2014 ROBOCUP PROGRESS REPORT 2

DETAILED DESIGN REPORT

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EXECUTIVE SUMMARY

This detailed design report is focused on a robot design intended to compete in the 2014 University of Canterbury Robocup. The 2014 Robocup involves two robots competing to collect the greatest mass of packages over a 5 minute time period.

An outline of the robot design is first provided highlighting the key modules contributing to the overall design of the robot. These modules included an obstacle detection system, navigation system, package identification system, package collection mechanism, base detection system and driving mechanism. A description of each of these modules in terms of their mechanical, electrical and software design is provided in this detailed design section. These descriptions are supported with justifications of the design decisions made in each of these domains.

A preliminary evaluation is then presented in this report assessing the effectiveness of each of the key modules. The evaluation highlighted the robots primary advantage was associated with its high speeds where the robot had a top speed of up to three times that of the competition. The key weakness of the robot was identified to be the robots inability to pick up packages which were overturned or positioned in a corner.

The final section of this report suggests further developments to improve the robots design. This included the suggestion that a secondary pickup mechanism may be required to pick up packages which are overturned or positioned in a corner.

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1.0 INTRODUCTION

The 2014 University of Canterbury Robocup takes the setting of a post zombie apocalypse where teams must design and build an autonomous robot to compete at collecting food packages about the 'city' or arena. Food packages (packages) take the exterior form of metal cylindrical weights and may be of 3 different masses of 0.5kg, 0.75kg and 1kg. The team with the winning robot is determined through a process of knockout rounds with each round involving two groups competing to collect packages scattered within an arena. The winner of each round is determined by the robot with greatest accumulative weight of packages including those either on-board the robot or within the robots color-coded headquarters (HQ). Based on this scenario the object of this project was to design and build an autonomous robot to collect the greatest accumulative weight of 'food packages'.

This report precedes a conceptual design report which presented and evaluated three concepts for the competition. The recommended design from this conceptual design report is presented in this report. The conceptual design report also outlined the general requirements. It was ensured in the detailed design of the robot that these general requirements were continued to be meet by the robot.

This report first outlines the details of each of the key modules which the robot consists of and then provides a preliminary evaluation of the design with suggestions for further developments. The full layout of components, dimensions and the costs of parts are included in the Appendices.

2.0 DESIGN DESCRIPTION

2.1 OVERVIEW OF DESIGN

The overall design of the robot can be considered as a combination of 6 key modules. These modules include an obstacle detection system, navigation system, package identification system, package collection mechanism, base detection system and driving mechanism. Appendix B includes an attached bill of materials used for the construction of the robot. Figure 1 illustrates the overall design of the robot.

Structurally the robot is designed into four different layers, from top to bottom, to encapsulate the electronic componentry, obstacle detection, package collection and package detection modules. The driving mechanism is integrated onto the outside of the chassis and consists of a set of 3D printed wheels driving a 16mm track. The package collection mechanism allows packages to be collected while the robot is moving with the use of paddles which can feed up to nine packages onto the rail storage system.

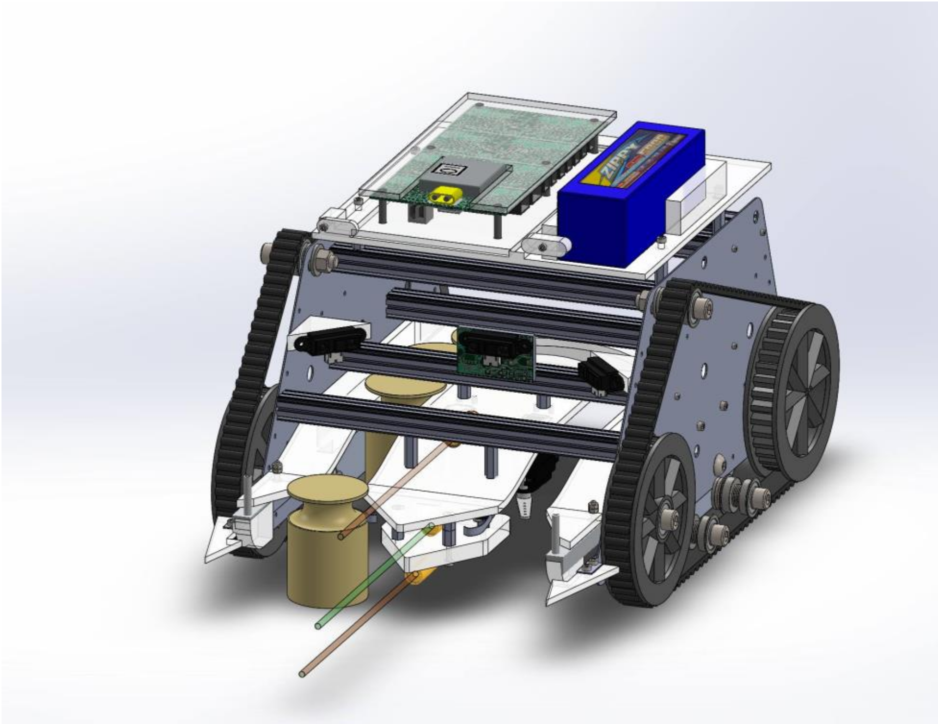


FIGURE 1: OVERALL DESIGN OF THE ROBOT

The design incorporates a range of electronic detection systems to recognise the surrounding environment. IR sensors are utilised as a means to detect obstacles and walls within the arena. Two positioning cameras are used in conjunction with a set of lasers to identify packages within the arena. In addition to these sensors a colour sensor identifies if the robot is in the oppositions base. Two DC motors were used as a method to actuate the driving mechanism of the robot.

The overall behaviour of the algorithm is implemented in software and is primarily defined by the navigation algorithm. Such an algorithm involves following the walls of the arena whilst executing routine searches for packages. As packages are identified the robot navigates towards them.

The core computational capacity for this robot is provided by an Arduino Mega ADK micro-controller. The micro-controller was programmed in C and utilized an extensive range of existing Arduino libraries to interface with the hardware components and the micro-controllers. The interfacing between the different key modules occurred within the software domain and is summarised in the N2 diagram in Figure 2.

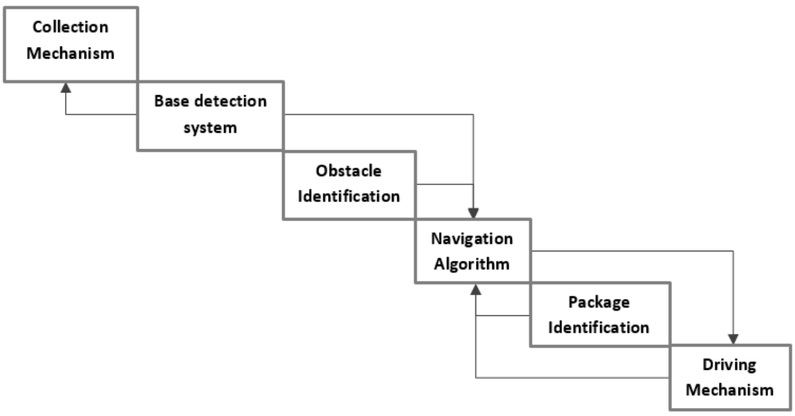


FIGURE 2: N2 DIAGRAM OF INTERFACING BETWEEN MODULES

2.2 DETAILS OF KEY MODULES

2.21 COLLECTION MECHANISM

DESCRIPTION

The collection mechanism was designed with a predominant focus on mechanical and software aspects. By considering these different aspects, the collection mechanism as illustrated in Figure 2 was designed to be relatively independent from the other modules. Such an independent design increased the robustness of the collection mechanism.

Packages are detected with the use of micro-switches from two collector inlets. These collector inlets are positioned to the left and right side of the front of the robot. Each of the collectors consists of a set of paddles which then feed packages onto and around a 'U' shaped rail storage system.

One of the key benefits of this design is that packages may be collected while the robot is moving. By allowing packages to be feed around the storage mechanism the 'U' shaped track ensures maximum storage capacity regardless of which inlet the packages are feed into. The overall design of the collection mechanism is outlined in Figure 3. A full detailed schematic with the critical dimensions of this mechanism can be found in Appendix C2.

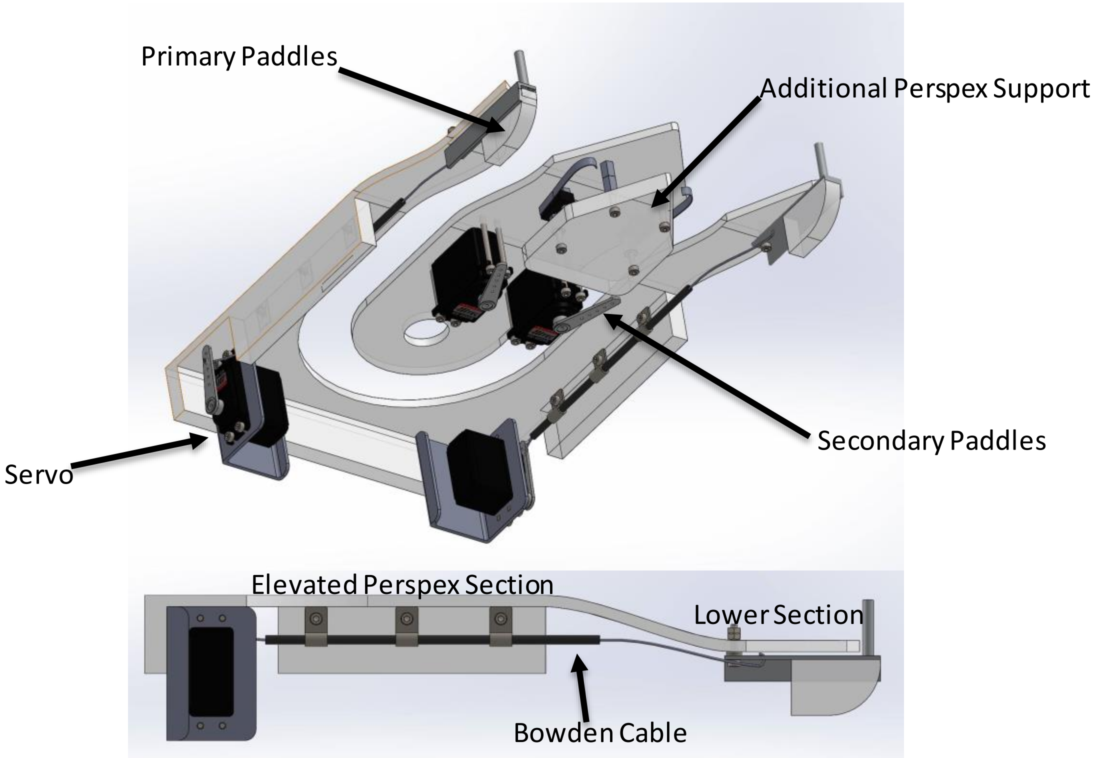


FIGURE 3: PADDLE COLLECTION MECHANISM ON "U" SHAPED TRACK

MECHANICAL DESIGN

RAIL STORAGE SYSTEM

The inner and outer Perspex sections of the 'U' shaped rail storage system were constructed as two separate parts. Each of these parts are shown in Figure 3 consisting of an elevated section for storage and a lower section for collecting packages. It was required that the rail storage system provided a smooth path for the packages to move freely between the elevated and lower section of the track. A template mould for these bends was constructed and used to provide a consistent and smooth bend when shaping the Perspex using heat.

The heights of the upper and lower sections of the rail storage system are critical dimensions to meet the general requirements of the design. In order to collect packages the lower portion of the track must be between 55mm and 65mm from the ground so that it is level with the side grooves of the packages. The minimum height from the ground of the elevated portion of the track was calculated (Appendix A1) to be 95mm. This height ensured that the stored packages would be high enough to not obtruct with any obstacles as per general requirement R2.2.

> R2.2: “The robot shall be able to navigate about obstacles including rectangular profile speed bumps no greater than 25mm high”

GENERAL REQUIREMENT 2.2

The shape of the lower section of the rail storage system was designed to channel the packages into the inlets whilst keeping them upright. To minimise the chance of knocking over packages an additional piece of Perspex was added to support the packages through their centre of mass as shown in Figure 3. It was found in experiments that without this additional support, packages would tip over when the robot was driving at full speed towards them. Additional Perspex guides were added to the outside part of the rail system to ensure packages are not overturned by the obstructing wheels. These features are illustrated in Figure 3.

