

Upgrade of the babyfoot vision control system

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1 System global architecture

For simplicity reasons, the following diagram describes the control loop of only one robotized rod of the baby-foot. Each rod follows the same principle and control chain.

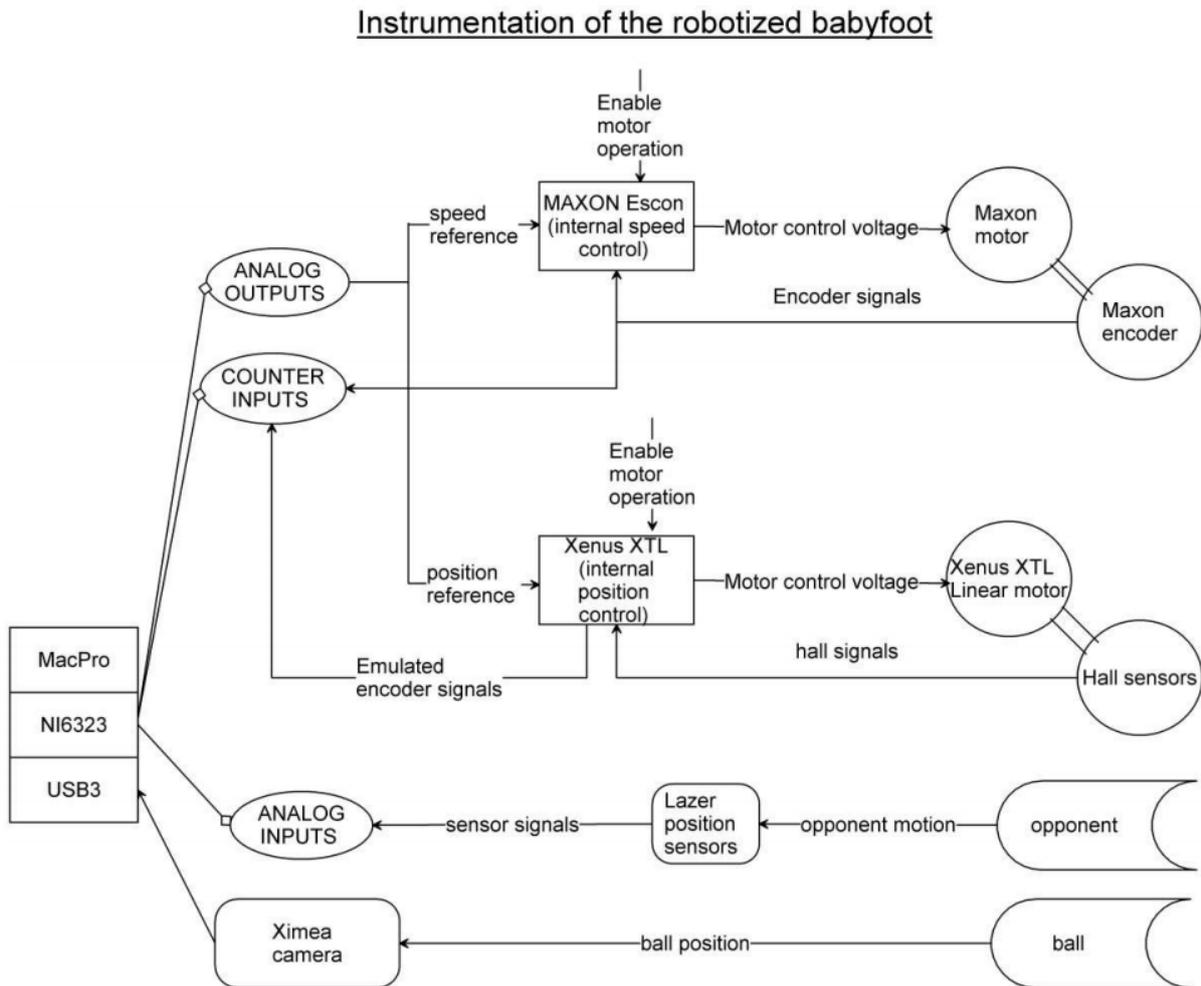


Figure 1: Babyfoot instrumentation

As we can see on figure 1, the linear and angular position controls are not performed similarly. Their operation are described in the next sections.

