HARDWARE DESIGN DOCUMENT

**Project:** L*EV3*RON

**Task:** Construct a robot that can play forward or defence in a game of soccer/basketball

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**Author:** Tristan Bouchard, Alexandre Tessier

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| --- | --- | --- | --- | --- |
| **Version** | **Date** | **Sections Updated** | **Summary** | **Author** |
| 1.0 | 06-03-17 | All | Preliminary version of the document | Tristan, Alexandre |
| 1.1 | 13-03-17 | 3, 4, 6 | New prototype after testing | Tristan |
| 1.2 | 14-03-17 | 10, 12 | Presentation of the final design | Alexandre |
| 1.3 | 20-03-17 | 9, 11 | Added sections 9 and 11 to better reflect the design process. | Alexandre, Tristan |
| 1.4 | 27-03-17 | 3.2.4, 6, 7, 8, 10.1,10.2,10.3,11.1,11.2, 11.3, 11.4, 12 | Addition of hardware versions with explanations for modifications  Addition of “Drawings” with captions and image numbers instead of just images. | Tristan |
| 1.5 | 03-04-17 | 10.1, 11.1, 11.4 | Remove defense mechanism explanation and placed into discarded ideas, minor adjustments | Tristan |
| 1.6 | 08-04-17 | 11.3 | New project name, corrected typos, updated the defense section to reflect the final design | Alexandre |

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# 2. DESIGN PROCESS

The hardware design process for the robot has, at its root, the Systems, Constraints, and Requirements document. From the information collected, a preliminary flowchart, which contains all the necessary components along with critical elements to keep in mind throughout the design, was generated (see Section 5).

To maximize the number of options available to us, three designs were then created. Most of the ideas behind those three designs come from experimentations carried out during the research and development phase of this project. From lab to lab, the best hardware implementations from all three teams forming the design group were taken and put together in order to create the best designs possible. All this was done while keeping in mind the constraints and ideas listed in the flowchart.

Once the three designs were completed, their advantages and disadvantages were compared, and a final design was created. This final design ended up being a modified version of one of the proposed designs, taking the best ideas out of all three designs and combining them in an efficient manner.

As the project progressed, testing of the chosen hardware design took place. From the feedback given by the testing team, modifications to the design were made in order to ensure that all the requirements were met. It must be taken into account that it is easier to modify software than to alter the physical design of the robot and, as such, software modifications were prioritized throughout the project. However, based on discussions between the software, hardware and testing team, the hardware design was, sometimes, revised.

# 3. GENERAL OFFENSE DESIGN INFORMATION

## 3.1 Purpose

As stated in the Requirements document, our design must be able to assume an offensive role, for which it must be able to fire a ball collected from a dispenser at a target. During its flight path, the projectile must bounce inside the “bounce area”, which is specified by WiFi before the competition round begins. As such, the design must contain a ball-launching mechanism that can fire the ball towards a target, that can be aimed and be variable in launch speed.

## 3.2 Design Constraints

### 3.2.1 Size

The size of the launcher must be limited. As the robot’s size is limited to allow it to fit inside a single tile, it is required that the launcher be as compact as possible. Also, because the design is meant to be rather narrow in order to be nimble and agile, the launcher cannot create large moments, such as catapult style swing arms, which incidentally also take up large amounts of space.

### 3.2.2 Operation

The launcher should only work when the robot is in “offense mode”, such that the routines for acquiring a ball from the dispenser are in effect. When not in offense mode, the launcher should not impede the function of the sensors used for localization nor the navigation of the robot.

### 3.2.3 Resources

As the selected design only uses a single brick, it is necessary for the launcher to only use a single motor, as all the other motor ports are used for both the navigation and the defense mechanism, which is described below. The design being compact, it should require few Lego pieces to construct. Also, as discussed with the clients, the launcher design can use a few elastic bands in order to aid it in its acceleration when firing.

# 4. GENERAL DEFENSE DESIGN INFORMATION

## 4.1 Purpose

As outlined in the Requirements document, the design created must be able to assume both offensive and defensive roles. As such, when required to play defense, the robot must be able to block incoming projectiles fired from the offensive robot. A mechanism thus needed to be devised to enable the robot to do so.