PADDLE SYSTEM

It was found that the primary paddles on their own do not provide enough torque to feed the packages around the ‘U’ shaped track. The primary paddles were therefore constructed to guide the packages up onto the rail system while the secondary paddles functioned to feed the packages around the ‘U’ shaped track. HXT12K servos were used to actuate the primary and secondary paddle system. With each of the servos providing $9kgcm^{-1}$ of torque they were sufficient to guide the 1kg packages along the rail system.

The primary paddles were designed with a height of 30mm this ensured a relatively large contact area with the packages. Such a large contact area was important to ensure the packages were supported through their mid-section as they were elevated onto the storage section. The secondary set of paddles were not required to have a large height as they were positioned to make contact with the packages near their centre of mass.

Due to space constraints at the front of the robot the servos for the primary paddles were positioned at the rear of the robot coupled with a Bowden cable. The Bowden cable is used to transmit the mechanical force from the servos via an inner cable enclosed in a helical outer housing. The Bowden cable and servo configuration is illustrated in Figure 3.

SOFTWARE DESIGN

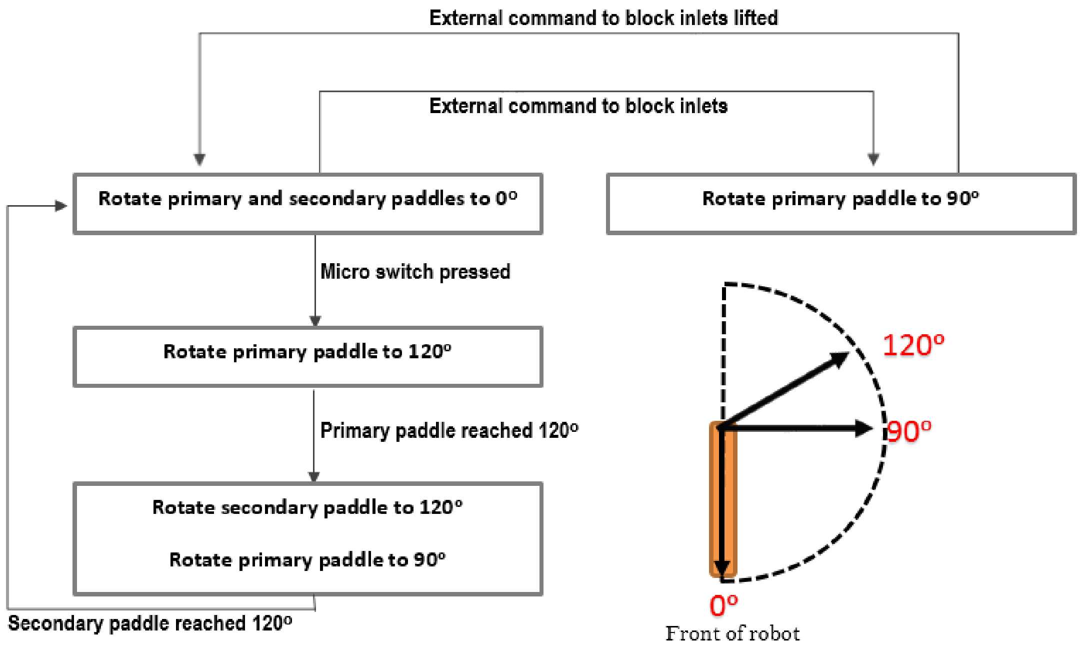


FIGURE 4: BEHAVIORAL DIAGRAM OF THE COLLECTION MECHANISM

The behavioural diagram in Figure 4 outlines the operation of the collection mechanism. When the micro-switch identifies a package the primary paddle is programmed to rotate the servo-motors by 120 degrees to feed the package onto the rail system. Once the paddle has finished rotating the secondary paddle then guides the package further along the rails. As this is occurring the inlet is obstructed by the primary paddle which are rotated to 90 degrees to ensure additional packages are not feed into the mechanism. Once the secondary paddle has rotated it rotates back to its initial position along with the primary paddle, ready to collect additional packages. An exception to this process occurs when the opposition's base is detected. In this scenario the base detection module will communicate with this module to obstruct both the inlets from collecting packages.

2.22 DRIVING MECHANISM DESIGN

DESCRIPTION

The driving mechanism was constructed primarily with a mechanical focus. The key features of this design include the 3D printed wheels, rear wheel drive DC motor system and support bearings. This module interfaces with the navigation algorithm which provides the desired path to be travelled by the robot. The module provides the distance travelled and angle rotated by the robot to the navigation algorithm. This is determined by the optical encoders inbuilt to the DC motors.

MECHANICAL CONSIDERATIONS

Such a predominant focus on the mechanical domain was made in order to harness a mechanical advantage over the other competing robots. Efforts were made to significantly improve the efficiency and speed of the supplied wheel design by modifying the track layout and increasing the size of the wheels. Full schematics of the components and layout of this driving mechanism design can be found in Appendix C3.

WHEEL DESIGN

Custom wheels were 3D printed with slots around the outer rim of the wheels to accommodate the supplied tracks. A significant increase in speed was expected by increasing the diameter of the wheels from 60mm to 100mm. It was approximated (Appendix A2) that this increase in diameter could result in a 70% maximum increase in the speed of the robot from the standard design. A disadvantage of this increased diameter however was the approximated (Appendix A2) 40% reduction in driving force provided by these modified wheels. This was identified as a potential weakness in this design, where the robot is required to manoeuvre over obstacles according to requirement R2.2.

The rear wheels were required to be directly attached to the DC motors. Two screw slots were placed through the rear wheels for this attachment to these motors drive shaft. A set of bearings were press fitted to the front wheels in order to reduce the bearing stresses and provide a relatively frictionless rolling support.

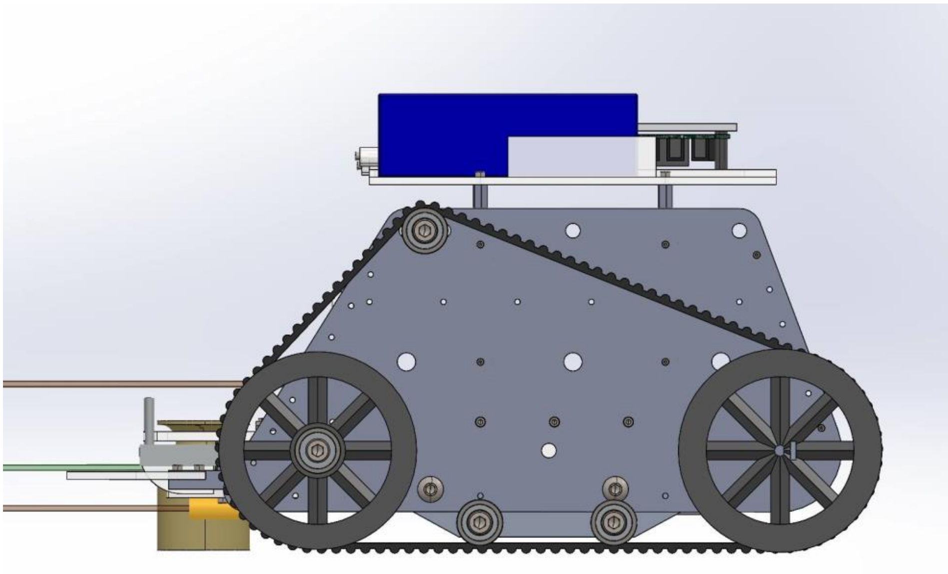


FIGURE 5: MECHANICAL DESIGN OF DRIVING MECHANISM

POSITIONING OF SUPPORT BEARINGS

One of the disadvantages with 3D printing the wheels was the reduction in strength inherent with this construction method. The bearing stresses induced on both the front and rear wheels were identified to be a potential point of failure with this design. It was found in an analysis that the bearing stresses on the rear wheels are 3.7 times greater than the front wheels. Support bearings were positioned beneath the chassis as shown in Figure 5 to relieve these stresses on the rear wheels by supporting the weight of the robot.

Additional bearings were positioned in a horizontal slot at the top of the chassis. This bearing slot arrangement allowed the tension in the tracks to be adjusted.

To maximise the efficiency of the driving mechanism the number of bends in the tracks were kept to a minimum. Where each of the bends contributed to additional frictional losses in the system.

ELECTRONIC CONSIDERATIONS

A rear wheel drive system was driven by two 28PA51G DC motors. These provided the maximum torque and speed compared to the other supplied motors. Unlike the stepper motors the DC motors did not require a cooling system. In addition to these benefits the optical encoders inbuilt into the DC motors could be conveniently used to determine the distance travelled and angle rotated of the robot. A disadvantage of the DC motors however is that their large size restricts the locations with which they can be installed.

In order to simplify the software control of the driving mechanism a 'tank mode' setting inbuilt into the Sabertooth dual 12A motor drivers is used. The tank mode setting drastically reduces the complexity of the driving system by only requiring two signals to be sent to the driver. These two signals included the desired linear speed of robot and differential speed of the wheels to actuate turning. The tank mode setting was activated with the dip switches on the motor driver.

SOFTWARE CONSIDERATIONS

The driving mechanism interfaces with the navigation algorithm in order to provide a closed loop control mechanism to actuate the desired path of the robot. This closed loop control is achieved through the feedback from the inbuilt optical encoders. Where the difference in the number of revolutions made by each of the wheels is used to determine the angle rotated by the robot. Similarly the distance travelled by the robot was determined by the number of common revolutions the wheels made. This rotational angle and distance was shared with the navigation algorithm to provide closed loop control of the robot. A disadvantage of inbuilt DC motor optical encoders was that they required the use of interrupts. With only five available hardware interrupts on the micro-controller this limited the resource budget to implement interrupts for other applications.

2.25 OBSTACLE IDENTIFICATION

Three IR sensors were used as a simple mechanism to detect walls and obstacles. Each of these sensors provided the distance of the closest object detected. This module is important as it provides the distances of objects from the front and sides of the robot to allow the navigation algorithm to avoid these objects.

LAYOUT OF SENSORS

The IR sensors mounted on the inside walls of the chassis were angled to detect obstacles as close to the sides of the robot as possible. An IR sensor was mounted to the centre rail of the robot to detect frontward facing objects. These side sensors were mounted opposite to the sides with which they detected objects as shown in Figure 6. This layout ensured obstacles could be detected from the sides of the robot with the sensors having a minimum range of detection of 10cm. The layout also provides a wide range of detection of objects as shown in the Figure 6.

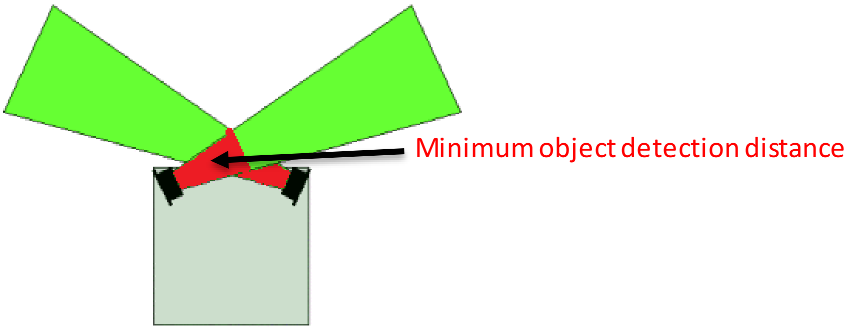


FIGURE 6: LAYOUT OF SIDE IR SENSORS

These IR sensors were positioned above the height of the packages to ensure packages were not identified as walls or obstacles. Mounts for these sensors were designed and constructed out of Perspex.

SOFTWARE

In order to provide reliable distances of obstacles from the robot the analogue input was filtered before being shared with the navigation algorithm. An averaging filter was used to achieve this and reduce the large fluctuations in output from the IR sensors. Such a filter was implemented by continuously averaging a circular buffer which stored 10 analogue input readings from the sensors. The average of these readings for each of the IR sensors was made available to the navigation algorithm.

