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PROJET D'INGÉNIERIE SIMULTANÉE

Babyfoot: from juggling to shot on goal

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1 Introduction

This project was proposed to continue the progress of the software of the automated babyfoot table. In a previous project juggling between attacking players has been realised (Babyfoot juggling, by Isaac Dinis, Fall 2020) [1]. The objective in our project was to find a way to shoot on the goal avoiding the defensive players starting from the juggling mode.

2 Methods and Calculations

2.1 Transition from juggling to shot

The essential criteria for a successful transition from juggling to shooting is to have a good timing. We defined conditions that determine whether a transition is possible or not:

- Ball moving towards the center of the field: Absolute ball velocity in y-direction larger than 60 [mm/s] and ball on the outer part of the babyfoot (ball position in $y > 90$ [mm] or < -90 [mm])
- Small ball velocity in x-direction: smaller than 15 [mm/s]

2.2 Finding shot locations for straight shot

Once the conditions for transition are satisfied, we need to know if and where we can shoot on the target without hitting the defence players. As it is the simplest case, we started considering straight shots so we just had to find a gap between players in front of the goal big enough to let the ball pass. We tried two different strategies:

- Calculate the best shot location: In this strategy the best shot location is calculated as the middle of the biggest gap between players or the goal extremities. It corresponds to the most often used strategy for humans. When the ball comes from one side exiting the juggling mode, the player follows the ball up to the shot location. The main problem with this strategy is that if the defense moves while the ball is on its way to the shot position previously calculated, the best shot position moves as well and the shot will never be executed in certain cases.
- Continuously check if the shot is possible: This strategy is an improvement of the previous one. As the ball moves from one side to the middle of the field, the middle attack player follows it. But unlike before, the player shoots as soon as there is a gap big enough in front of the goal. It doesn't wait for the position to be the best.

2.3 Calculations on straight shot with moving ball

Reaction time of the motors When the laterally moving ball reaches the surroundings of the shot position, the problem of the shot timing occurs. If we command the motors to shoot when the ball is in the good position, the ball will obviously already have left this position when the motors actually react. Therefore we defined a zone around the shot position Δy and as soon as the ball enters this zone, the shot will be triggered. As this threshold depends on the reaction time Δt of the motors, but itself is given in units of length (mm), we deduce that it is proportional to the ball speed in y-direction:

$$\Delta y_t = v_{\text{ball},y} \cdot \Delta t \propto v_{\text{ball},y}$$

Shot with angular or linear motors? The automated babyfoot has two different motors for every rod. So shots can possibly be done using either one of them or both at the same time. We decided to shoot using only the rotation of the rod while keeping the translation for the positioning of the player with respect to the ball.

Geometry As the ball is in motion we cannot just hit the ball with the center of the foot if we want to have a straight shot on the goal. In fact the lateral velocity of the ball would result in a slightly inclined trajectory. The ball has to be hit with the angle of the foot to counteract this lateral velocity. Under the assumption that the player velocity v_{player} stays constant during the shot (i.e. is not measurably decelerated by the impact of the ball), we can study an elastic collision of the ball with the players foot. To simplify we make the geometrical considerations in the reference system of the foot.

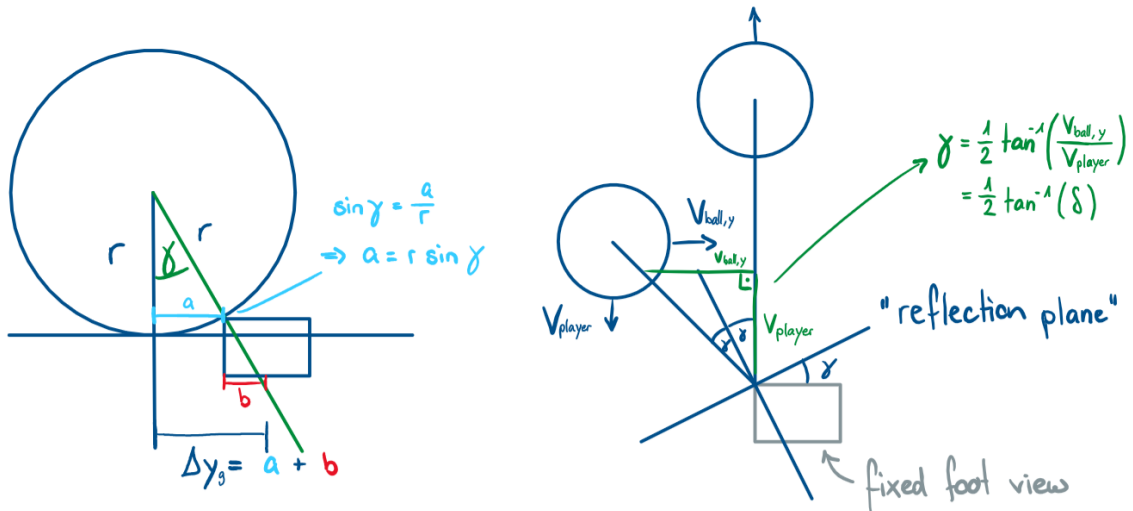


Figure 1: Geometrical considerations for straight shots

From the angles on figure 1 we can conclude the following formula for Δy_g :

$$\Delta y_g = a + b = r \cdot \sin(\gamma) + b = r \cdot \sin\left(\frac{1}{2} \arctan(\delta)\right) + b = \frac{r}{\sqrt{2}} \frac{\delta}{\sqrt{\delta^2 + 1} \sqrt{\frac{1}{\sqrt{\delta^2 + 1}} + 1}} + b$$