## 4.2 Design Constraints

The defense mechanism is subject to many constraints concerning size, operation and resources available to its construction.

### 4.2.1 Size

As the design being created needs to be small in order to be agile, it is necessary to fit a large amount of sensors and motors onto a relatively small platform. The design therefore needs to be as compact as possible when not in use, not impeding the function of other mechanisms and sensors. However, when in operation, the goal of this mechanism is to take up as much space as possible in order to cover the most area from which projectiles could arrive. The best case situation would be that the mechanism covers the ring perfectly, blocking any balls. Taking into consideration these limitations, the mechanism should be folding, only taking up space when the robot is required to play defense.

### 4.2.2 Operation

The operation of the mechanism should be very simple in both software and hardware, being deployed only once in defensive position.

### 4.2.3 Resources

Resources allocated for the construction and operation of the defense mechanism are limited. As we have chosen to stay with a single brick design to limit both size and complexity of the design physically and digitally, we are limited by the number of actuators and ports. As two motors are absolutely required for the wheels, two ports are remaining that can be used to construct our offense and defense mechanisms. As for Legos, we have more than enough for this simplistic design.

# 5. FLOWCHART



***Figure 5.1*** *: Mechanical mechanisms flowchart, project week 1*

# 6. PRELIMINARY DESIGN #1



**Features**

* Catapult style ball launcher: Two motors provide the torque necessary to launch a ball. The long swing arm is designed to maximize the ball’s velocity once released from the mechanism. A counterweight is added in order to maximize performance.
* Wide base: A relatively wide base is used to ensure the stability of the robot, which is key when using a catapult to launch projectiles. The sudden change in momentum can often make the robot tip over, but a wide base should compensate for this effect.
* Deployable net: A deployable net is used to catch balls. The netting material used takes up lots of volume when deployed, but takes up very little volume when folded.

**Sensors and Motors**

* 2 light sensors to perform localization and, if needed, odometry correction
* 1 ultrasonic sensor to perform localization and detect obstacles
* 1 EV3 medium motor to allow the ultrasonic sensor to rotate
* 4 EV3 large motors : 2 for navigation and 2 for the ball launcher mechanism

**Advantages**

* The use of two bricks allows us to take advantage of more sensors and motors. It also gives us the ability to distribute resource-intensive computational tasks over 2 processors.
* By having the ultrasonic sensor mounted on a motor, it allows the robot to detect obstacles all around the robot, as the sensor can be rotated. This eliminates most of the problems associated with detecting objects using a ultrasonic sensor fixed at 45°.
* The use of 2 light sensors can decrease the amount of time spent localizing, as a more efficient process than the ones used in the lab can be implemented.

**Disadvantages**

* The use of two bricks (master and slave) complicates the software design process. Feedback from teams having competed in previous semesters indicates that getting the master and slave bricks to communicate properly is a challenge.
* The use of a wide base can affect the efficiency of the robot’s navigation system, as rotations can be slower.
* There is no guarantee that the robot will not tip over when launching a ball, therefore rendering the entire design useless.

# 7. PRELIMINARY DESIGN #2



**Features**

* Pincer type launcher mechanism: Using a relatively short swing arm, a ball is compressed until it is launched with a velocity dependant on the force applied. It is therefore possible to vary the distance travelled by the ball by changing the velocity and the acceleration of the motor. This launcher design has been ruled out after testing, as it was impossible for it to get the required distance.
* Deployable netting: Netting can be deployed using a single motor with an assembly of gears and long rods. It can then be placed in front of the main goal to block any incoming projectiles. The net can be folded when it is not in use, thus making sure it does not affect the robot’s other features, such as when acquiring balls from the dispenser.
* Compact design : The use of a compact design has the advantage of making our robot relatively nimble. Most importantly, it should easily be able to rotate.