The baby-foot has been instrumented in order to provide the following measurements:

- The linear position of each robotized rod
- The angular position of each robotized rod
- The linear position of each human controlled rod
- The angular position of each human controlled rod
- The capture of the ground seen from below with which we determine ball position

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In addition, the following values can be controlled:

The linear position of each robotized rod

The angular position of each robotized rod

The main components of the robotized system are:

4x Xenus XTL-230-18-S for linear motion drive and control

4x Escon 50/5 for rotary motion drive

4x STB 2504 S linear motor

4x 3Phase Maxon rotary motor

2x NI 6323 acquisition card

1x USB3 Ximea camera for frame acquisition

8x Waycon lasers LAS-T5-500-420A

1x MacPro running windows

1.1 Angular position control loop

The angular position control is achieved via a PID implemented in the control program. This control delivers a speed reference to the Escon 50/5 drive which will feed the motor with the corresponding voltage. The output signals of rotational encoders are wired to counter inputs of the NI6323 acquisition card and provide the feedback measurements.

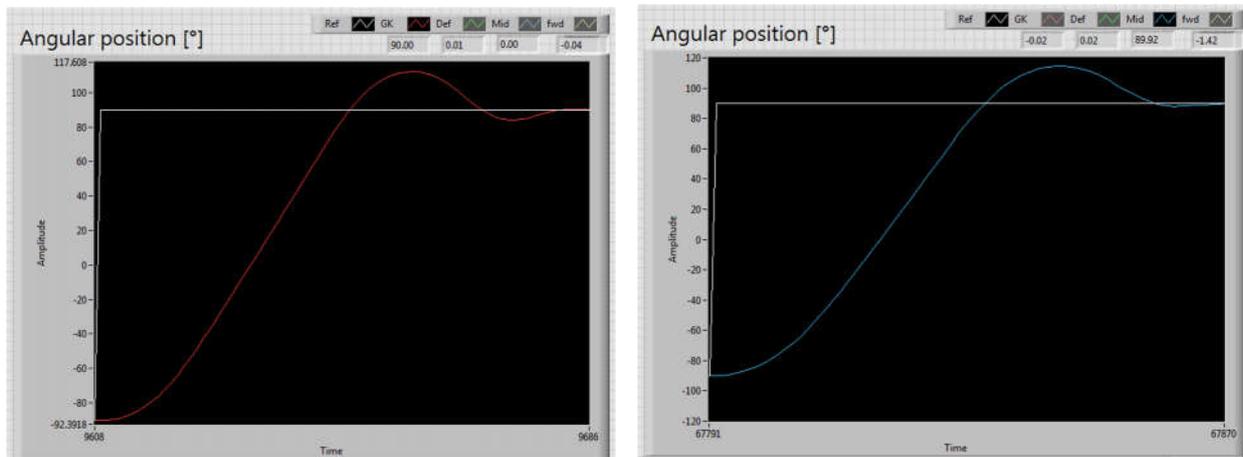


Figure 2: -90° to 90° step response for goalkeeper and midfielders (time in ms)

Responses obtained on figure 2 show a very slow response time (below 100ms) even with the midfielders rod which is the one with the biggest inertia. Moreover, the maximum output current of the Escon 50/5 controller has been limited to 10A when the maximum output current can go up to 15A. Without limiting the output we would obtain even faster response time. This limitation aims to preserve mechanical parts. Notice that these values are peak currents and not continuous ones and can be maintained only for short periods of time (when we need to accelerate the rod violently).

1.2 Linear position control loop

On the other hand, there is no control implemented in the control program for the linear position regulation. Indeed the control program simply provides a position reference to the Xenus XTL controller which is itself in charge to perform the whole control of the position. This controller also provides emulated encoders signal which are also connected to the counter inputs but these information are not used to close the loop.

The coefficient are set inside the Xenus controller with the coppley CME2 program. Backups of configurations can be found within the *Xenus_config* folder. These files can be loaded onto the corresponding controller using the CME2 program.