Where $\gamma = \frac{1}{2} \arctan(\delta)$, $\delta = v_{\text{ball},y}/v_{\text{player}}$ and a and b are shown in figure 1. Assuming that the player velocity is much larger than the ball velocity we can simplify the above equation neglecting the quadratic terms of δ :

$$\Delta y_g \approx \frac{r \cdot \delta}{2} + b = \frac{r}{2v_{\text{player}}} \cdot v_{\text{ball},y} + b$$

$$\Delta y = \Delta y_t + \Delta y_g \approx \left(\Delta t + \frac{r}{2v_{\text{player}}}\right) \cdot v_{\text{ball},y} + b = C_1 \cdot v_{\text{ball},y} + b$$

2.4 Finding shot locations for angular shot

When we pass from a straight shot to an angular shot we can significantly increase the possible shot locations. We only have two limiting factors:

- The defense player: We project the y position of the three players on the line where $x = x_{\text{ball}}$. So if y_{ball} is in the range of one of these projected intervals the shot would hit a defense player and is therefore not possible.
- The ball must not be too close to the extremity of the field in order to be correctly playable. For this purpose we defined the threshold y_{max} with the condition that $|y_{\text{ball}}| < y_{\text{max}}$

For simplicity, independent of the position of the ball, we always target at a point x_0 in the middle behind the goal (see figure 12 in the appendix). A more complex strategy that considers shots in all directions on the goal would give more shot possibilities but would also imply longer calculations and a higher sensibility to inaccuracies.

2.5 Calculations on angular shot with moving ball

For an angular shot we need to reconsider the Δy_g found under the assumption of a straight shot. We can assume that the offset in y direction will also depend on the desired angle. On figure 2 we see that effectively γ now depends on the desired angle α .

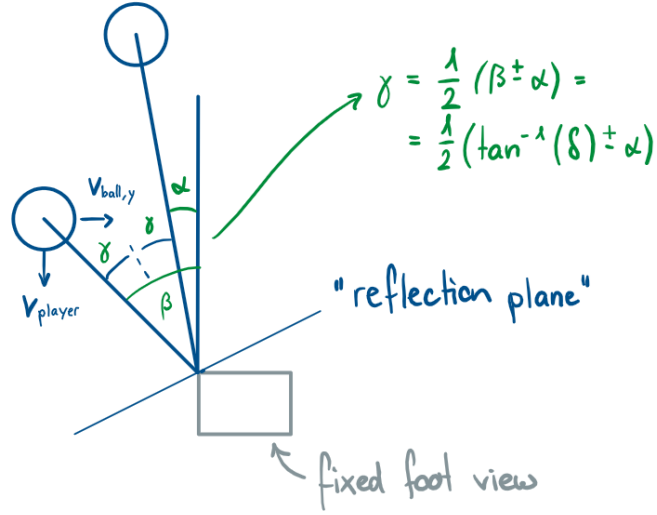


Figure 2: Geometrical considerations for shots with angle

From the angles on figure 1 and 2 we can conclude the following formula for Δy_g :

$$\begin{aligned} \Delta y_g &= a + b = r \cdot \sin(\gamma) + b = r \cdot \sin\left(\frac{1}{2} \arctan(\delta) \pm \alpha\right) + b \\ &= r \cdot \left(\underbrace{\sin\left(\frac{1}{2} \arctan(\delta)\right) \cdot \cos\left(\frac{\alpha}{2}\right)}_{(i)} \pm \underbrace{\cos\left(\frac{1}{2} \arctan(\delta)\right) \cdot \sin\left(\frac{\alpha}{2}\right)}_{(ii)} \right) + b \end{aligned}$$

Where $\gamma = \frac{1}{2} \arctan(\delta)$, $\delta = v_{\text{ball},y}/v_{\text{player}}$ and a and b are shown in figure 1. We realize that the first part (i) is the same as we already calculated for the straight shot. We only need to calculate the second term (ii) in the limit for small δ . Assuming that the player velocity is much larger than the ball velocity we can simplify the above equation neglecting the quadratic terms of δ :

$$\cos\left(\frac{1}{2} \arctan(\delta)\right) = \frac{\sqrt{\frac{1}{\sqrt{1+\delta^2}} + 1}}{\sqrt{2}} \approx 1 \text{ (neglecting quadratic terms in } \delta)$$

To conclude we can express Δy_g as follows:

$$\Delta y_g \approx \frac{r \cdot \delta}{2} + b = \frac{r}{2v_{\text{player}}} \cdot \cos\left(\frac{\alpha}{2}\right) \cdot v_{\text{ball},y} \pm r \cdot \sin\left(\frac{\alpha}{2}\right) + b$$

$$\Delta y = \Delta y_t + \Delta y_g \approx C_1 \cdot \cos\left(\frac{\alpha}{2}\right) \cdot v_{\text{ball},y} \pm r \cdot \sin\left(\frac{\alpha}{2}\right) + b$$

In our experience, angular shots didn't work well. This may be due to imprecision or poor implementation. As the theoretical work is shown in this report maybe a future project can develop this idea further and make it work. For a good implementation of this formula in LabVIEW, code a proper distinction between the different cases that may occur (ball moving outwards or ball moving towards center).

2.6 Change juggling side

In order to change the side on which we're juggling, the idea is to rotate backwards the attack players to let the ball pass from one side to the other and then restart the juggling on the new side. We again implemented some conditions that control this process, which are very similar to the ones we used for the juggling to shot procedure:

- The *Change side* button must be turned on
- Ball speed in x direction must be less than 15 [mm/s]
- Ball must be on "sides" of the babyfoot (i.e. ball y-position larger than 30 [mm] (right side) or less than -30 [mm] (left side)) and going towards the center (ball speed in y direction must be larger than 60 [mm/s] (left side) or less than -60 [mm/s] (right side))

Once all these conditions are verified, the players rotate backwards, let the ball pass and the juggling restarts on the other side.