2.23 PACKAGE IDENTIFICATION

The package identification module consists of two IR positioning cameras (modified to detect light in the visible spectrum), two 5mW red line lasers, a 5mW green laser and a servo. The positioning cameras are used to search for the reflected laser beams, providing a viewing angle of approximately 60 degrees. The red line lasers are used in conjunction with this camera to identify and confirm the locations of packages within a reasonably close proximity. The green laser provides a dot instead of a line which has a greater light intensity than the dispersed red line lasers. It is therefore expected that the green laser will identify potential packages from a longer range however will not able to independently distinguish between packages and other objects at this range. Based on experimentation the reflected green laser can detect potential packages of distances greater than 4.6m which is the maximum potential distance of a package from the robot within the arena.

The bronze surface of the packages reflect a relatively high intensity beam compared to the surrounding obstacles. The detection of a package was therefore indicated by an increase in light intensity from a reflected beam. Figure 7 identifies the four cases as viewed by the positioning camera to illustrate how the module differentiates between a package, an external light source, another object and a potential object at a distance.

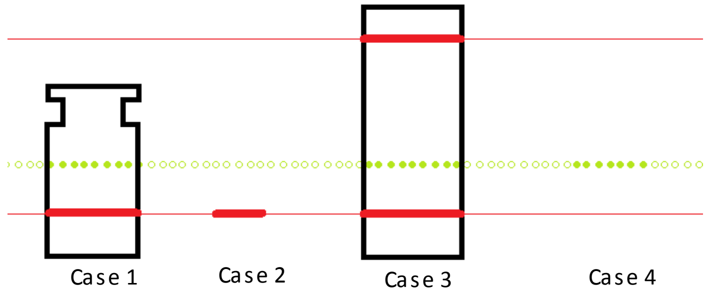


FIGURE 7: USE OF LASERS TO DIFFERENTIATE BETWEEN THREE DIFFERENT SCENARIOS

As shown in case 1 a potential package is identified if an object is detected by the lower red laser but not by the upper red laser. The detection of the green laser verifies that the lower detected light source is a reflection of light from a package and not an external light source as shown in case 2. An object other than a package is identified if both the red lasers are detected by the positioning camera as shown in case 3. Case 4 illustrates the detection of a long range potential package where only the green laser is reflected from the packages.

A predominant focus was made on the electronic design with the use of multiple lasers to dramatically simplify the software aspects. Two circuits were developed to assist in the operation of this module. A variable voltage regulator was used to provide the desired power to the lasers and a multiplexing circuit was required to implement a multiple positioning camera configuration. Where it was found only one camera could be connected to the i^2c bus without the multiplexing circuit.

ELECTRICAL DESIGN CONSIDERATIONS

LASER SYSTEM

The red line lasers are positioned to provide two horizontal lines spanning the space in front of the robot. One of these red lasers is positioned on the chassis at a height of 30mm to detect packages while the other is positioned above the packages at a height of 85mm. The green laser is positioned vertically between these two lasers and is to be rotated on a HXT servo. Such an arrangement allows the module to distinguish between packages and other objects as illustrated in Figure 7.

A variable voltage regulator circuit is used to adjust the light intensity of the green laser. This regulator was connected between the lasers and 5V output pins from the servo power supply unit. The variable voltage regulator circuit is illustrated in Figure 8.

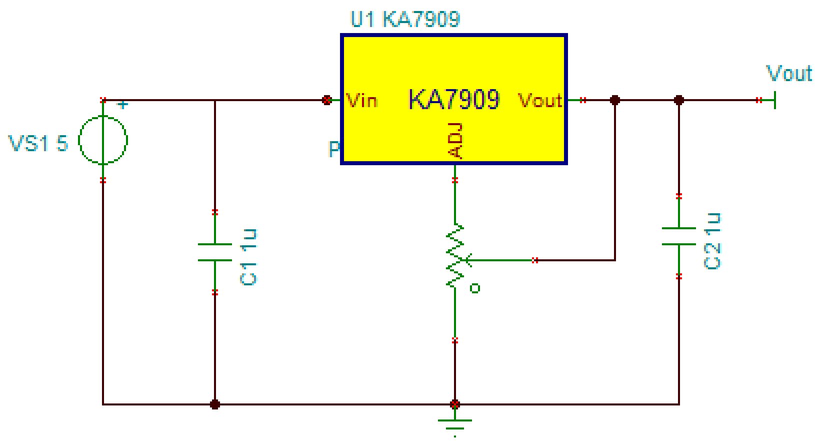


FIGURE 8: VOLTAGE REGULATOR CIRCUIT SCHEMATIC

A potentiometer was used as a voltage divider as shown in Figure 8 to adjust the output voltage and therefore supplied power to the lasers. The capacitors are used in this circuit to ensure both a steady input and output regulator voltage. Such a steady voltage is desired to provide a consistent power output to the lasers.

POSITIONING CAMERA

A positioning camera was determined as a superior means of package detection over a colour camera. It was found that the colour camera would have a sampling rate of approximately 1Hz whereas the positioning camera has a greater sampling rate of 20Hz. Furthermore the positioning camera was chosen as it does not require intensive image processing, significantly reducing the complexity of the software implantation of this module.

The positioning cameras function by identifying the 4 points on the image with the greatest light intensity and returning the co-ordinates of these 4 points. The IR filters on these cameras were removed to enable them to detect the reflected light in the visible spectrum from the lasers. The lasers were positioned as shown in Figure 9 to provide an approximate viewing angle of 60 degrees with each camera having a 33 degree viewing angle.

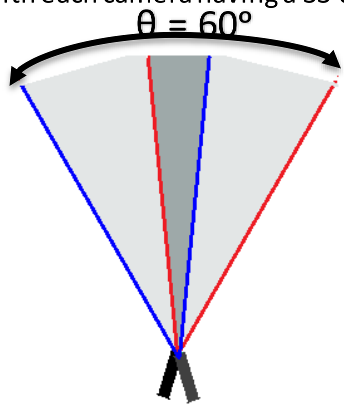


FIGURE 9: USE OF MULTIPLE POSITIONING CAMERAS TO INCREASE VIEWING ANGLE

As both cameras were required to interface over the same address register they were multiplexed in order to distinguish which camera at a given time was writing to this register. The circuit uses a PCA9540BD i^2c multiplexing chip which was programed directly over the i^2c bus to select which camera to take readings from. Although the electronic circuit is fairly simple it is required for the implementation of two IR positioning cameras. The multiplexing circuit is outlined in Figure 10.

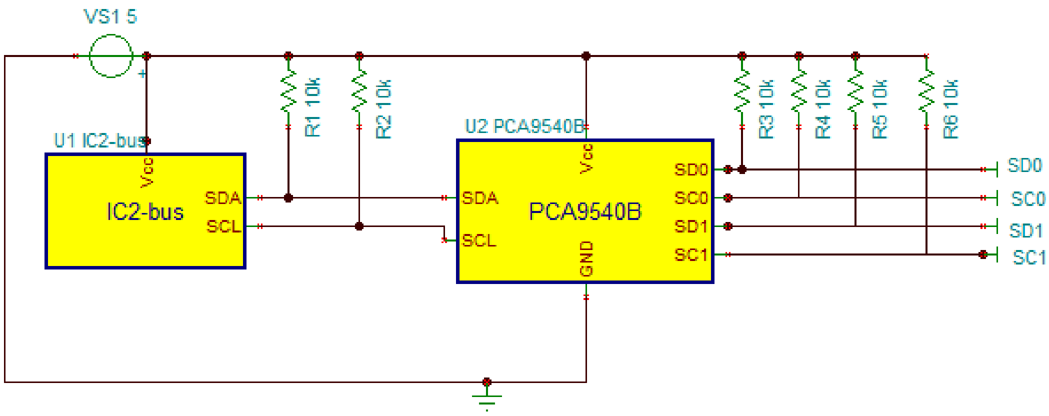


FIGURE 10: MULTIPLEXER CIRCUIT SCHEMATIC

SOFTWARE DESIGN CONSIDERATIONS

By increasing the complexity in the electronic domain the software complexity for this module was dramatically decreased. The software for this module was designed to make available the location of the closest potential package to the navigation algorithm. The behavioural diagram in Figure 11 outlines the software functionality for the package identification module to provide the angle relative to the robot which identifies this location. This module interfaces with the navigation algorithm by storing the locations of packages or potential long range packages as a shared global variable. This variable is only modified by the package identification module to eliminate any data sharing problems.

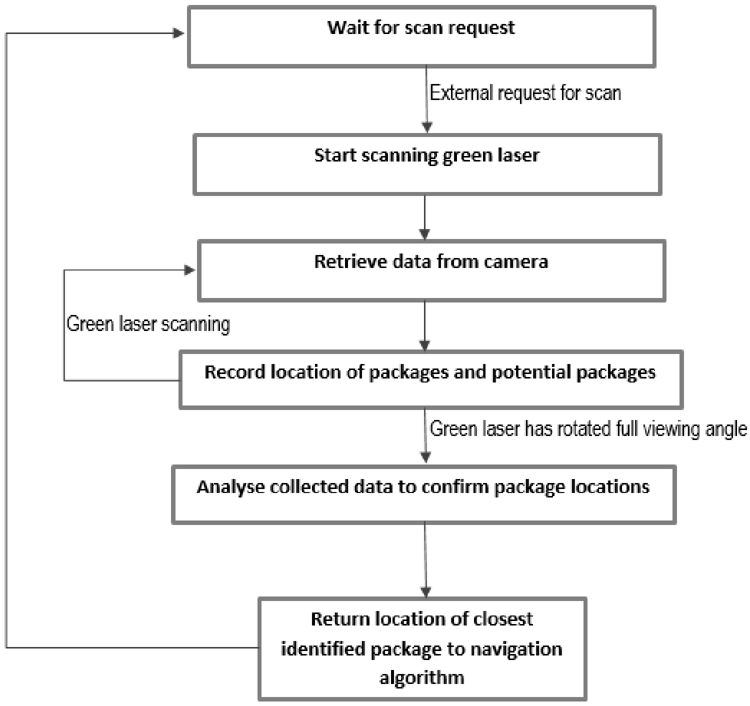


FIGURE 11: BEHAVIOURAL DIAGRAM ILLUSTRATING OPERATION OF PACKAGE IDENTIFICATION MODULE

2.24 NAVIGATION ALGORITHM

The navigation module for the robot was implemented in the software domain with an algorithm programed to determine the desired path for the robot. This module interfaces with the package identification, object detection and base detection systems to determine the path with which the robot should navigate. The navigation algorithm also receives information about the distance travelled and angle rotated from the driving mechanism module. The functionality of the Navigation algorithm is outlined in the finite state machine as illustrated in Figure 12 as a series of states and sub states.

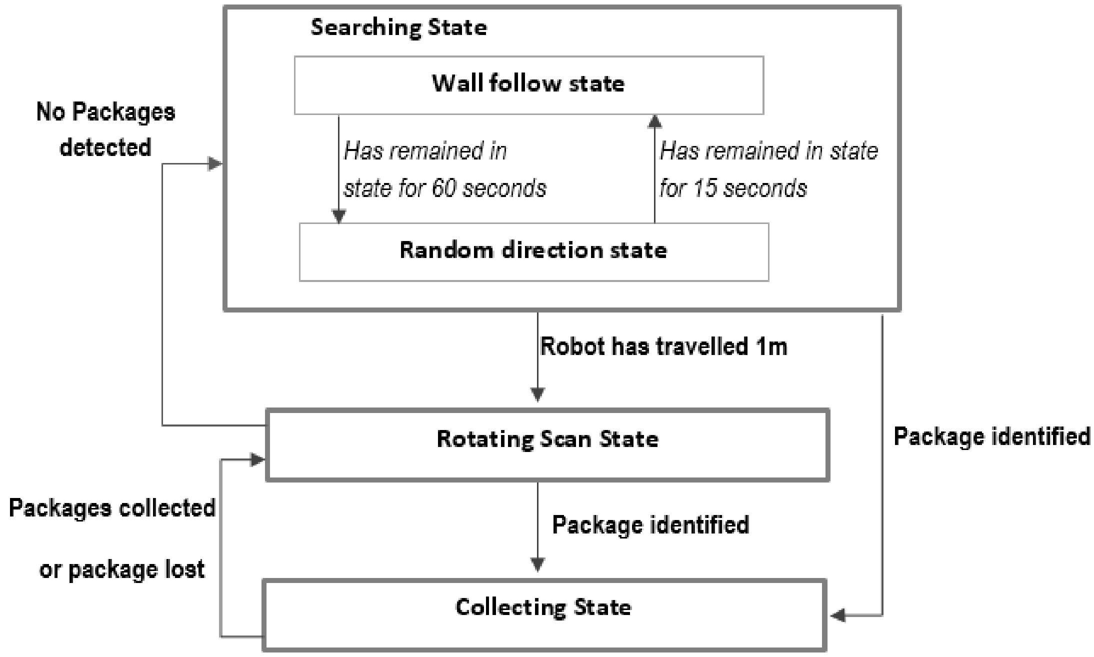


FIGURE 12: FINITE STATE MACHINE USED TO IMPLEMENT NAVIGATION ALGORITHM

Within the searching state two sub-states, the wall follow and random direction states, were utilized in order to increase the robustness of the design. Interfacing with the object detection mechanism in the wall follow state the distance of the robot from its closest wall is maintained using a proportional-differential (P-D) controller. The navigation algorithm remains in this state for 60 seconds whilst no packages are detected to ensure enough time for the robot to navigate about the outside walls of the arena.