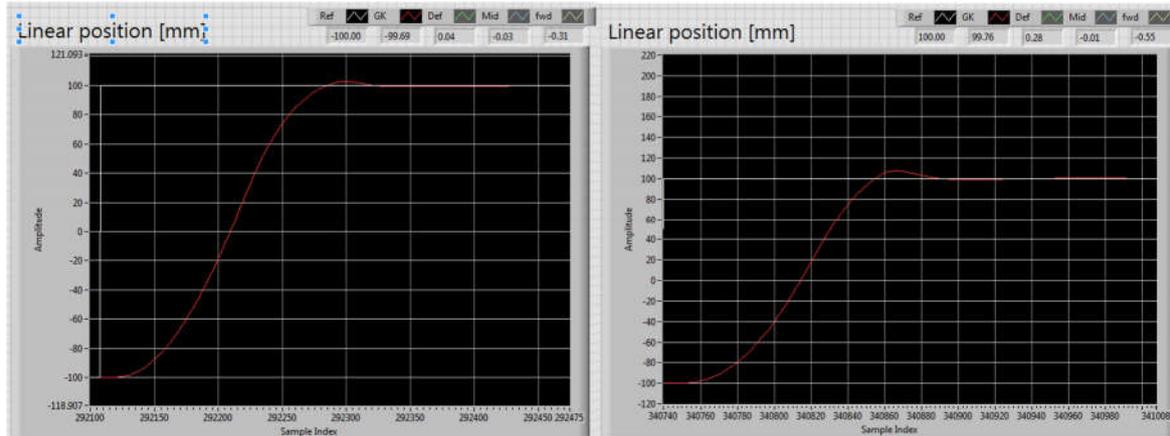


Figure 3: Step response for different acceleration limits: 20m/s^2 and 40m/s^2

The main factor intervening in the linear motion performances is the maximum acceleration limit. With the configuration files provided this limit is set to 20m/s^2 in order to limit mechanical efforts. But it is possible to increase this limit if better response times are required.

i.e: on the left, we have an establishment time of around 180ms when this time is around 110ms in second case which shows a significant improvement.

The drawback of such an increase of the limit is vibrations and constraints induced on the baby-foot. We will have to find the trade-off between performance and durability.

Of course, another important factor is the maximum speed. In our configuration files, this limit is set to 8m/s . It does not appear that this limit has been reached but a setting value too low could result in poor performances.

The maximum motion amplitude is set within the controller in order to avoid out of range displacement. This amplitude is centered on the homing position.

1.3 Opponent vision

In order to design an intelligent strategy, the position rods controlled by human players must be known. Also a specific part has been designed and coupled to the human controlled rods. This part, attached on the rods, has a particular shape: a plane surface and a helical one running in the longitudinal axis. This part allows to measure the linear position by aiming the plane surface with the first sensor laser beam and the angular one using a second laser aiming at the helical surface (see figure 4). By making the difference between the two measured distances and knowing the slope of the helical, we can determine at which angle the rod is.



Figure 4: 3D view and real part mounted on one of the manually controlled rod (design by Norbert Crot)

Unfortunately, sensors that have been chosen, provide a 4-20mA measurement output and our acquisition card only accepts voltages as input. To overcome this little issue, we had to design a little PCB in order to convert 4-20mA to 2-10V. (The design of this PCB can be found in the provided folder). This PCB basically supply the sensor and make the output current flow through a 500Ω precision resistor. The voltage between resistor leads is linearly varying between 2 and 10V with respect to the sensor output current.

1.4 Ball position

The ball vision system relies on the frames acquired by the camera Ximea MQ003CG-CV which has a 648x488 resolution and can go up to 500 fps. This camera is coupled with a M13VM246 TAMRON lens which is a wide angle lens. The camera is seeing the baby-foot ground from below through a transparent plane. Due to the distortion introduced by the lens, the image acquired must be calibrated in order to “come back in real world”. This step is mandatory since when pixels we are interested in go away from the center of the camera frame, distances tends to be contracted due to the lens effect. The NI Vision tracking algorithm in charge of the ball detection returns pixel coordinates. We must then convert these pixel coordinates in real world units (millimeters in our case) in order to have a measurement of the ball position.

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Ball position detection loop diagram

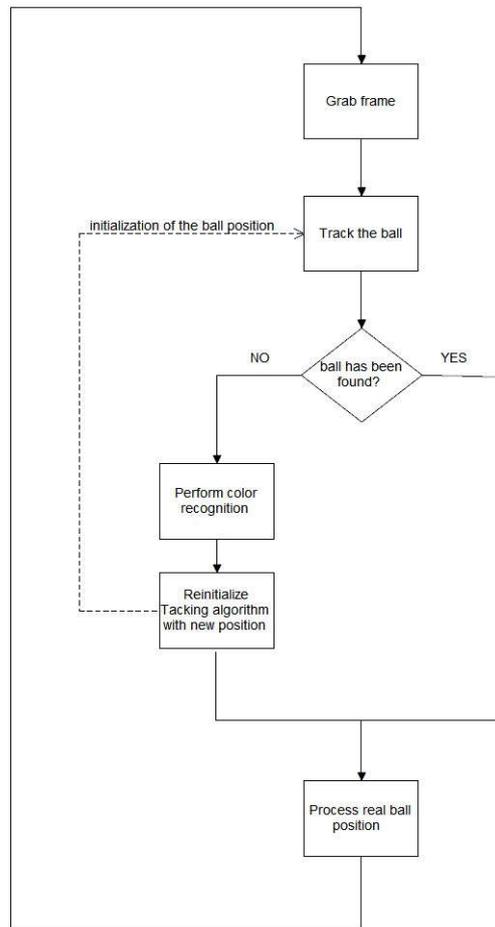


Figure 5: Diagram of the ball detection loop

When the ball is being tracked, the loop runs at maximum speed (the frequency of the camera) and this is the optimal case. But it happens, quite often, that the ball is lost by this algorithm and it needs to be re-initialized in order to retrieve the ball. This re-initialization is made by a color threshold function that take much more time to execute.