3 LabVIEW VI's and explanations

3.1 Front Panel

We are using the front panel from last years but we have included some new indicators, such as a scheme of the babyfoot which was taken from an old VI showing the position of the ball and of all the players as they are captured by the captors and camera.

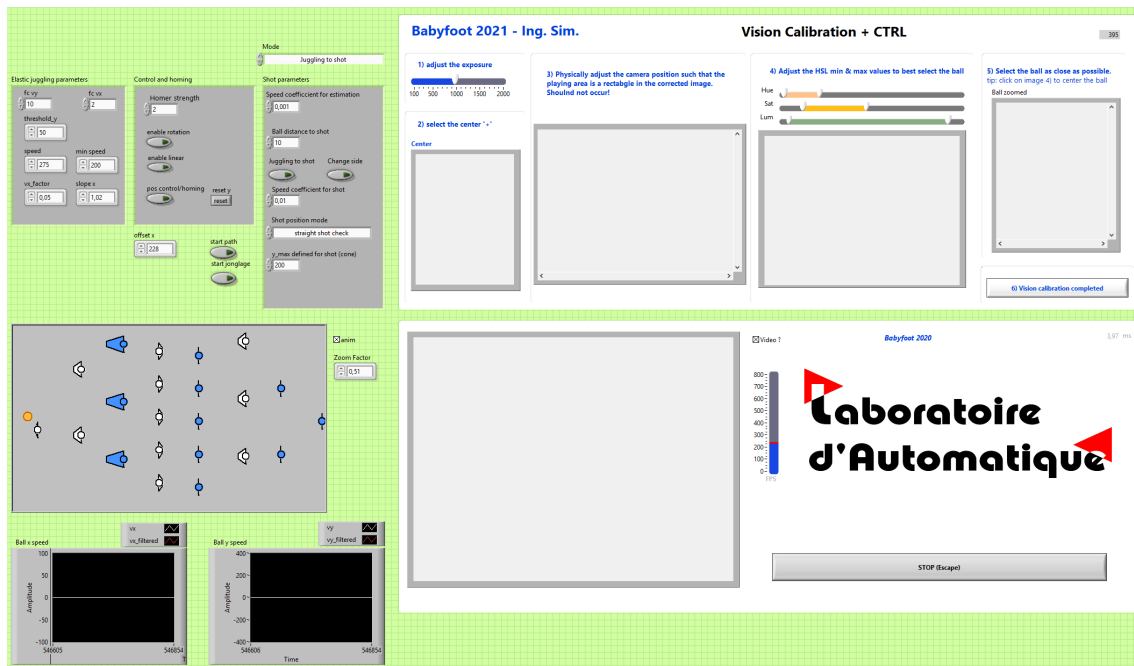


Figure 3: Front Panel of the LabView code

We also included a new cluster to control the 'juggling to shot' process. This new cluster is shown in figure 13 in the appendix, where the initial values of these parameters are displayed.

The *Shot parameters* cluster displays some parameters to control the shooting process. The different elements are :

- *Speed coefficient for estimation*: coefficient governing the position of the estimation process to check if a shot is possible (defenders in front of the estimated position)
- *Ball distance to shot*: coefficient impacting the threshold to start shooting (coefficient $b = 10$ [mm] from section 2.3 corresponding to half of a players foot)
- *Speed coefficient for shot*: coefficient multiplying the ball y-speed value, impacting the threshold value to start shooting (coefficient $C_1 \approx 0.01$ from section 2.3, determined experimentally)
- *Juggling to shot*: button to press in order to go from juggling to shooting
- *Change side*: button to press in order to change juggling side
- *Shot position mode*: type of shot to perform
 - *Straight shot check*: constantly checking if a shot is possible and shooting as soon as it is the case
 - *Straight shot*: shooting where the largest gap between the defenders is detected
 - *Shot with angle*: shooting with an angle
- *y max defined for shot (cone)*: is the value y_{max} described in section 2.4

3.2 General structure

In order to add the shot to the code, we added one big case structure to the code we received. All the work that already has been done for juggling is kept unchanged in the case *Juggling*. Our modifications to the juggling mode and the procedure to shoot is in the case *Juggling to shot*. The two modes can be selected on the Front Panel.

All the rest of the explanations will only concern the mode *Juggling to shot*: It contains itself the VI *Conditions to change mode* (see section 3.3.1) that determines the mode of another case structure. The possible modes are:

- 0 - Juggling: Contains the same VI's responsible for juggling as in the Mode *Juggling* taken from a previous project.
- 1 - Follow the ball: Contains the VI *Path to shot* (see section 3.5) that calculates the path the player has to follow to get behind the ball and follow it there.

- 2 - Shoot: Rotates the rod of the attacking players by 200 [mm] (more than possible to ensure speed) forwards to shoot the ball.
- 3 - Change side: Rotates the rod of the attacking players by 30 [mm] backwards so that the ball can pass to the other side of the field.

3.3 Conditions to change mode

A typical example of the process *juggling to shot* is switching from mode 0 (juggling) to mode 1 (following the ball with the middle player) and then to mode 2 (shooting in the goal avoiding the defenders). Another example is from 0 (juggling) to 3 (change side), back to 0, then 1 (follow the ball) and on to 2 (shoot).