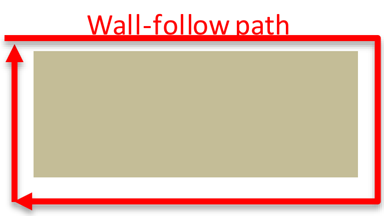


FIGURE 13: CONTIUNOUS LOOP PATH SCENARIO FOR WALL FOLLOWING ALGORITHM

Figure 13 shows a scenario in the wall follow state where the robot is stuck in a loop continuously following the walls of an object within the arena. The random direction state exists within the searching state to avoid this scenario where upon the detection of a wall this state determines a random direction to travel in. This state will increase the chances of the robot travelling towards the centre of the arena compared to the wall following state.

Navigating towards the centre of the arena is desirable as it increases the likelihood of detecting packages.

Within the rotating scan state the robot performs a 360 degree scan of the arena about the centre of the robot. This is achieved by performing a scan for packages with the robot rotating 90 degrees between each scan. Such a scanning state was implemented to the algorithm to increase the probability of detecting a package.

With the many packages scattered widely about the arena it is expected that the navigation algorithm will predominantly stay in the collecting state with the frequent detection of packages. Within this state the navigation algorithm uses a P-D controller to navigate towards the package with the assistance of the package identification system. This system provides the angle of a detected package relative to the front of the robot. If an obstacle is detected the navigation algorithm first avoids this obstacle and once cleared uses the P-D controller to navigate back towards the package.

2.25 BASE DETECTION SYSTEM

The base detection module is relatively simple and helps to facilitate requirement R3.4 from the general requirements.

> R3.4: The robot shall not pick up other food packages identified to be in a HQ.

GENERAL REQUIREMENT 3.4

Such a system requires a method of detecting the colour of the arena beneath the robot. The physical module consists of a colour sensor mounted underneath the front of the robot. This colour sensor provides a numerical value of the overall intensity of the red, green and blue components of the colour detected. A tolerance range of each of these components was set to detect the blue and green colours of the bases. This tolerance range was required as the output readings from the colour sensor fluctuated with the variations in blue and green colours in the arena.

When the robot is initialised the colour of the home base is recorded. A global variable for this module then indicates if the robot is located on a home base, opposition base or the black arena. This global variable provides a means of interfacing this module with the navigation algorithm and package collection mechanism.

3.0 EVALUATION

A preliminary assessment of the robot is summarised in this section of the report. Aspects including the package collector, driving mechanism, identification methods and costs are assessed in this evaluation. Where noteworthy, comparisons with the original design specification are made to make these assessments.

3.1 PACKAGE COLLECTION

The ability of the robot to collect packages at full speed without decelerating was identified as the key advantage of this collection mechanism. One of the primary disadvantages of the collection mechanism is that objects may only be collected if they are positioned upright and away from the corners in the arena.

Testing was performed to determine the frequency with which the robot, when travelling at full speed, knocked over packages. Packages were distributed at various angles relative to the robot as illustrated in Figure 14 to simulate a wide range of potential scenarios in these tests. From these tests it was found that in no case the robot knocked over packages as they were being collected. When two packages are collected from the same inlet simultaneously it was found that the second package feed into the inlet would prevent the secondary paddle from returning to its initial position. This prevented the second package from being feed onto the rail system.

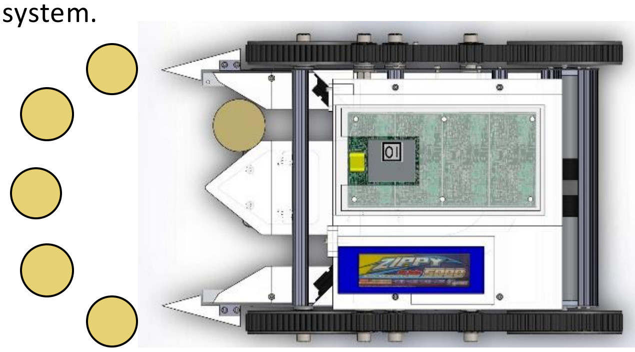


FIGURE 14: VARIOUS DISTRIBUTION OF PACKAGES PLACED IN FRONT OF THE ROBOT.

3.2 DRIVING MECHANISM

The speed of the robot was found to significantly increase with the use of the custom 3D printed wheels. As highlighted in the calculations (Appendix A3) it was found the larger wheels resulted in a 70% increase in speed compared to the original wheel design. The maximum speed of the robot was found in tests to be $0.62ms^{-1}$. This maximum speed was determined by measuring the average time it took for the robot to drive from one side of the arena to the other. Testing showed that the robot could navigate about the walls of the empty arena in a time of approximately 19 seconds. Other robots in the competition with driving mechanisms similar to the supplied setup were measured to have a top speed of approximately $0.20ms^{-1}$. The modified driving mechanism is therefore approximately three times faster than the standard design. This significant increase in speed was identified as the most significant advantage of the designed robot over the other robots in the competition. Where a faster robot will be able to collect more packages.

The ability of the robot to manoeuvre over obstacles was identified as a potential concern with the driving mechanism with the lower calculated driving force of the custom wheels. The larger wheels were however found to significantly increase the robots ability to move over objects. This was attributed to the mechanical advantage of the larger wheels. Testing proved the robot was able to manoeuvre over objects up to 40mm. With the maximum height the rectangular profile speed bumps specified to be 25mm the driving mechanism was deemed to be superfluously sufficient at manoeuvring over these obstacles.

3.3 IDENTIFICATION

Due to problems with shipping from the suppliers the lasers required to implement the package identification module did not arrive in time for this preliminary evaluation. The robot was however successfully programmed to rotate towards a bright light within the field of view of the positioning camera. Testing showed that a 5mW red laser reflecting from a package could be detected up to 4.6m away by the positioning camera. Based on these tests the green laser with this same output power is predicted to yield similar results. Approximations of the maximum distance with which the red line lasers could be detected could not be made. With the beam from the 5mW lasers dissipated over a larger area the range of detection of these reflected beams are expected to be significantly less.

The reliability of the base identification module was tested. It was found in testing that the robot would occasionally falsely identify a headquarters as it drove over the speed bump surrounding the headquarters. This was attributed to the lifting of the sensor changing the detected intensity of the green, blue and red components as measured by the colour sensor.

The IR sensors used for object detection were found to be accurate to half a centimetre. These sensors were found to be sufficient when used with the wall following algorithm to maintain a distance of 150mm from the wall.

3.4 BATTERY LIFE

The robot was required to operate on the same battery for a minimum of 5 minutes. In order to verify this specification is to be met an energy usage analysis was performed to determine the minimum battery life of the robot. Table 1 summarises the calculations of the power consumption of the various components on the robot with the battery having an estimated energy capacity of 128kJ. Further details of these calculations are outlined in the Appendix A2.

Component	Number of units	Current (A)	Working voltage (V)	Total power Output (W)
DC motor:	2	3.6	12	86.4
Microcontroller	1	5	5	25
IR sensors	3	0.033	5.5	0.54
Servos	5	0.5	6	15
5mW lasers	3	-	-	0.015
Total power usage (W)				**126**
Estimated duration				**16 minutes 55 seconds**

TABLE 1: SUMMARY OF POWER CONSUMPTION FROM COMPONENTS ON ROBOT

As shown in Table 1 it was calculated that the robot has an approximated operating time of 17 minutes thereby satisfying the battery life requirements. Experimental tests were performed to verify the satisfaction of this requirement. The robot was found in these tests to have an average battery life of over 30 minutes when manually driven around the arena with no packages. This longer run time of the robot in testing was expected where it was assumed in the calculations that all of the components are continuously running at full power. Overall both the tests and calculations verify that the robot can operate on the same battery for the minimum required 5 minutes for each round.

3.5 COST

In order to comply with requirement 5.1 outlined below a cost evaluation of the robot was made. The total cost of the robot including the costs of supplied equipment was estimated to be $522.54 as calculated in the bill of materials (Appendix C). It should be noted that some components were not included in this costing analysis as the prices of these components were not available. When considering this cost evaluation only the additional costs were considered relevant to meet this requirement. To reduce costs many of the components were imported at US exchange rate of $1.17.

> R5.1 The total cost of additional components must be no greater than $50. The following additional allowances which shall not be exceeded are available in excess of this.
>
> R5.1.1 An allowance of $5 to accommodate for circuit board componentry.
>
> R5.1.2 An allowance of $10 (200g of material) for 3D printed componentry.

GENERAL REQUIREMENT 5.1

TYPE OF BUDGET	COST
CIRCUIT COMPONENTRY	$4.55
3D PRINTING	$20.15
ADDITIONAL COMPONENTRY	$49.32
TOTAL	$63.87

TABLE 2: SUMMARY OF ADDITIONAL COMPONENTRY COSTS

As shown in Table 2 the robot adheres to the cost requirements for the competition. Whilst the 3D printing budget was exceeded, these exceeded costs were covered by the additional componentry budget. The major cost incurred on this additional componentry budget was the additional IR camera which cost $22.32. If further developments are therefore required on the robot it is suggested that this camera is excluded from the design with the camera having a relatively low cost to benefit ratio.

4.0 FURTHER DEVELOPMENT

4.1 ADDITIONAL INTERFERENCE MECHANISMS

Many of the competing robots use IR cameras to identify packages. In order to inhibit these mechanism additional infra-red LEDs are to be mounted around the outside of the chassis.

Several other robots were also identified to use lasers for the detection of packages within the arena. To interfere with these detection systems mirrors may be placed around the sides of the chassis. These mirrors will cause the competitions detection mechanisms to detect high intensity reflections from these mirrors.

The implementation of these interference mechanisms will be dependent upon the remaining funds available from the additional componentry budget as they were not determined as essential to the functionality of the robot.

4.2 SECONDARY COLLECTION MECHANISM

As identified in the evaluation one of the significant disadvantages of this design is that it cannot collect packages which are positioned in the corners of the arena or packages which are not upright. A secondary pickup mechanism positioned at the rear of the robot is therefore suggested to enable to robot to collect these packages. It is proposed that this secondary pickup mechanism consists of a Neodymium magnet which can drag the packages along behind the robot.

The implementation of such a mechanism would require modifications to package identification system and navigation algorithm. The package identification module would need to be modified to detect if a package was not upright or positioned in a corner. Furthermore the robot would be required to reverse into packages which were identified as overturned or in a corner. Such a change in functionality would therefore require modifications to the navigation algorithm.

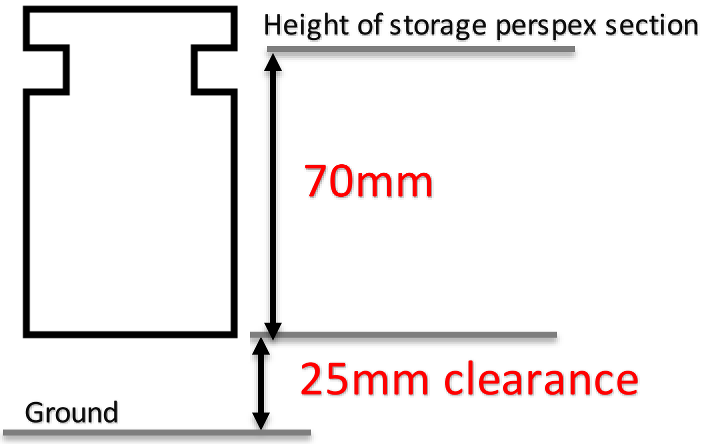
With the limited space at the rear of the robot it is estimated that such a mechanism would only be able to collect one or two packages. It is assumed however that as few packages will be required to be collected by this mechanism this limitation will not be a major design issue.