**Sensors and Motors**

* 2 light sensors to perform localization and, if needed, odometry correction
* 2 ultrasonic sensors to perform localization and detect obstacles
* 1 EV3 medium motor used to deploy the net
* 3 EV3 large motors : 2 for navigation and 1 for the ball launcher

**Advantages**

* The low volume ball launcher mechanism is mechanically simple, which reduces the risks of mechanical failures.
* The compact design allows for sharp turns and reduces the errors in the odometer associated with turning.
* The use of 2 ultrasonic sensors allows the robot to detect obstacles around itself, providing a better coverage of the field.
* The use of 2 light sensors can decrease the amount of time spent localizing, as a more efficient process than the ones used in the lab can be implemented.
* A stabilizing mechanism is included in order to minimize the effects of slack in the wheels, which can improve the precision of the odometer.

**Disadvantages**

* The angle at which the ball is launched at is not adjustable. Having the ability to change the launch angle can improve the flexibility of the ball launcher, as the distance travelled by the ball can be modified easily. However, this can be fixed by adding a medium motor to the launch mechanism.
* The fact that the wheelbase is relatively narrow makes the robot more vulnerable to navigation errors and motor slack. Motors will have to be selected such that they have very little slack, and extra effort will be have to be made to minimize wheel slippage in the programming, by adjusting the acceleration. Thus, the speed of localization may be affected.

# 8. PRELIMINARY DESIGN #3



**Features**

* Wide wheelbase: This design features a very wide wheel base, taking up a very large footprint in the 1 square foot tile. This large platform is very stable, and thus can support a variety of launchers, defense mechanisms and sensors. Also, because the wheels must rotate more than a narrower design in order to turn to a certain angle, the effect of motor slack is greatly reduced, and errors in navigation are minimized.
* Impact-Pincer mechanism: This design features another type of launcher discussed by our team. It features a swinging arm like the pincer mechanism above, but this design allows the arm to accelerate before striking the ball, allowing more energy to be transferred (Testing must still be done to determine the actual performance of this launcher).
* Deployable netting: This design also features the deployable netting defense mechanism, which utilizes a single EV3 medium motor and an assembly of gears which allow the net to be deployed to cover the target when in use, but does not impede the other functions of the robot, such as when the robot is playing offense.

**Sensors and Motors**

* 2 Large EV3 motors used for the wheels
* 1 Large EV3 motor used for the impact launcher mechanism
* 1 Medium EV3 motor used to actuate the deployment of the netting mechanism
* 2 EV3 Color Sensors, placed at the extremes of the robot
* 1 EV3 US Sensor

**Advantages**

* This design is affected very little by navigation errors and motor slack, due to its very wide wheelbase.
* The positioning of the light sensors makes minimal errors in angle detectable and correctable.
* Very precise in navigation when travelling along grid lines.
* Very stable for launcher mechanisms.
* Impact launcher may be able to launch the projectile further that the pincer type launcher, due to the additional impact it has with the ball.

**Disadvantages**

* This design is very wide: We require the robot to travel at an angle to grid lines, and as such this design may not be very accurate nor agile when avoiding obstacles in the playing area.
* The fact that it is wider may reduce turn speed, and thus will place a physical limitation on localisation speed.
* The impact launcher may hit the ball incorrectly and thus throw the ball off target. More testing will have to be made in order to test the performance of the launcher.

# 9. COMPARISON OF THE 3 DESIGNS

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Design #1** | **Design #2** | **Design #3** |
| **Advantages** | - Uses 2 bricks: Allows for more motors & sensors  - 180° obstacle detection  - Faster localization | - Simple launcher  - Can turn rapidly  - 180° obstacle detection  - Faster localization  - More stable | - Less vulnerable to navigation error (wide wheelbase)  - Faster localization  - More stable  - Can possibly launch the ball further |
| **Disadvantages** | - More complex in terms of the software (2 bricks)  - Slower rotations (wide base)  - Robot can tip over due to moments created by launcher | - Fixed launch angle  - More vulnerable to navigation error (narrow wheelbase) | - Possibly inaccurate navigation  - Slower rotations  - Questionable ball launcher performance |

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# 10. FINAL DESIGN

## 10.1 Robot Version 1.0



The first version of the final design (Seen in **Image 10.1-1,** above) was built using elements from all three of the preliminary designs. This was done in order to try to reduce the disadvantages associated with each design, while trying to keep most of the advantages. Moreover, some parts of the design, such as the pincer-style mechanisms, did not perform as well as expected. We therefore had to come up with new ideas in order to meet all the requirements.