3.3.1 Conditions to change mode

The conditions to change between the modes explained above are:

- The condition to enter in mode 1 (following) is the boolean which is the output *Follow ball ?* of the *Conditions following ball VI* (see section 3.3.2).
- The condition to enter in mode 0 (juggling) is either the condition to restart the juggling after a change of sides or a reset of the *juggling to shot* process.
- The conditions to enter the mode 3 (change side) are the conditions mentioned in section 2.6.
- The condition to enter the mode 2 (shooting) is the boolean *Shot trigger?*, output of the *Conditions trigger shot VI* (see section 3.3.3).

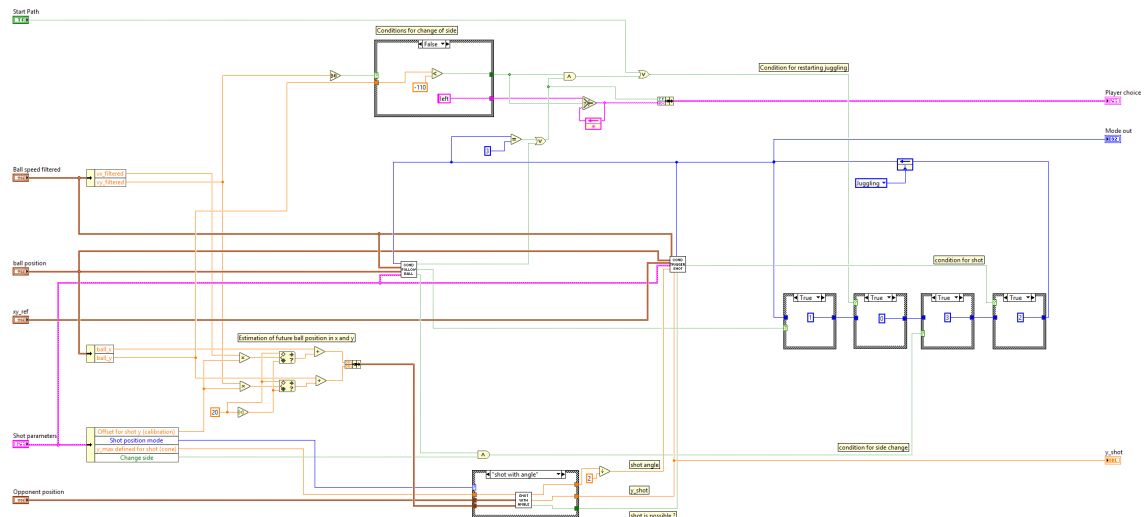


Figure 4: Conditions_change_mode.vi

3.3.2 Conditions following ball

The conditions to start following the ball are:

- The *Juggling to shot* button must be turned on
- The current mode must be 0 (juggling)
- Ball speed in x direction must be less than 15 [mm/s]
- Ball must be on "sides" of the babyfoot (i.e. ball y-position larger than 90 [mm] (right side) or less than -90 [mm] (left side)) and going towards the center (ball speed in y direction must be larger than 60 [mm/s] (left side) or less than -60 [mm/s] (right side))

This VI also contains the main conditions for the "change side" process. These conditions are explained in section 2.6.

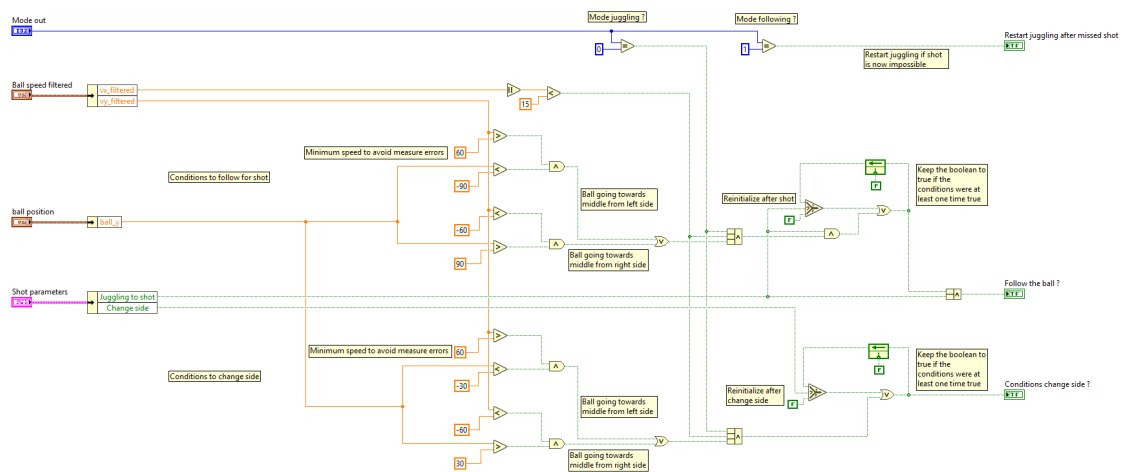


Figure 5: Conditions_following_ball.vi

3.3.3 Conditions trigger shot

The conditions to trigger the shot are:

- The *Juggling to shot* button must be turned on
- The current mode must be 1 (following the ball)
- The difference between the ball y -position and the y_{shot} value should be less than the threshold
- The ball x -position should be in the 200 to 270 [mm] range
- The difference between the ball and the player y -positions should be less than *thresh* (a threshold initially set to 30 [mm])
- The boolean *Shot possible ?* should be true meaning there will be no defender blocking the shot and that the ball is within the range of the goal (see section 3.4)