The additional IR positioning camera will need to be removed from the robot if this design is to be implemented in order for the design to meet the general cost requirement specified in R5.1. Implementing this secondary collection mechanism will therefore reduce the angle of detecting packages from approximately 60 degrees to 30 degrees.

APPENDICES

APPENDIX A -CALCULATIONS

APPENDIX A1 –REQUIRED HEIGHTS FOR COLLECTION MECHANISM PERSPEX SECTION



The figure above shows that the minimum height of the storage Perspex section is 95mm to ensure that a 25mm clearance is present between the ground and bottom of the stored packages.

APPENDIX A2 –DRIVING MECHANISM CALCULATIONS

RELATIVE TORQUE AND VELOCITY CALCULATIONS OF DIFFERENT SIZED WHEELS

Relevant concept information:
Original wheel diameter: 60mm (standard supplied wheel size)
Custom wheel diameter: 100mm

Note: Assume constant angular velocity of wheel;

$$\boldsymbol{v = \omega \cdot r}$$

$$v_{original} = 0.030\omega; \qquad v_{custom} = 0.50\omega;$$

Compared to the original wheel design

$$v_{custom} = 1.7\ v_{original}$$

VELOCITY ESTIMATIONS RELATIVE TO STANDARD WHEEL DESIGN

These rough calculations illustrate the potential gain in speed of the robot which can be achieved with larger wheels.

Note: Assume torque provided by motor to wheel is constant;

$$F = \frac{\tau}{r}$$

$$F_{original} = 33.3\tau; \qquad F_{custom} = 20\tau;$$

$$F_{custom} = 0.6\ F_{original}$$

DRIVING FORCE ESTIMATIONS RELATIVE TO ORIGINAL WHEEL DESIGN

BEARING STRESSES INDUCED ON 3D PRINTED WHEELS

Rear wheel inner axle diameter: 6mm

Front wheel inner bearing diameter: 22mm

Width of wheels: 16mm

$$\sigma_{bearing} = \frac{F}{Width\ of\ wheel * inner\ diameter\ of\ wheel}$$

$$\sigma_{rear} = \frac{F}{6 * 16 * 10^{-6}}$$

$$\sigma_{front} = \frac{F}{22 * 16 * 10^{-6}}$$

$$\frac{\sigma_{rear}}{\sigma_{front}} = 3.7$$

$$\sigma_{rear} = 3.7\sigma_{front}$$

APPENDIX A3 -BATTERY LIFE CALCULATIONS

Battery Capacity (I): 4 Ahr
Battery Voltage (V): 11.1 V
Max depth of discharge (D): 80%

$$Energy\ capacity\ of\ battery = I * V * D$$

$$= 128kJ$$

$$Maximum\ power\ dissipation\ of\ element = Current * Working\ voltage$$

$$Battery\ life = \frac{Energy\ capacity\ of\ battery}{Maximum\ power\ dissipation\ of\ concept}(s) * 60\left(\frac{min}{s}\right)$$

Component	Number of units	Current (A)	Working voltage (V)	Total power Output (W)
DC motor:	2	3.6	12	86.4
Microcontroller	1	5	5	25
IR sensors	3	0.033	5.5	0.54
Servos	5	0.5	6	15
5mW lasers	3	-	-	0.015
Total power usage (W)				**126**
Estimated duration				**16 minutes 55 seconds**

APPENDIX A4 –COSTS OF ADDITIONAL COMPONENTRY

Cost Report of Supplementary Componentry

Item	Cost/unit	Unit	Number of Units	Total Price
	Additional componentry budget			
Green laser	$ 7.35	Component	1	$ 7.35
Red laser	$ 4.75	Component	2	$ 9.50
IR Camera	$ 22.32	Component	1	$ 22.32
	Circuit componentry budget			
Multiplexing Circuit	**$ 1.35**	**Component**	**1**	**$1.35**
4 surface mount resistors	$ 0.04	Component	4	
PCA9510B	$ 1.19	Component	1	
Voltage regulator	**$ 3.20**	**Component**	**0**	**$ 3.20**
10K Potentiometer	$ 1.00	Component	1	1
Capacitor	$ 0.10	Component	2	0.2
Voltage regulator	$ 2.00	Component	1	2
	3D printing budget			
3D printed wheels	$ 0.05	g	403	$ 20.15
	Summary of additional costs			
Circuit componentry costs	$ 4.55			
3D printing	$ 20.15			
Additional componentry (Including supplementary 3D printing)	$ 49.32			
Total additional costs	$ 63.87			

	Price per unit		Number of units		Model	Price	
			Sensors and Motors				
Motor DC	$	53.00	2	DFRobot	FIT0277	$	106.00
Servo Standard	$	12.00	4	Hobbyking	HXT12K	$	48.00
Servo Small	$	4.00	1	Hobbyking	HXT900	$	4.00
IR Distance sensor	$	17.00	2	Sparkfun	2D120X	$	34.00
IR Distance sensor	$	18.00	2	Sparkfun	2Y0A02	$	36.00
IR Camera	$	25.00	1	DFRobot	SEN0158	$	25.00
Colour Sensor	$	10.00	1	AdaFruit	SEN0019	$	10.00
Micro switch	$	1.50	2	SonarPlus	SM1039	$	3.00
4000mah 11.1v Lipo	$	32.00	1	Hobbyking	n/a	$	32.00
RGB LED	$	2.00	1	DFRobot	DFR0239	$	2.00
			Mechanical Materials				
AL U Bar	$	0.80	1	Ullrich	n/a	$	0.80
Perspex 300*300*5	$	6.00	1	Dotmar	n/a	$	6.00
Perspex 300*150*10	$	8.00	2	Dotmar	n/a	$	16.00
Servo mount	$	6.00	2	Pro Metal	n/a	$	12.00
Main Body single side	$	16.00	2	Pro Metal	n/a	$	32.00
Roller bearings		Not Priced	16	UC	n/a		
16mm Timing Belts		Not Priced	2	UC	n/a		
AL Extruded bar		Not Priced	2.1	Pro Metal	n/a		
Perspex battery/Arduino bay		Not Priced	1	Dotmar	n/a		
AL Plate 300x300		Not Priced	1	Pro Metal	n/a		
6mm Socket head Bolts		Not Priced	8	UC	n/a		
Springs (Various)		Not Priced	8	UC	n/a		
Heat-sink		Not Priced	2	UC	n/a		
Cable ties		Not Priced	10	UC	n/a		
Construction Bolts/Nuts 3mm		Not Priced	50	UC	n/a		
Misc construction materials		Not Priced	1	UC	n/a		

Robot Controller Boards

	Price per unit	Number of units	Model		Price
Servo Board	Not Priced	1	UC	n/a	
Battery Board	Not Priced	1	UC	n/a	
Power regulator	Not Priced	2	ProDCtoDC	n/a	
IO Board	Not Priced	1	UC	n/a	
Arduino Micro board	Not Priced	1	RobotShop	n/a	
DC motor Driver	$ 92.43	1	RobotShop	n/a	$ 92.43
DC Motor cables	Not Priced	2	UC	n/a	
Colour Sensor cables	Not Priced	1	UC	n/a	
RJ45 Patch cables	Not Priced	n/a	UC	n/a	

Additional Items

Red laser	$ 4.75	2	DX.com	n/a	$ 9.50
3D printed wheels	$ 5.04	4	UC	n/a	$ 20.16
IR Camera	$ 23.32	1	DFRobot	SEN0158	$ 23.32
Cable sleve	$ 0.05	1	HobbyKing	n/a	$ 0.05

Electronic circuits

Green laser	$ 7.35	1	DX.com	n/a	$ 7.35
KA7909	$ 1.12	1	Element 14	KA7909	$ 1.12
1uf Capacitor	$ 0.10	2	Element 14	n/a	$ 0.20
10k Potentometer	$ 0.20	1	Element 14	n/a	$ 0.20
PCA9540BD	$ 1.19	1	Element 14	n/a	$ 1.19
Resistor 10k	$ 0.02	6	Element 14	n/a	$ 0.12
PCB board	Not Priced	2	UC	n/a	
LED	$ 0.02	5	Element 14	n/a	$ 0.10
				Total Price	**$ 522.54**