**Features**

* Catapult style ball launcher: One motor provides the torque necessary to launch a ball, along with a few elastic bands to help accelerate the motor during launch. The relatively short swing arm is designed to maximize the ball’s velocity once released from the mechanism. A counterweight is added in order to maximize performance and remove the event of it tipping over.
* Energy storage: Multiple elastics are used to store energy in order to ensure that the ball launcher can throw balls at the required distance.
* Medium base: A medium base is used to ensure the stability of the robot, which is key when using a catapult to launch projectiles. The sudden change in momentum can often make the robot tip over, but a wide base compensates for this effect. Yet, the fact that the base is not quite wide allows us to increase the turn speed of the design which aids in obstacle avoidance

**Sensors and Motors**

* 1 light sensor to perform localization.
* 1 ultrasonic sensor to perform localization and detect obstacles
* 1 EV3 medium motor to allow the ultrasonic sensor to rotate
* 2 EV3 large motors used for navigation

**Advantages**

* By having the ultrasonic sensor mounted on a motor, it allows the robot to detect obstacles all around the robot, as the sensor can be rotated. This eliminates most of the problems associated with detecting objects using a ultrasonic sensor fixed at a certain position, or even using multiple sensors to achieve the same effect.
* A stabilizing mechanism around the wheels is included in order to minimize the effects of slack in the wheels, which can improve the precision of the odometer.
* This design is affected very little by navigation errors and motor slack, due to its relatively wide wheelbase.
* The use of a counterweight placed at the back of the robot minimized the effects of the sudden change in momentum caused by the catapult-style ball launcher. It is also used to prevent the robot from tipping over.
* Lots of space for sensors due to its relatively low volume. We have a lot of freedom as to their position and operation.

**Disadvantages**

* The fact that it is wider may reduce turn speed, and thus will place a physical limitation on localization speed.

## 10.2 Robot Version 1.1

* Addition of elastics to the launching mechanism. This modification allows the launcher to throw the ball the maximum distance required of 8 tiles, as more energy is stored. The addition of these elastics was required as the launcher design in hardware version 1.0 did not work well when the battery charge was anything less than full.
* Modification of the battery counterweight attachment, located at the back of the robot, seen in **Image 10.2-1**. This modification was executed to allow the EV3 brick to be charged when not in use without removing any pieces and to allow more batteries to fit inside. It was also redesigned to better counteract the moments created by the launcher arm, to provide a more stable base and to better secure the counterweight to the robot.
* Addition of multiple pieces of Lego to better attach the EV3 brick. This modification was required due to the added weight of the counterweight which, while picking up the robot after testing, would cause the brick to detach itself from the chassis. Thus, Lego was added to make this link more sturdy, but at the same time still allows for an easy access to the brick in order to swap the battery if necessary.
* Modification of the ultrasonic sensor position on the EV3 medium motor, seen in **Image 10.2-2** below. This modification was required in order to get the ultrasonic sensor to have the full 180 degrees of rotation of freedom required by our obstacle avoidance routine. Also, the structure was modified to remove any obstructions such as the wires to the light sensor that could be picked up by the US sensor and thus cause errors.



## 10.3 Robot Version 1.2

* The addition of 2 light sensors at the back of the robot (as seen in **Image 10.3-1** below) allows for navigation correction, allowing the robot to travel in straight lines without drifting or curving and to correct the X and Y coordinates as it travels. The algorithm is discussed in the Software document section 4.9.



## 10.4 Robot version 1.3

The reason for this revision was the launcher mechanism. After extensive testing, we realised that lowering the arm actually took a substantial amount of battery power, and holding it against the stored energy of the elastics caused the robot to underturn. A possible explanation is that the sudden reduction of the power distributed to the motors used for navigation had a drastic impact on their ability to rotate a provided number of rotations. As such, the medium motor used to rotate the ultrasonic sensor was repurposed. It now serves as a locking mechanism for the launcher arm, greatly relieving the stress on the motors as they can now be set to float mode, removing any power to the launcher motor. This therefore mitigates the problem. The ultrasonic sensor remains mounted on a medium motor for ease of adjustment, but the motor is not connected to the EV3 and thus is fixed in the position in which it starts.