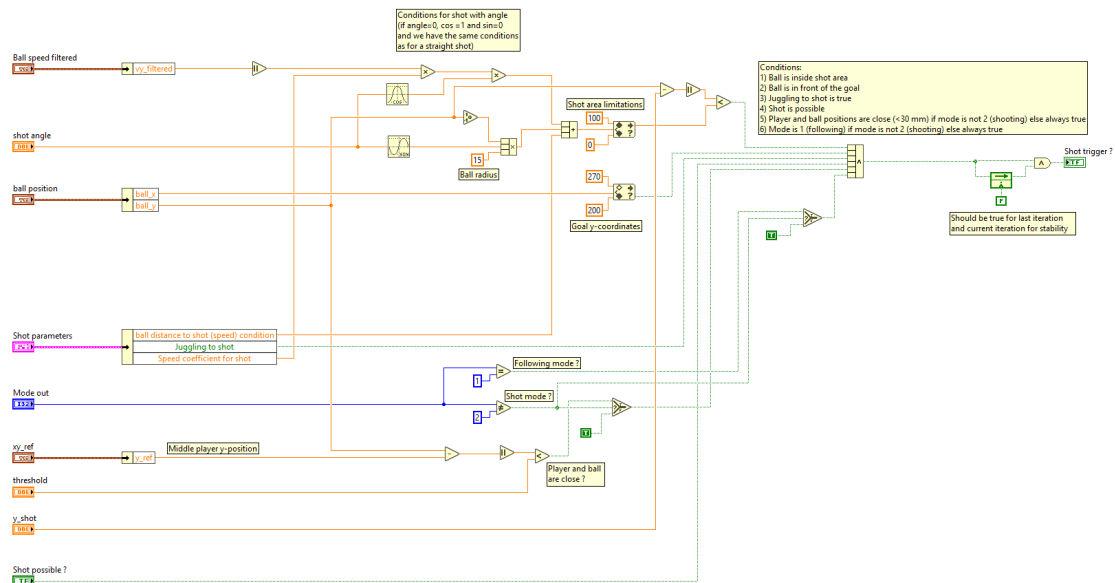


Figure 6: Conditions_trigger_shot.vi

3.4 Shot location modes

The *conditions change mode* VI contains a case structure which launches different VIs depending on the value of *shot position mode*. Here are the three cases:

3.4.1 Straight shot

This VI computes the "best" location for a shot considering the position of the two defenders and the goalkeeper. This location called *y shot* lies in the middle of the largest free space between two defenders.

Output *shot free gap* is the value of this gap.

Output *shot possible* is a boolean which is true if *shot free gap* is greater than the ball diameter and false otherwise.

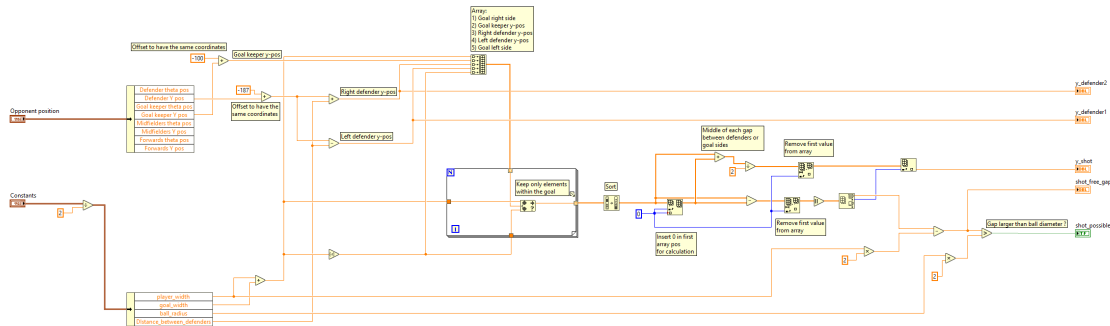


Figure 7: straight_shot.vi

3.4.2 Straight shot check

This VI aims to check if a shot at a given position is possible or not. The input *ball pos estimate* is the position to evaluate the possibility of the shot. Output *y shot* is the estimated ball position *ball pos estimate*, location at which the shot is going to happen. Output *shot possible* is true if no defenders are in front of the estimated ball position and if the ball is in front of the goal.

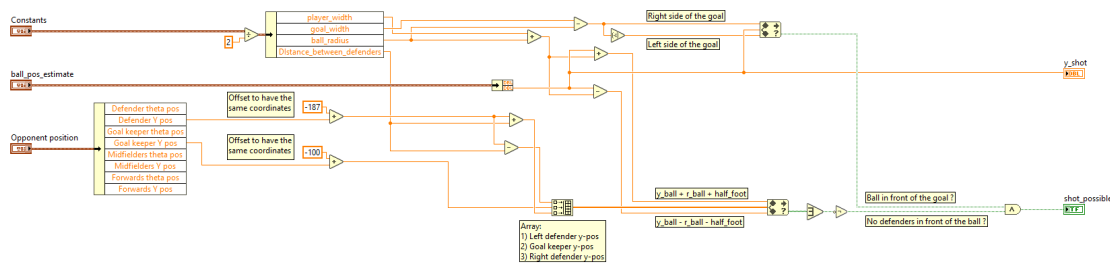


Figure 8: straight_shot_check.vi

3.4.3 Shot with angle

This VI calculates if for a given ball position an angled shot on the goal is possible or if there are defenders that would block the ball. The strategy explained in section 2.4 is applied, that means that for simplicity the trajectory of the ball is calculated to intersect a point x_0 behind the goal (see figure 12 in the appendix). To find out if there is a player on the way, the three player positions are projected on the line where $x = x_{ball}$. Afterwards, it is checked if the ball position y_{ball} is in one of those projected intervals and the shot angle is calculated according to the formulas from section 2.5.