APPENDIX C – DRAWINGS AND SCHEMATICS

APPENDIX C1 – OVERALL ROBOT DESIGN

Only selected drawings included in example report

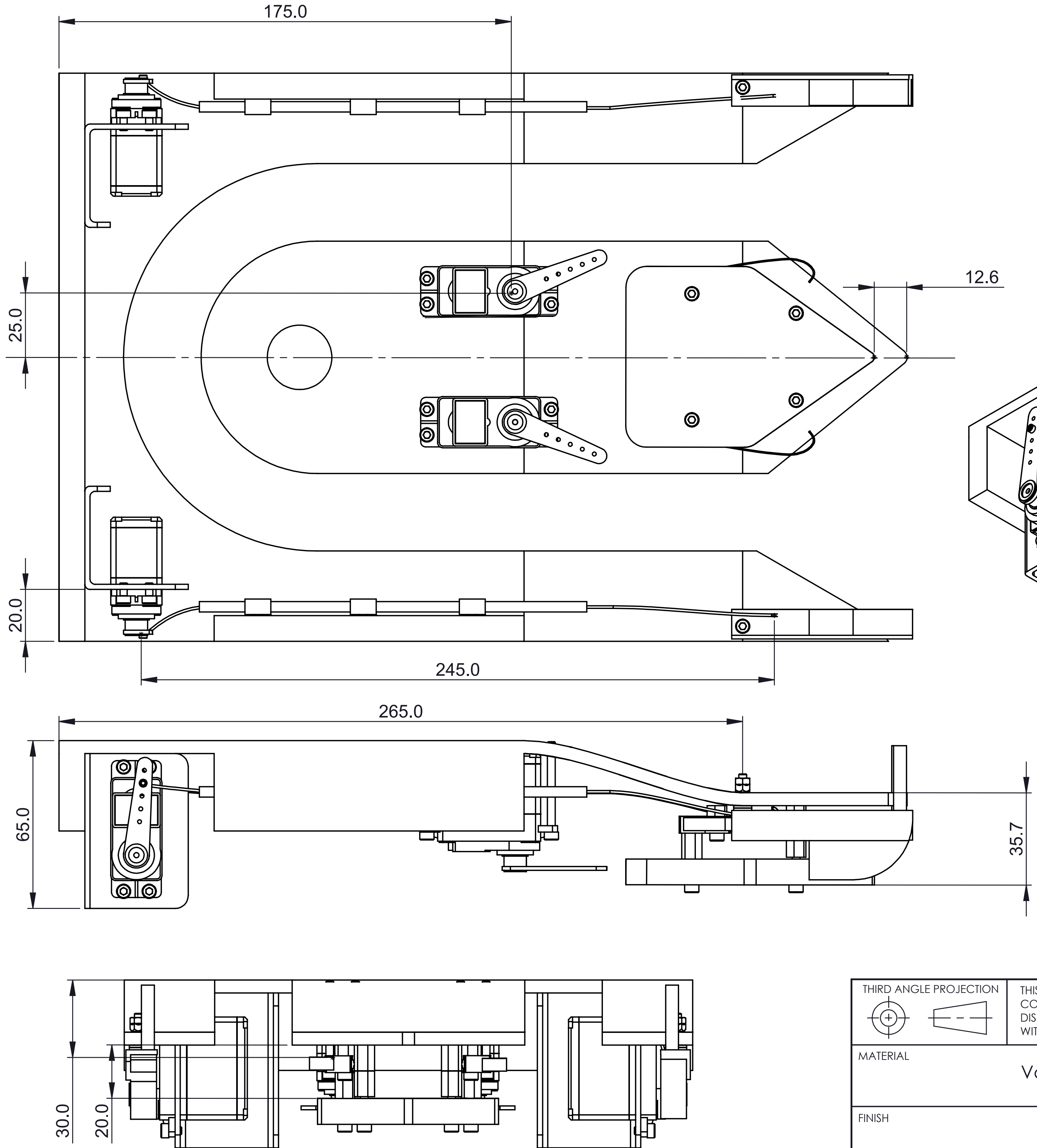
APPENDIX C2 – COLLECTION MECHANISM

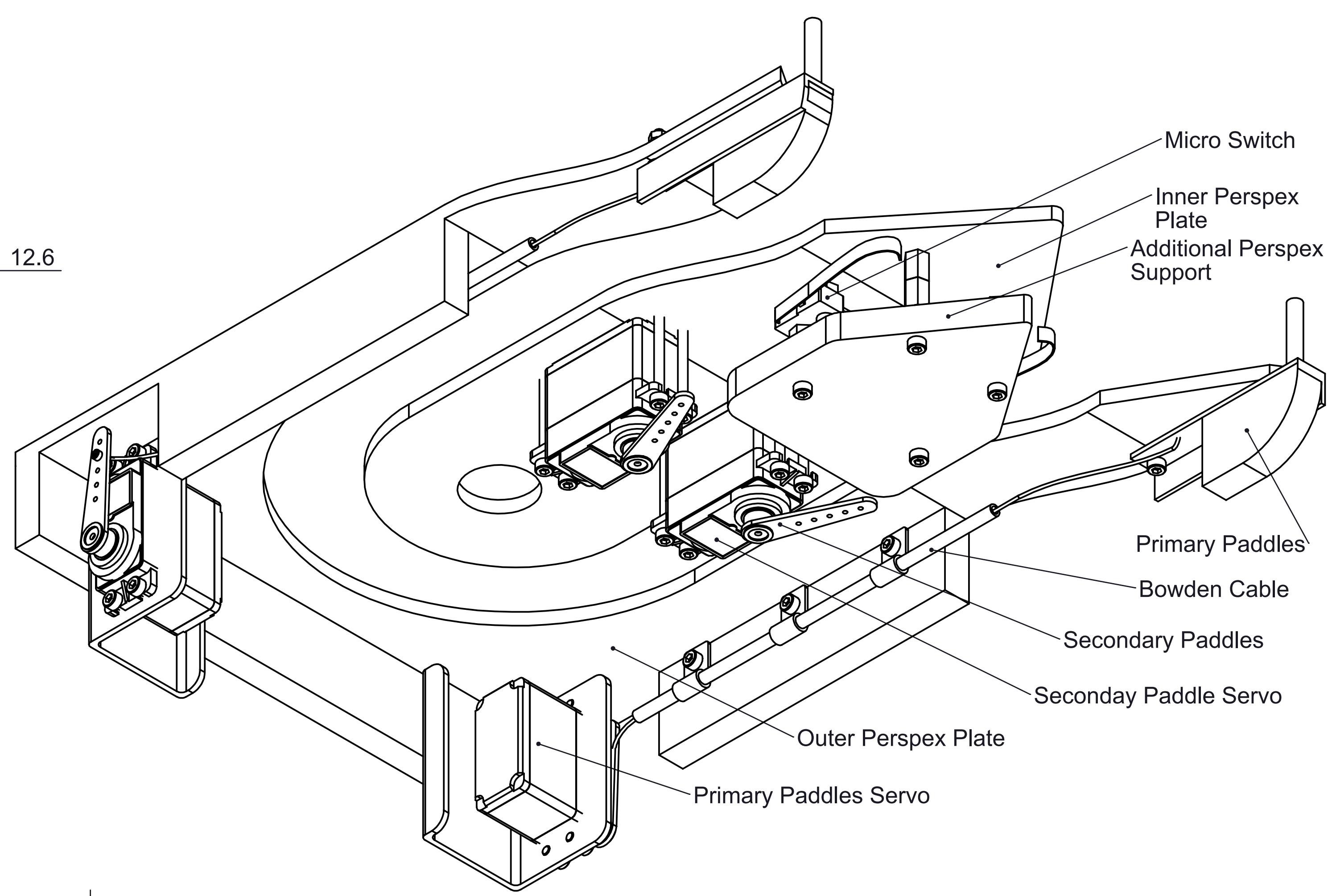
NOTES - (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS IN MILLIMETERS.
2. GD&T AS PER ISO1101-2004.

REVISIONS					
ZONE	REV.	DESCRIPTION	ECO	APPROVED	DATE
	REV1	RELEASE		XXX	01JAN13

Collector System Component Layout





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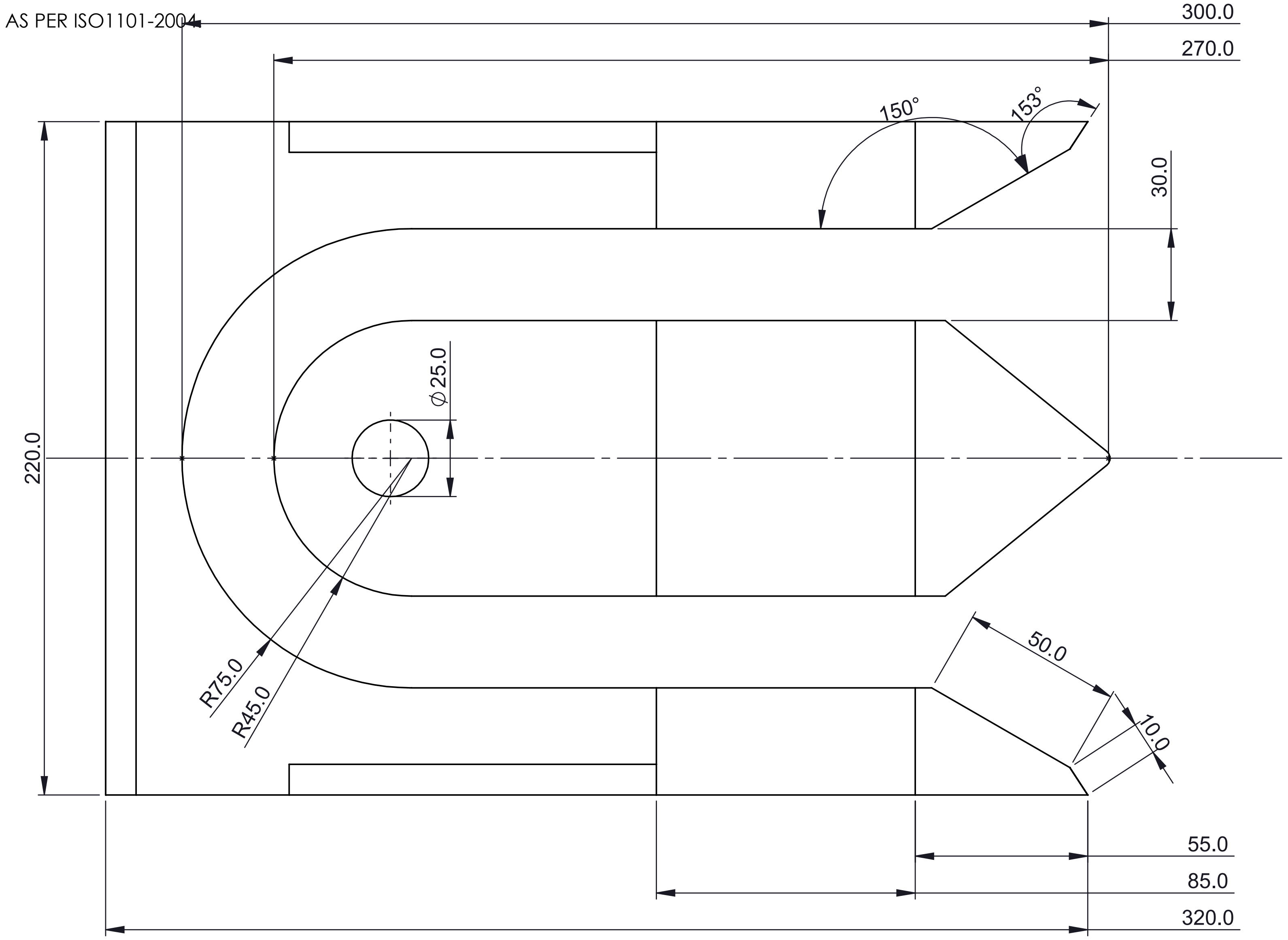
MATERIAL: Various Components		Collector Layout	
FINISH		DESIGN: SMS193	DWG NO.: V1.0
		DRAWN: SMS193	PROJECT: ROBOCUP
TOLERANCE (UNLESS OTHERWISE SPECIFIED) DECIMAL mm		SUPERVISOR: ZZ010	ISSUE DATE: 16/09/2014
.X ± 0.1 .XX ± 0.01 .XXX ± 0.001 ANG. ±1 °		DRAWING NOT TO SCALE	SHEET 1 OF 1

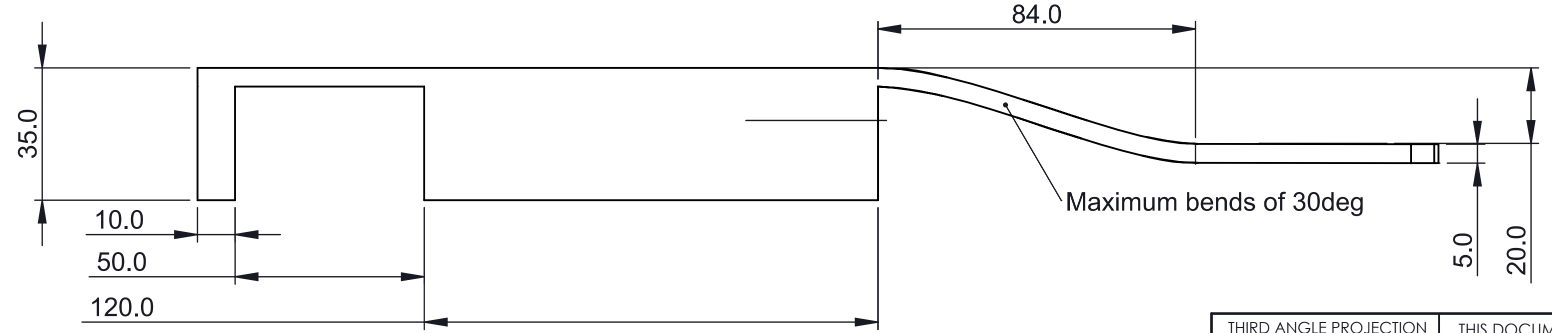
REV 1.0

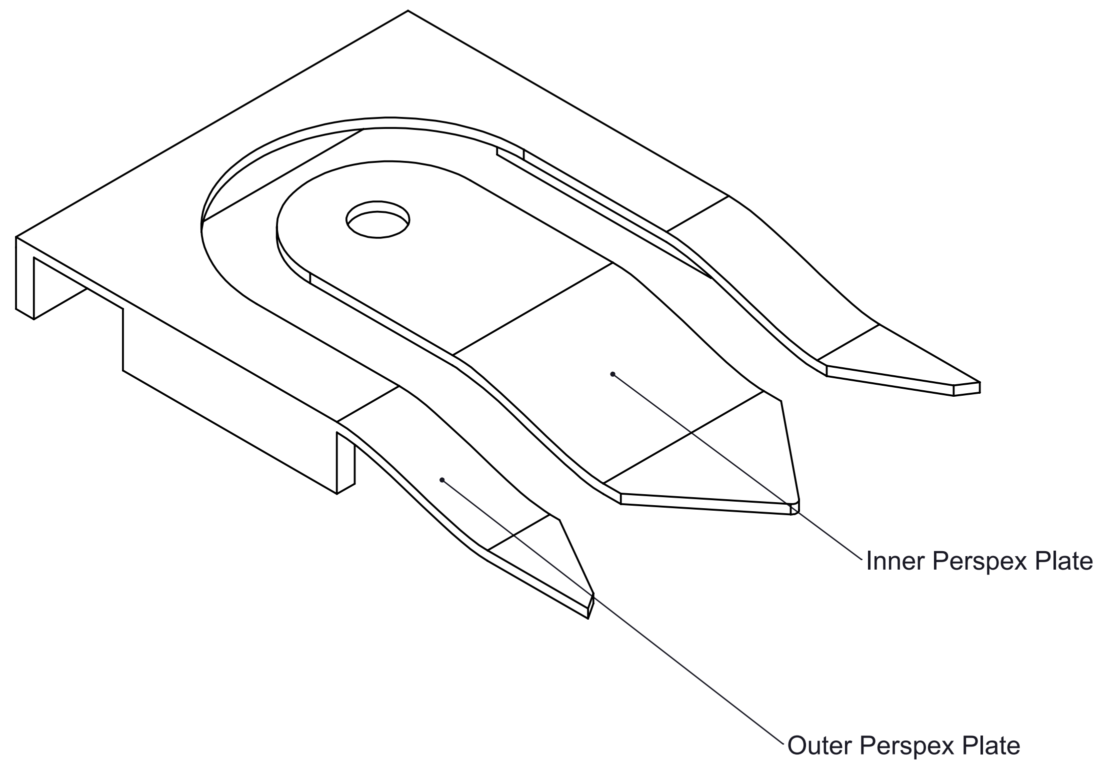
NOTES - (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS IN MILLIMETERS.
2. GD&T AS PER ISO1101-2004