# 11. BUILDING PROCESS

## 11.1 Chassis

* The structures surrounding the wheels were designed to maximize the robot’s stability by making sure the wheels remain straight and not bending at the axles.
* The medium (larger than narrow, but narrower than large) wheelbase was chosen to increase the robot’s performance in terms of the navigation, especially when it comes to rotations and turning, such as when the robot performs localisation.
* A counterweight consisting of batteries was added at the rear of the robot to compensate for any unwanted motion generated by the ball launcher, which could throw off the odometry if not counteracted.
* The chassis holding the brick is designed to hold the brick just enough that the robot is solid, but the battery is readily accessible if the necessity arises to change it.

## 11.2 Ball Launcher

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* The crisscross pattern used when placing the elastics increases the amount by which the elastics are stretched. This therefore maximizes the storage and delivery of energy as well as prevents the elastics from jamming into the motor as it rotates.
* The motor was positioned relatively high in order to increase the arclength described by the catapult’s arm. This increases the distance at which the mechanism can throw a ball.
* The structures surrounding the launcher were designed to ensure the stability of the motor and of the launching mechanism.
* A horizontal Lego piece was placed to prevent the arm from rotating in an undesired direction due to the force applied by the elastics. Also, this crossbar sets the arm in an initial position, from which it can be rotated through a fixed amount to enter launching position.
* The structure consisting of the ball holder was intentionally designed to minimize its grip on the ball as it is being launched. This therefore guarantees that a significant portion of the energy outputted by the motor is transferred to the ball. However, the basket containing the ball is structured such that the ball does not fall out when navigating from the ball dispenser to the launching position.

## 11.3 Defense Mechanism

As the project progressed, we mainly focused on improving the Localization, Navigation and Odometry/Odometry Correction routines. Therefore, due to time constraints, no dedicated defense mechanism was implemented. Moreover, we did not have any free motors to deploy a netting mechanism, as all 4 ports were currently in use in the final design. In order to be time efficient and to not have a defense mechanism that could possibly impede the proper functioning of the ball launcher, we decided to give a dual purpose to the launcher. The launcher, in its raised position, is tall enough to block some balls from entering the bounce zone when the robot is appropriately positioned (i.e. directly in front of the target, in the defense zone).

## 11.4 Discarded Ideas

* **Mechanism for a deployable net (Image 11.4-1):** When the main gear is rotated using a motor, the arms are unfolded, thus unfolding a net. This net could have been used to catch balls and prevent the opponent from scoring.

**Reason for discarding the idea:** Although it would have been an efficient way of deploying a net, it requires a motor. Three of the four motors were already used when designing this solution. Afterwards, a decision was made to prioritize the use of a motor in order to lock the catapult arm. This meant that we could not use this mechanism for the net anymore.

* **Pincer style launcher:** The original design idea (as seen in **Image 11.4-2** on the next page) was discarded, as it was not performing to the required standards: It could not launch the ball the required distance of 5 tiles, let alone 8. Also, the design did not allow for angle adjustment without the addition of another motor controlling a platform which would then adjust the tilt of the entire mechanism. Because of this unwieldiness and difficulty of use, the idea was discarded.



# 12. DESIGN HISTORY

|  |  |  |  |
| --- | --- | --- | --- |
| **Version** | **Date** | **Summary** | **Builder(s)** |
| 1.0 | 10-03-17 | First version of the final design | Tristan |
| 1.1 | 20-03-17 | Addition of elastics to reach total distance of 8 tiles.  Addition of lego pieces to stabilize the battery counterweight.  Addition of Lego to better attach brick.  Modification of US sensor (So it rotates better) and Light sensor positions (Such that the wire connecting it is not picked up by the rotating US sensor. | Tristan |
| 1.2 | 27-03-17 | Addition of 2 light sensors for odometry angle correction and localisation routine while navigating  Minor solidification of design | Tristan |
| 1.3 | 03-04-17 | Removal of rotation capacity for US sensor, addition of launcher arm locking mechanism with medium motor. | Tristan |

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