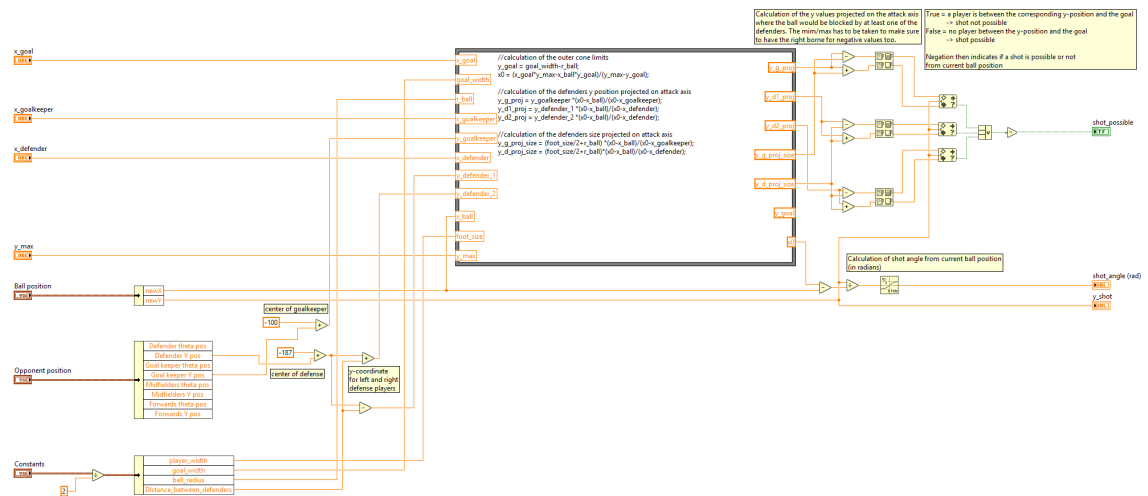


Figure 9: shot_with_angle.vi

3.5 Path to shot

In this VI the path of the middle player is calculated, in the case where we want to follow the ball (when we are in mode 1). In that mode, we want the y-position of the player to be the same as the ball's, while the x-position has an offset relative to the ball's, so that the player moves behind the ball. The output variable of this VI is a 3x2 matrix, called *path*, that includes the x and y values of the player's current position, an inclined position and the final position behind the ball. The inclined position is necessary so that the player doesn't touch the ball while finding its position behind it.

Since we only shoot straight we don't want to follow the ball with the left and right attackers. While the ball is located between $y = \pm 85$, the middle player follows it in order to be ready to shoot. But when the ball leaves that zone, the middle attacker remains at the border of it and does not follow the ball anymore. If possible, a new juggling sequence is commenced.

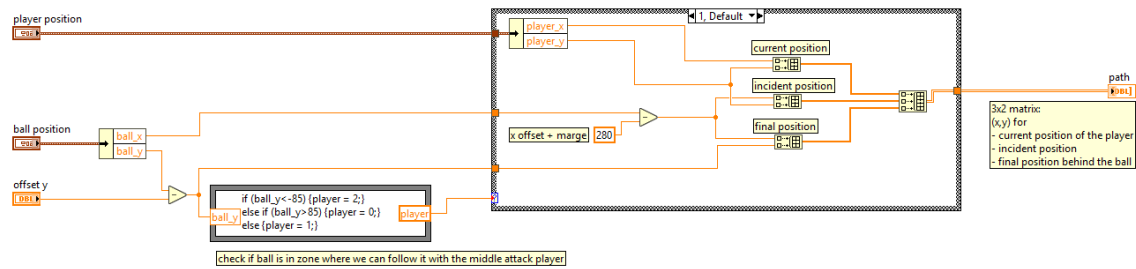


Figure 10: `path_to_shot.vi`

3.6 Init jonglage sides

This VI is a copy of the VI *init_jonglage.VI* from Isaac's project. we only added the following part to be able to reuse his work for changing the juggling side. When *start path* is activated (at the begin of juggling), nothing changes and the side is determined by the preceding code of the VI that is explained in Isaac's report [1]. When *start path* is deactivated (during juggling) the value of the previous execution of the VI is kept except if the boolean in the cluster *Player choice* coming from *Condition_change_mode.VI* is true. In this case the output *left/right* takes the value that is in that same cluster.