The precision of the ball position measured depends mainly on the calibration quality. The calibration has to be performed each time the camera position changes. The way the calibration is made is described in the “How to” section.

2 How to

2.1 Vision calibration

The vision system must be calibrated in order to provide measurements as accurate as possible but also to minimize the computation time. To do so, there is two main things to accomplish. First, we must ensure that the distortion calibration has been made properly. Second, we must set several parameters, such as exposure time and the color thresholding values.

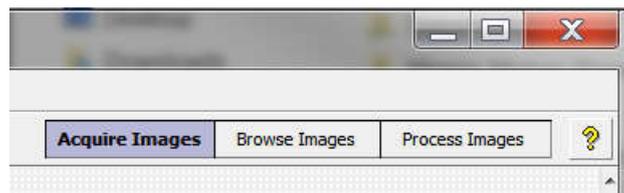
2.1.1 Create a calibration image

This part has to be made every time the camera position change with respect to the field of play. This calibration will ensure that the conversion from pixel to real units returns accurate values. In order to create this image, we will use the NI Vision assistant and proceed as follow.

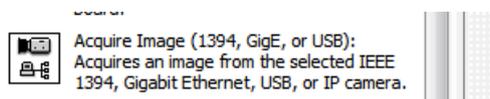
Step1: Acquire an image of the calibration pattern.

Place the calibration pattern on the field and adjust its position to fit the contours. Note that the paper sheet must be as plane as possible in order to do not introduce distortion not due to the camera.

Once the calibration pattern is properly installed, launch NI Vision Assistant. On the top right side on the window, select “acquire image”.



You now have several possibilities proposed on the left. Select the second option:

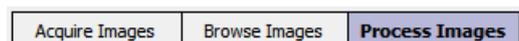


The program no propose to select the camera you want to acquire image with, select the Ximea Camera.

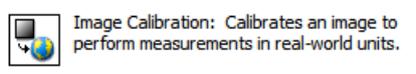
You can now get a frame of the Babyfoot field with the calibration pattern. Once you are satisfied with the frame acquired, select close on the bottom left portion of the window and click “Yes” when the program asks if you want to send the image to the image browser.

Your picture is now stored in the program memory. Save it to your work directory.

We now have to add some information to this frame in order to make it become a calibration image: select “process image” in the top right portion of the window:

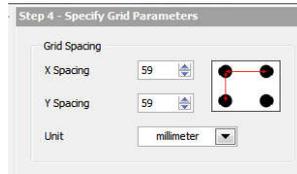


Go to the “Processing function: image” tab on the left and select:

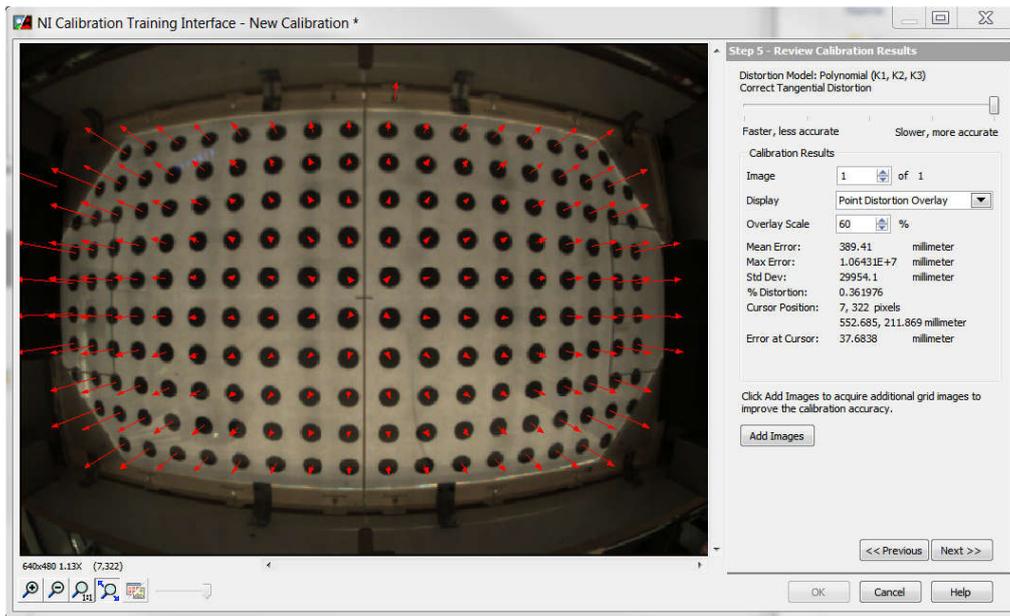


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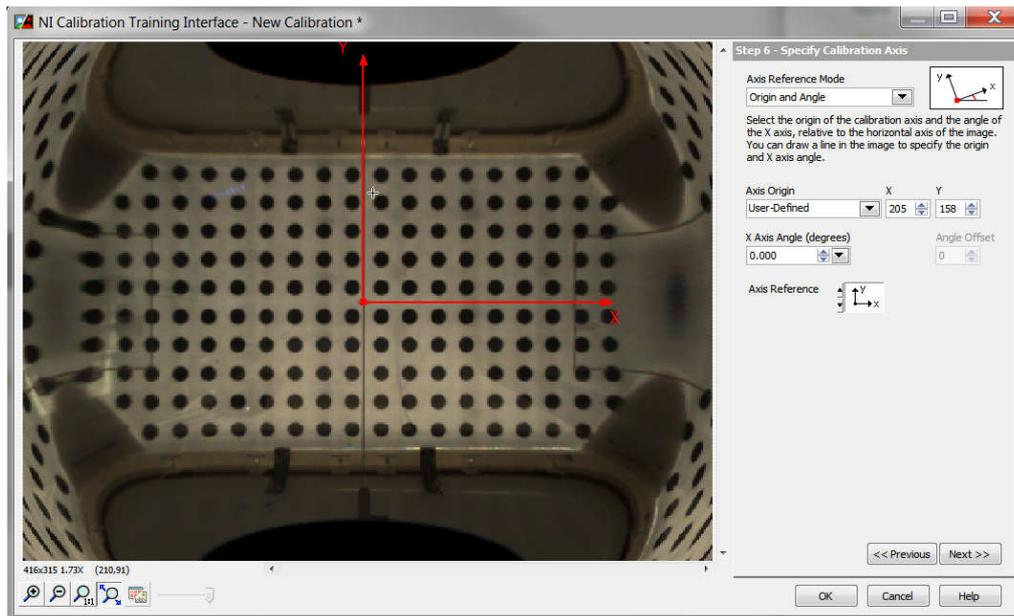
The program now propose to enter the grid parameters to make the relation between pixel and real units. In our case, the grid is 59x59mm:



Go to the next step and select the type of distortion model you want to use (the one shown on next screenshot is recommended for better results):



Next, you have to set the coordinates origin. Place the reference as follow and click next.



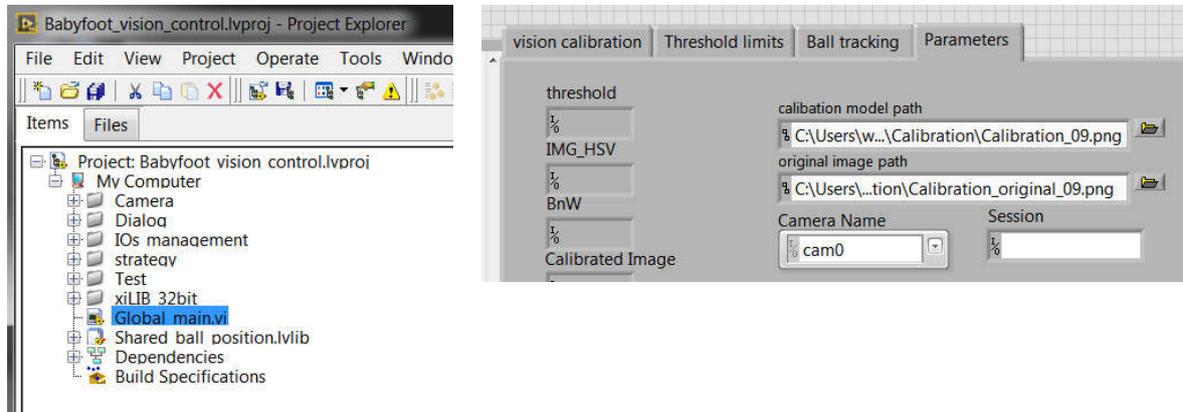
On next window, verify if everything is correct, click OK and save the calibration in your work directory. You will have to set this path in the Global_main VI in order to correct acquired images.

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Step 2: Set the paths in Global_main.vi

The NI Vision library will use the calibration image we have created to correct the distorted images we acquire. To do so, it needs to know the path to both images we previously created.