REVISIONS					
ZONE	REV.	DESCRIPTION	ECO	APPROVED	DATE
	REV1	RELEASE		XXX	01JAN13







THIRD ANGLE PROJECTION

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MATERIAL: Perspex Acrylic Sheet

Collector Plate

FINISH

TOLERANCE (UNLESS OTHERWISE SPECIFIED)

DECIMAL mm

.X ± 0.1 **.XX** ± 0.01 **.XXX** ± 0.001 **ANG.** ±1 °

DESIGN	DWG NO.	REV
SMS193	V1.0	1.0

DRAWN	PROJECT
SMS193	ROBOCUP

SUPERVISOR	ISSUE DATE		SHEET
ZZ010	16/09/2014	DRAWING NOT TO SCALE	1 OF 1

NOTES - (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS IN MILLIMETERS.
2. GD&T AS PER ISO1101-2004.

REVISIONS					
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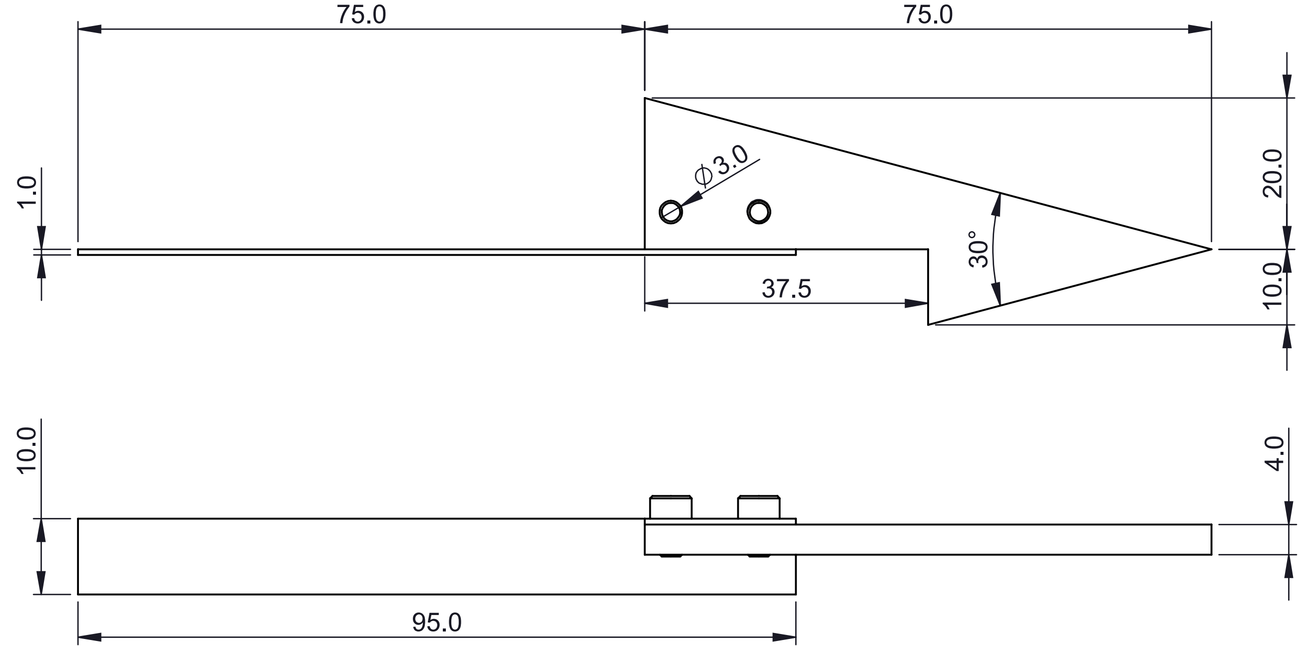
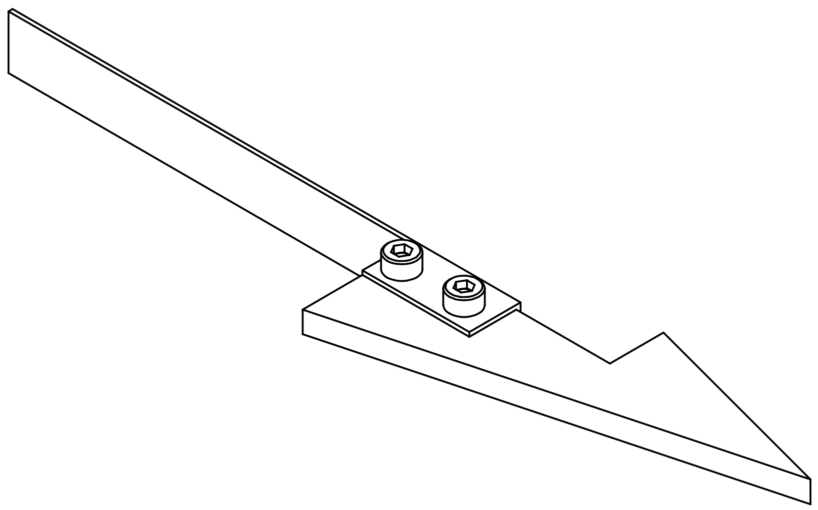
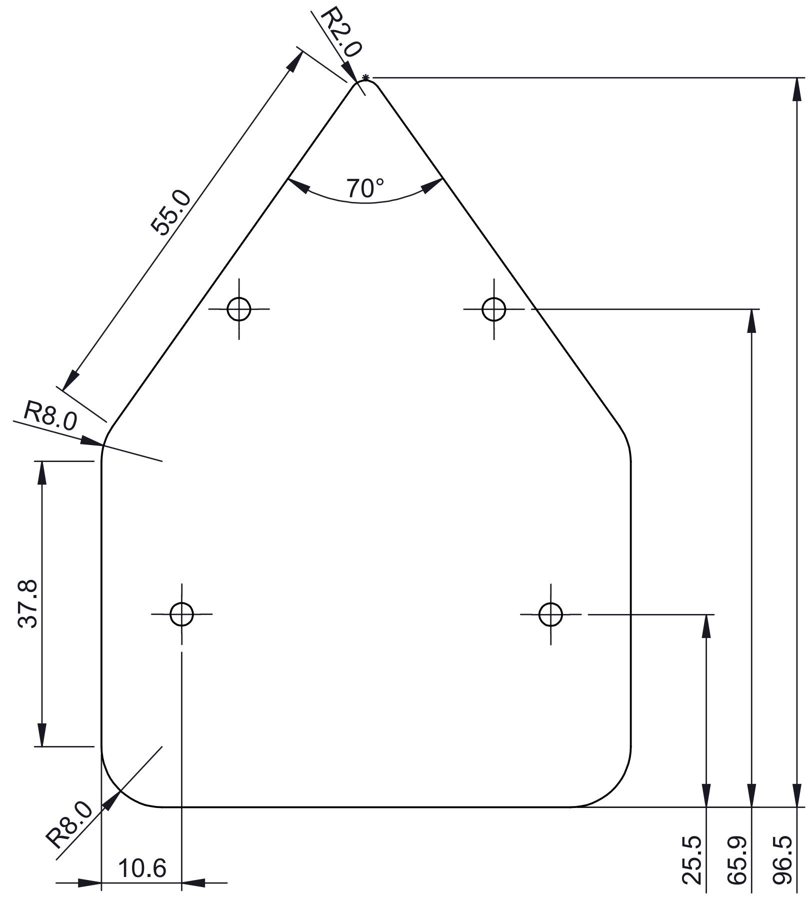
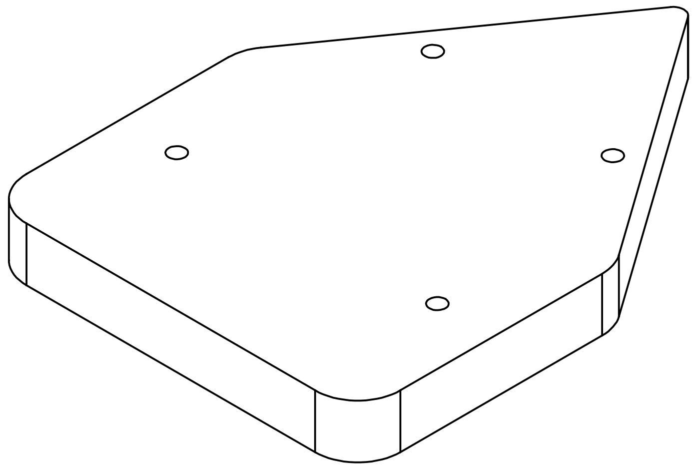
	REV1	RELEASE		XXX	01JAN13



Outter Perspex Guides







Additional Perspex Support

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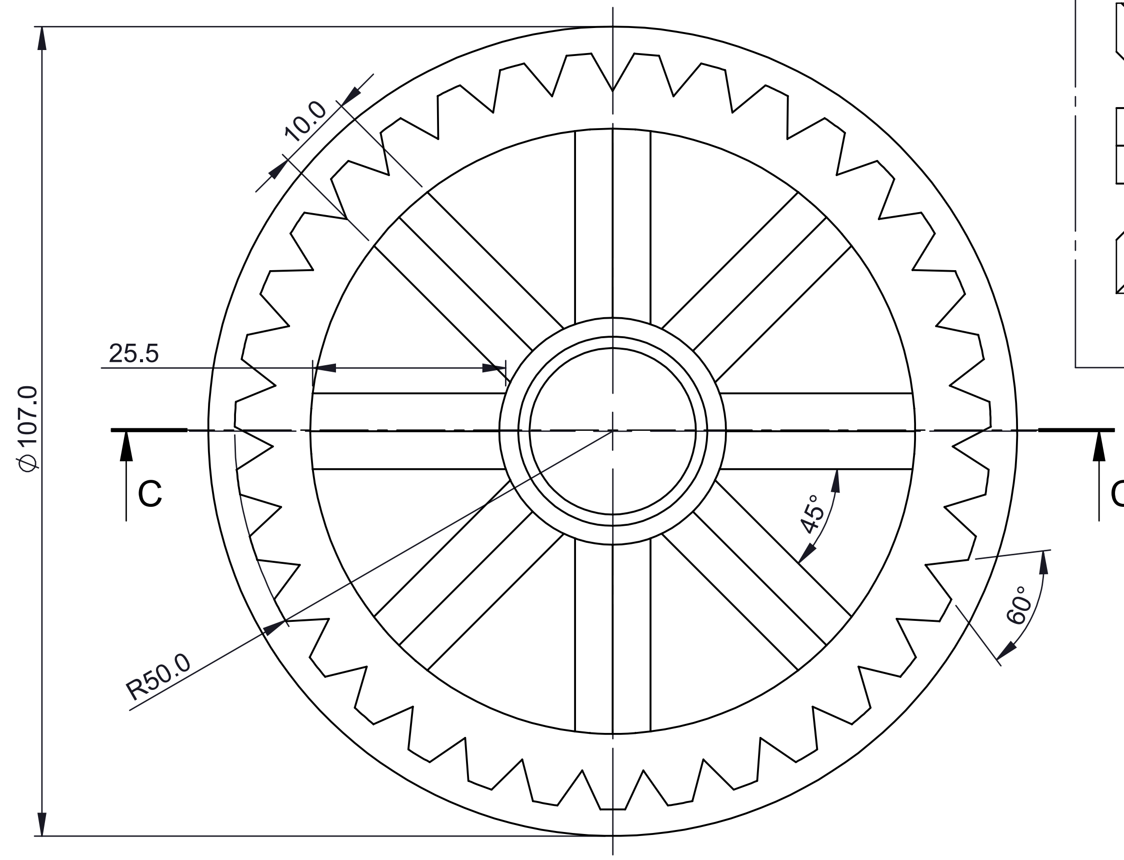
MATERIAL	Perspex Acrylic Sheet	Collector Parts		
FINISH	SEE PART DRAWINGS	DESIGN XXXSMS193	DWG NO. V1.0	REV 1.0
TOLERANCE (UNLESS OTHERWISE SPECIFIED)		DRAWN SMS193	PROJECT ROBOCUP	
DECIMAL mm		SUPERVISOR ZZ010	ISSUE DATE XXX16/09/2014	DRAWING NOT TO SCALE / SHEET 1 OF 1
.X ± 0.1 .1 **.XX** ± 0.01 .03 **.XXX** ± 0.001 .010 **ANG.** ±1 1°				