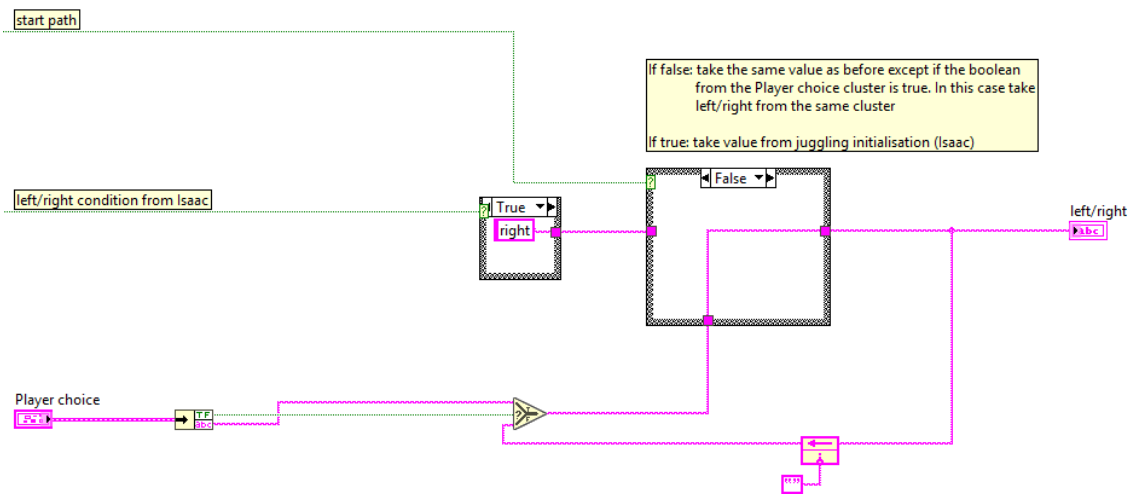


Figure 11: modified part of init_jonglage_sides.vi

4 Current state of the babyfoot

4.1 Common issues and solutions

4.1.1 Camera freeze

Issue The camera sometimes freezes while juggling or shooting. According to Mr. Salzmann this is a well known problem with the babyfoot already encountered in previous projects. It could be due to electromagnetic fields that disturb the signal in the cable of the camera when the linear motors are in motion.

Solution -

4.1.2 Precision of the ball velocity

Issue The velocity of the ball is calculated from the ball position which depends on the pixels of the camera. So when the ball is on the border between two pixels, the velocity can suddenly be very big even if the ball doesn't move.

Solution Many projects already tackled this problem and proposed filters for the speed. In our experience the speed was most precise after successively filtering with *SpeedEulerYann.vi* and *ball_speed_filter.vi*.

In addition, if the ball speed changes suddenly even if the ball doesn't move, try to redo the vision calibration. We observed that the way you draw the rectangle around the ball can have an impact on the precision of the ball velocity.

Also cleaning the glass-floor has a positive impact :)

4.1.3 Changing parameters

Issue We observed that from one week to another the shot worked with changing parameters. That means that we often had to readjust them when we saw that the ball was hit in advance or too late.

Solution We didn't find a reasonable explanation for this phenomenon. We recommend to only adjust the parameter *Speed coefficient for shot* as the other parameter *Ball distance to shot* has been calculated from the geometry of the players foot (see section 2.3).

If the triggering was too early, decrease *Speed coefficient for shot*.

If the triggering was too late, increase *Speed coefficient for shot*.

4.1.4 Ball is lost while juggling

Issue Often the ball is lost in the first attempts of juggling after restarting the babyfoot.

Solution If the ball is lost because juggling is too much towards the goal (i.e. in front of the attackers): decrease *Offset x* on the front panel of the main VI.

If the ball is lost because juggling is too much towards the middle (i.e. at the back of the attackers): increase *Offset x* on the front panel of the main VI.

4.1.5 Juggling speed

Issue Increasing juggling speed is possible to a certain point where it becomes critical. When hit too hard, the ball starts to rebound off the floor. This could lead to a loss of the ball while juggling. An example for this phenomenon can be seen on a slow-motion video of the juggling.

Solution -

4.2 Best Practice for juggling and shot

In order to avoid errors in the handling of the babyfoot, we propose the following workflow for operating the juggling and shot code:

- Light up the babyfoot with the LED and turn off the neon lamps of the room to avoid disturbance of the camera. The two safety buttons have to be switched off (upper position).
- Make sure that the player of the attacking rod are vertical.
- Run the LabView Front Panel with all controls disabled.
- Do the vision calibration as indicated in the window.
- Enable the rotation and linear motion with the corresponding controls.
- Execute the homing of the attacking rod with *pos control/homing* and reset the y value when the rod has stopped moving.
- Choose between the Modes *Juggling* and *Juggling to shot*.
- Place the ball now near the attacking rod and push *start path* and remove it after some seconds.
- Push *start jonglage*. The babyfoot should now start juggling.
- If you have chosen the Mode *Juggling to shot*, you can now change the juggling side with the control *Change side* or shoot with the control *Juggling to shot*.
- A shot is triggered at the first possible location after pushing the button. If it doesn't work, try to change sides and shoot from there.
- **After a shot, push *start path* again and let it turned on for a second to be sure that the rod doesn't move when placing the ball for the next try.**

In general try to avoid putting your fingers and hands too close to the rods and manipulate the ball with a ruler for example.

5 Conclusion

It has been a very interesting project to work on for us, and we are quite satisfied with our achievements. We found conditions we can impose on different measurements, that allow us to change from juggling into a shot process, which overcomes the opponent's defense and scores a goal through a straight shot. The conditions can be regulated over parameters that we determined via calculations and experiments. If the shot process fails, the program restarts a juggling session and tries again to score. If needed, we can choose to change the side on which the juggling is executed, to destabilize the opponent's defense even more.

This strategy works well. When the parameters are well regulated, it is very hard to defend against it. However, it can take some time to find such a well performing setting. Maybe in a future project this weakness can be eliminated and the sequence made more robust.

Another interesting idea that needs to be checked out more in the future is the angled shot. We made experiments around it and created some code, but we didn't test it out that much. It would surely be an interesting addition to a, in our opinion, already good working attack strategy.

6 Acknowledgments

We would like to thank Pr. Salzmann for supervising this Bachelor project. The working conditions were very pleasant and we could always rely on support if needed.