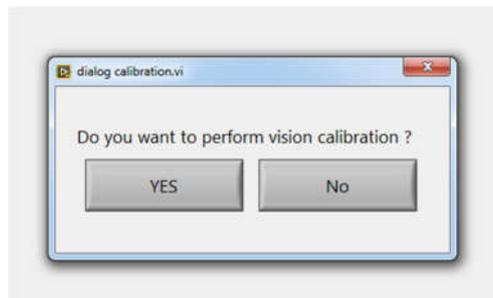
Open the VI Global_main.vi and without running it, go to the “Parameters” tab on the right.



2.1.2 Threshold values and reference setting

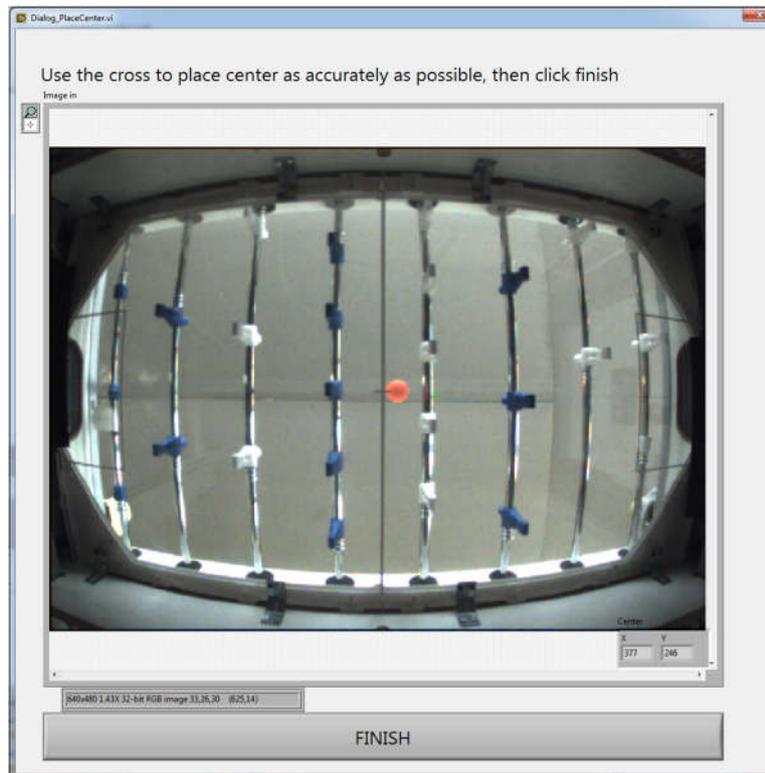
This setting has to be done every time the lighting conditions change or at first start-up. It consist in giving the coordinates reference to the vision algorithm, setting the exposure time and the color threshold limits.

Once the VI Global_main has been launched, it asks the user whether he wants to perform the calibrations with the following window:

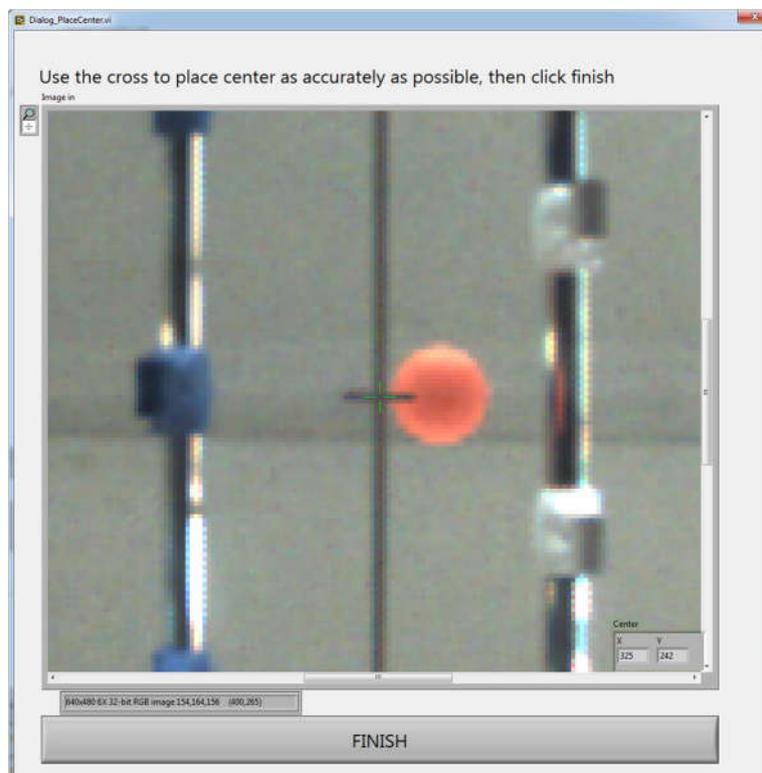


If you answer yes, the program enters in the calibration procedure and asks to indicate the center of the field. In this window a picture of the field is shown and you have to drag the green cross to the center of the field. In order to ease the process, use the magnifier tool to zoom on the region of interest.

