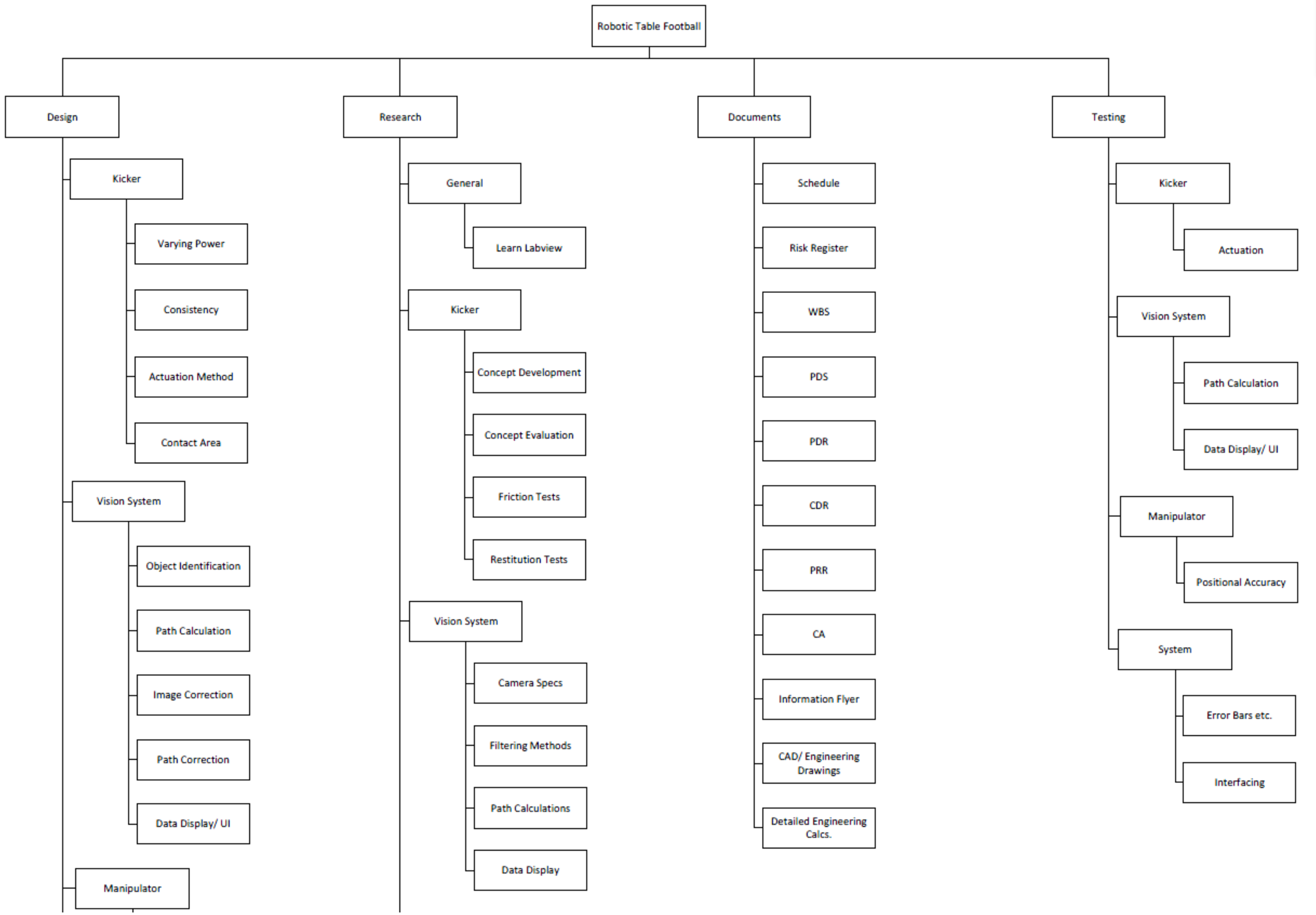
9.2 Appendix 2 - Risk Register

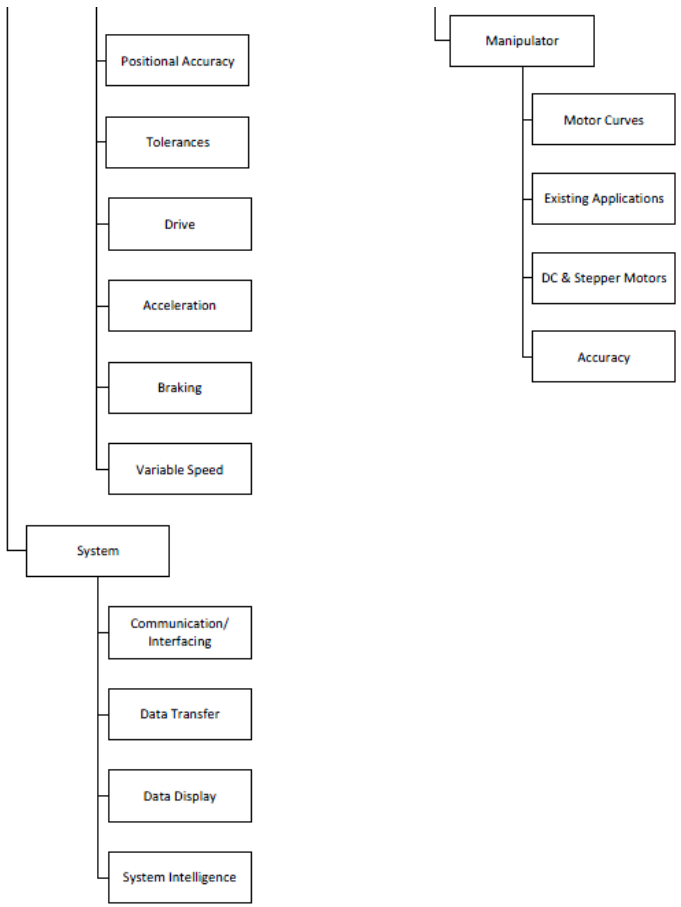
Risk ID	Risk (Description)	Owner	Date Raised	Probability	Impact	Severity	Mitigation	Trigger Date	Status
1	Software failure on demonstration day.	ALL	08/02/2016	2	4	8	Revert to last know working version.	On Going	Open
2	Delay of kicker Manufacture.	S.M.	08/02/2016	2	5	10	Ensure drawings are signed off and all files/ drawings are delivered to workshop on time.	22/04/2016	Closed
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.	On Going	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.	On Going	Open
5	Lab is out of action during project.	ALL	08/02/2016	1	3	3	Ensure all files are available outside of labs.	On Going	Open
6	Behind schedule for PDR	ALL	08/02/2016	2	4	8	Maintain regular progress meetings and continually review progress on schedule.	28/04/2016	Closed
7	Camera malfunctions during manufacture/ assembly.	H.T.	08/02/2016	2	5	10	Ensure valid calibration and code backup routine is established early on.	28/04/2016	Closed
8	Malfunction of sub system.	ALL	08/02/2016	3	5	15	Ensure all sub systems are thoroughly tested throughout project.	On Going	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.	13/05/2016	Closed
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.	On Going	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.	On Going	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.	On Going	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.	22/04/2016	Closed
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.	22/04/2016	Closed
15	Deliverables are not in line with customer requirements.	ALL	08/02/2016	3	3	9	Develop thorough PDS and reference this PDS throughout project.	On Going	Open
16	Ordered parts don't arrive on time or are unavailable.	ALL	09/03/2016	2	3	6	Ensure stock before ordering and order early.	22/04/2016	Closed

17	Behind Schedule for CDR	All	09/03/2016	2	4	8	Maintain regular progress meetings and continually review progress on schedule.	05/05/2016	Closed
18	Behind Schedule for Final Demonstration.	All	09/03/2016	2	4	8	Maintain regular progress meetings and continually review progress on schedule.	09/05/2016	Open
19	Poor Lighting Effects Vision System	H.T.	26/04/2016	3	3	9	Test operating ability of the vision system and assertain best conditions.	25/04/2016	Closed
20	Manipulation system creeps forward losing home position.	A.L.	26/04/2016	2	2	4	Monitor home position during operation.	On Going	Open

9.3 Appendix 3 - 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