APPENDIX C3– DRIVING MECHANISM

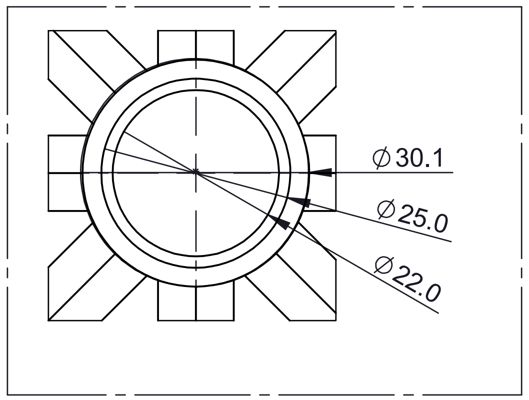
NOTES - (UNLESS OTHERWISE SPECIFIED)

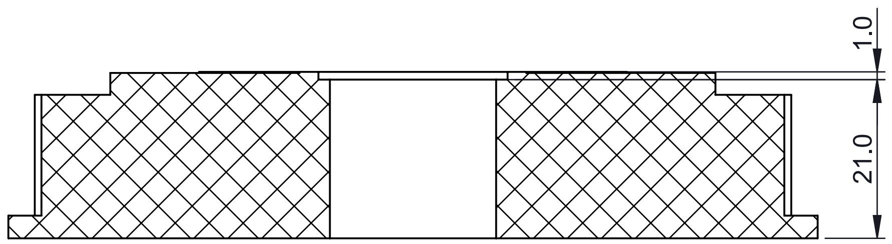
1. ALL DIMENSIONS IN MILLIMETERS.
2. GD&T AS PER ISO1101-2004.

REVISIONS					
ZONE	REV.	DESCRIPTION	ECO	APPROVED	DATE
	REV1	RELEASE		XXX	01JAN13



Break-out Bearing Insert





SECTION C-C
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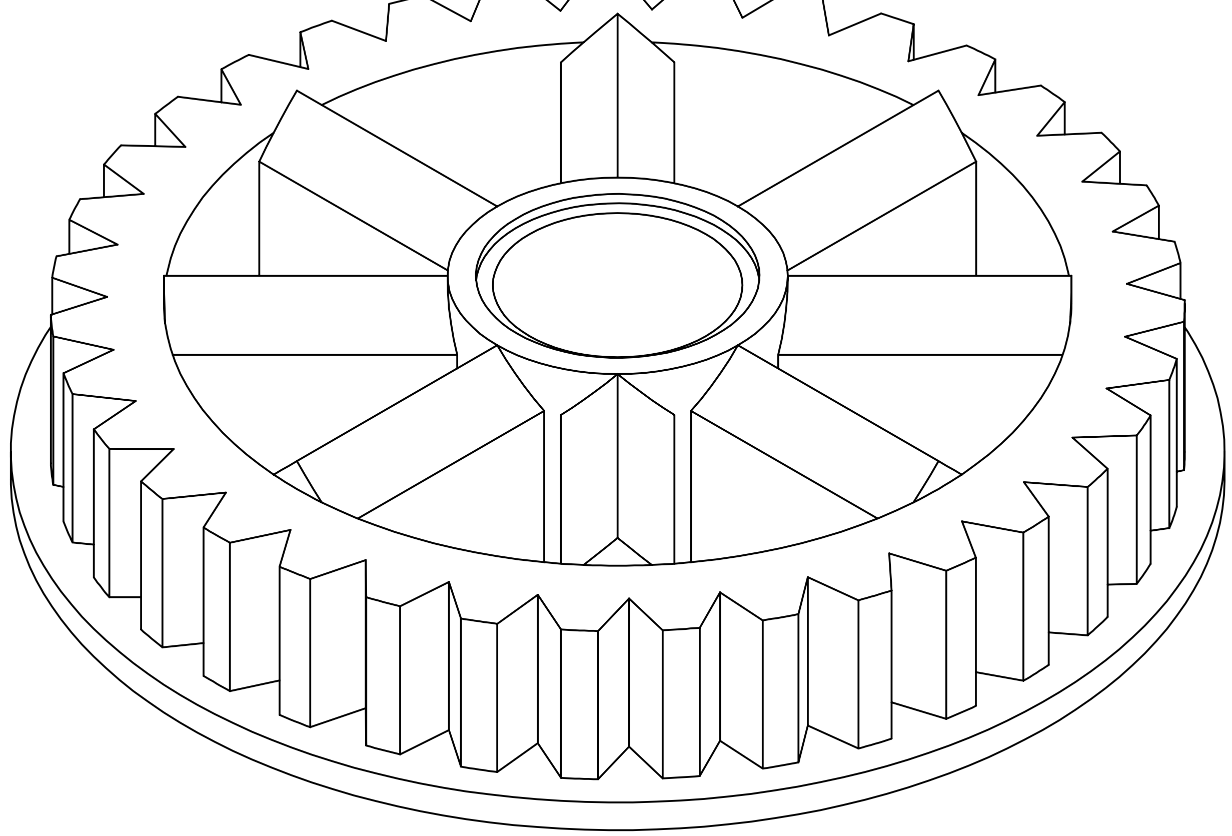

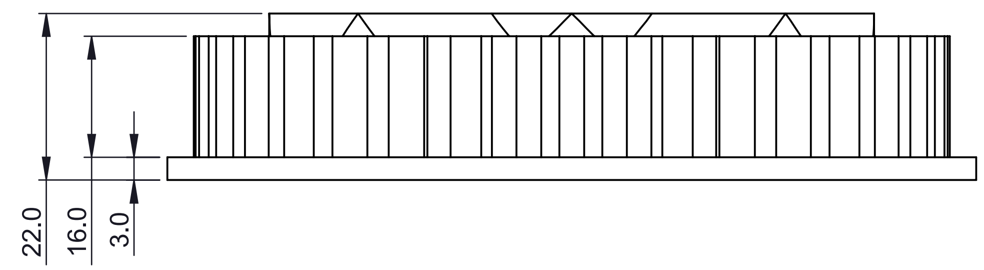

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MATERIAL: Polylactide (PLA)

FINISH:

Front Wheel

DESIGN	DWG NO.	REV
SMS193	V1.0	1.0

DRAWN: SMS193 | PROJECT: ROBOCUP

SUPERVISOR: ZZ010 | ISSUE DATE: 16/09/2014 | DRAWING NOT TO SCALE | SHEET: 2 OF 10

TOLERANCE (UNLESS OTHERWISE SPECIFIED)

DECIMAL mm

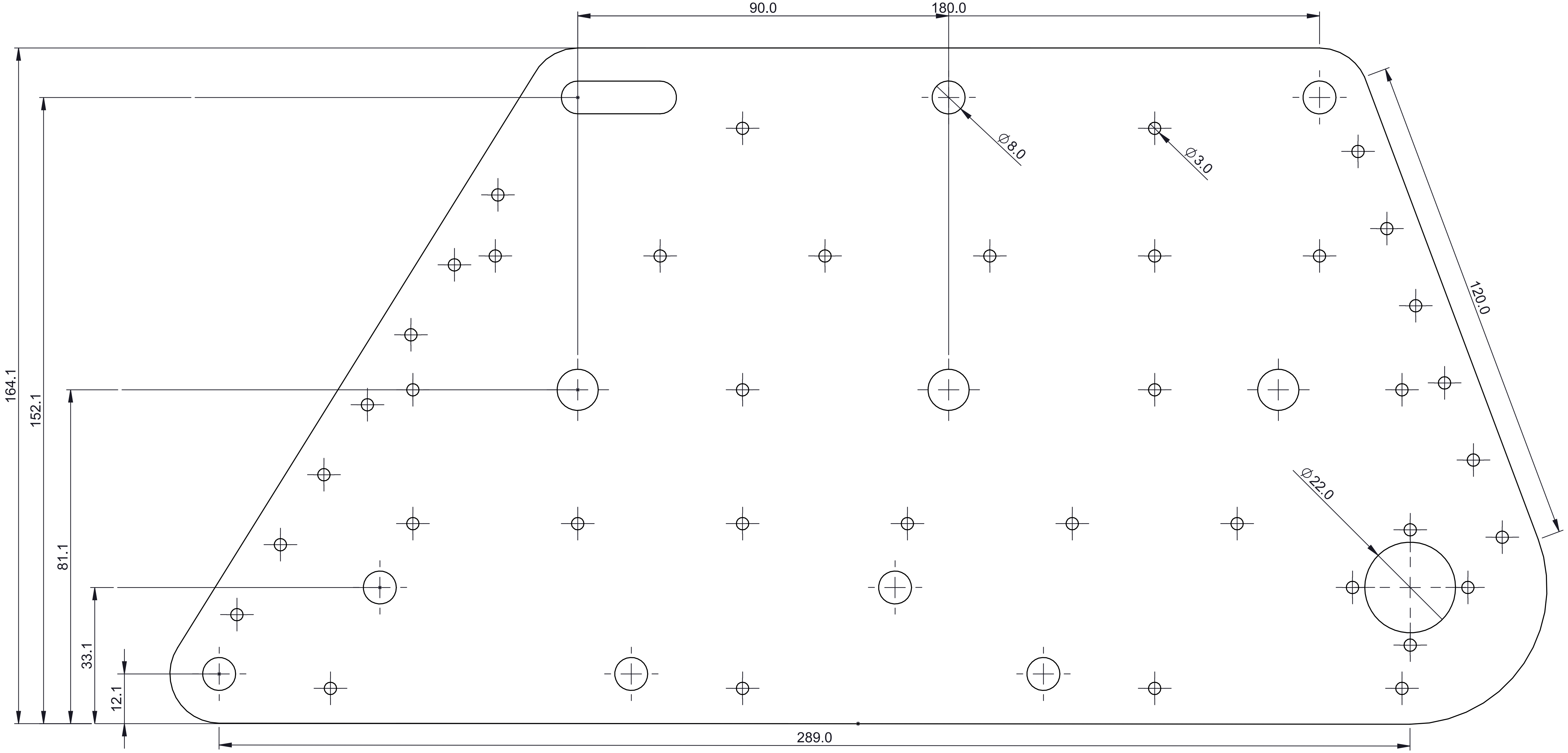
.X ± 0.1 .XX ± 0.01 .XXX ± 0.001 ANG. ±1 °

APPENDIX C4– WALL PLATE CHASSIS

NOTES - (UNLESS OTHERWISE SPECIFIED)

1. ALL DIMENSIONS IN MILLIMETERS.
2. GD&T AS PER ISO1101-2004.

REVISIONS					
ZONE	REV.	DESCRIPTION	ECO	APPROVED	DATE
	REV1	RELEASE		XXX	01JAN13



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MATERIAL	Alminium Plate
FINISH	

TOLERANCE (UNLESS OTHERWISE SPECIFIED)
DECIMAL mm
.X ± 0.1 .XX ± 0.01 .XXX ± 0.001 ANG. ±1 °

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Wall Plate

DESIGN	DWG NO.	REV
SMS193	V1.0	1.0

DRAWN	PROJECT
SMS193	ROBOCUP

SUPERVISOR	ISSUE DATE		SHEET
ZZ010	16/09/2014	DRAWING NOT TO SCALE	1 OF 1