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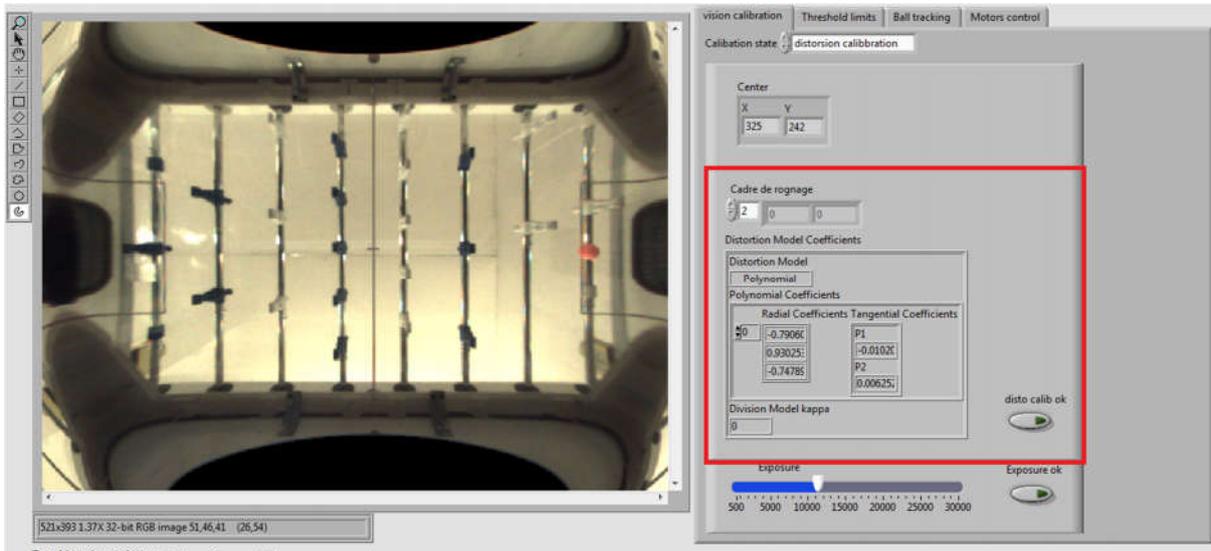
The result should be similar to this:



Once the center is properly set, click finish to go to next step.

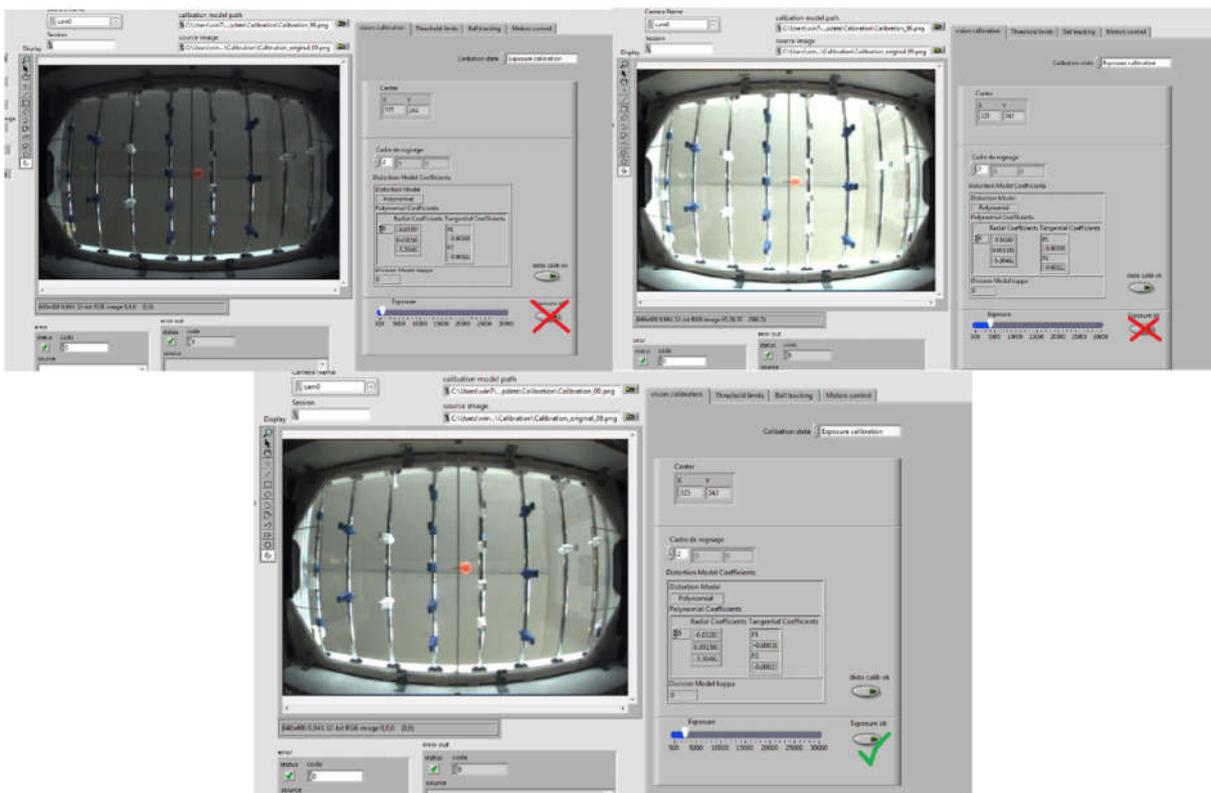
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The next step consist in verifying if the corrected image match the real environment. The program display the corrected image and you have to perform a quick visual inspection to check if it corresponds to the reality. The filed lines should be straight and the field should not be distorted in the region the ball evolve. On the following picture, the image is properly corrected. This step is just a visual inspection.