References

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Appendix

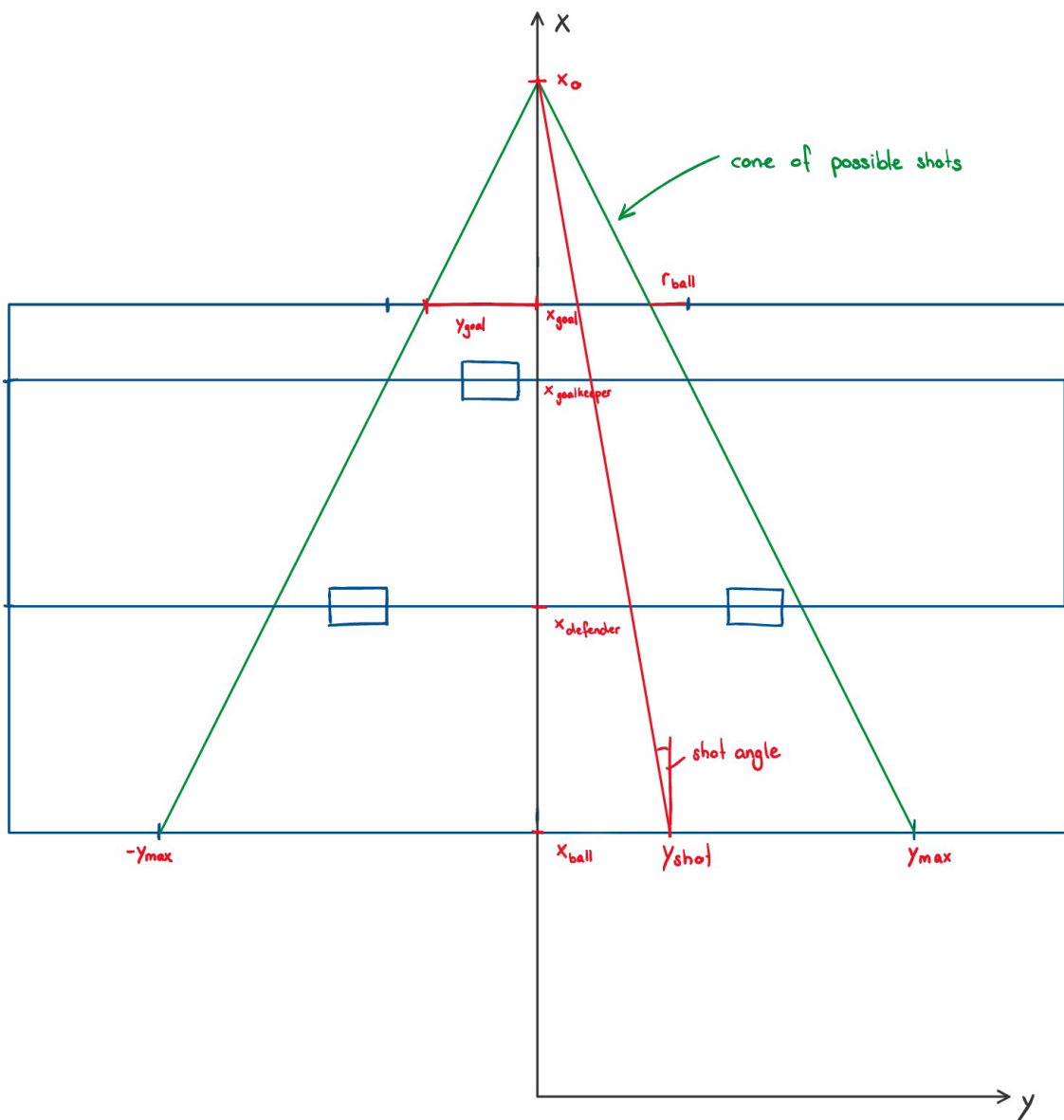


Figure 12: Schema for shots with angle

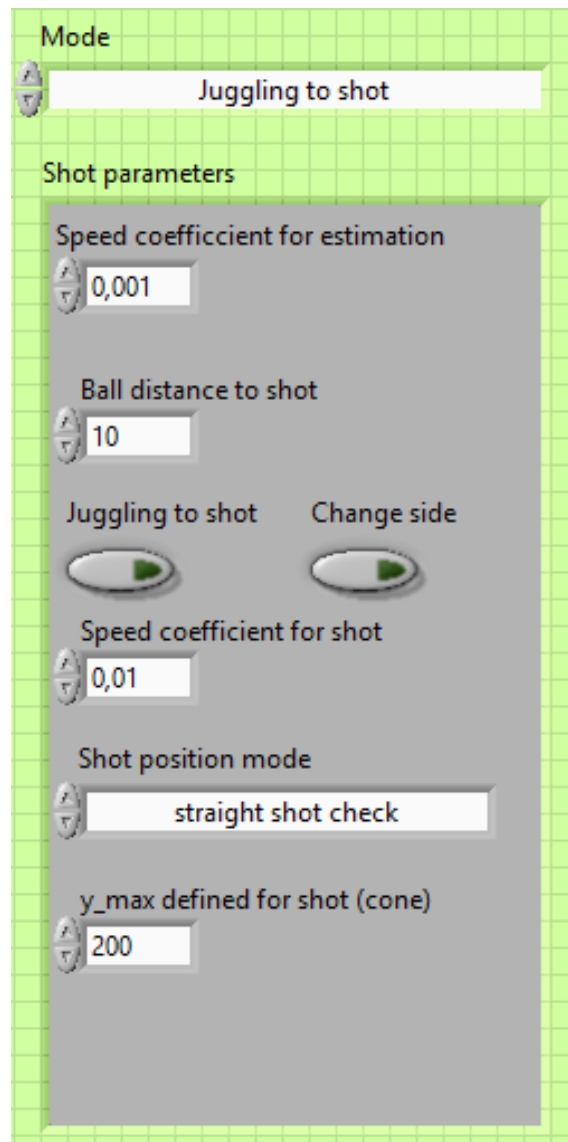


Figure 13: Parameters of the Front Panel