Once ok click on “disto calib ok”. To go to exposure setting.

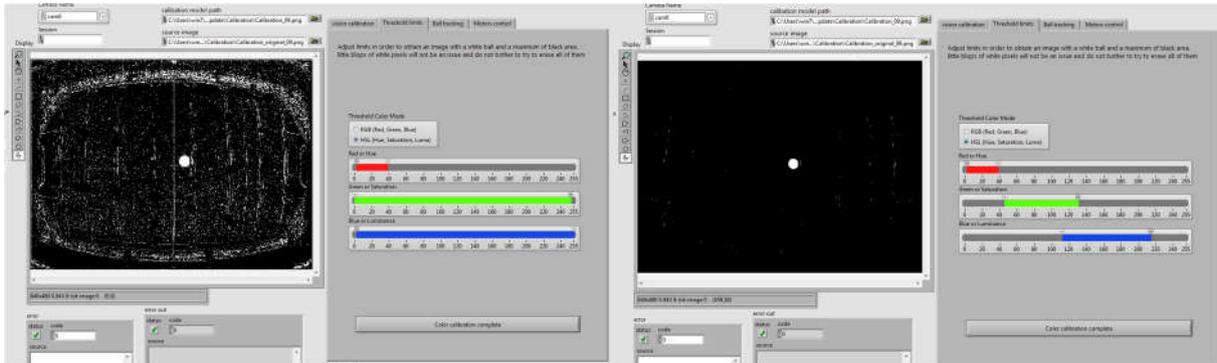
The exposure setting is adjustable with the slider. As the exposure time affects the framerate, it must not be set un-necessary high. You can see below 3 settings and their validity.



Once you have found the correct exposure value, click on “exposure ok” to proceed to last vision calibration step.

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The last step is critical since the parameters you choose are used by the color detection function which re-initialize the tracking algorithm. The limits are defined by finding the range in which most of the pixels of the ball are not erased by the filter. You can see on the picture below 2 different sets of ranges. The first one represents an invalid setting and the second an acceptable one.



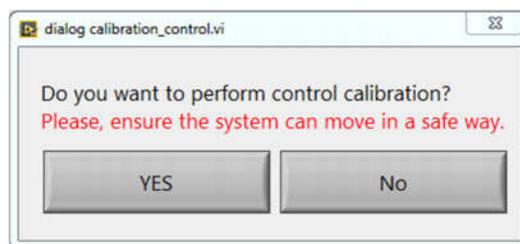
You do not have to find the perfect setting and little area of white pixels can remain on display but it is more important to ensure that the ball is properly visible in all areas of the field and especially in the one with darker enlightenment. Once satisfied with your settings, click on “color calibration complete”.

2.2 Position calibration

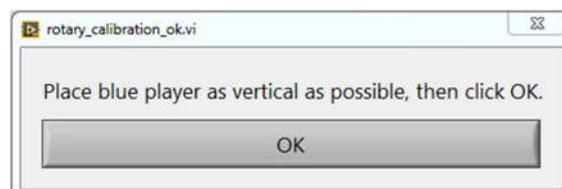
The position calibration is required each time the system is powered up and if the program has been interrupted while the rod were not in the initial position. The dialog box asks if you want to perform the position calibration at each run of the “Global_main” VI.

WARNING: Starting from this point, the system motion system is activated and can move unexpectedly. Do not place your hands in the reach of the robotized players.

The first step is the linear position calibration. Click “Yes” on the window shown below if you want to perform the position calibration.

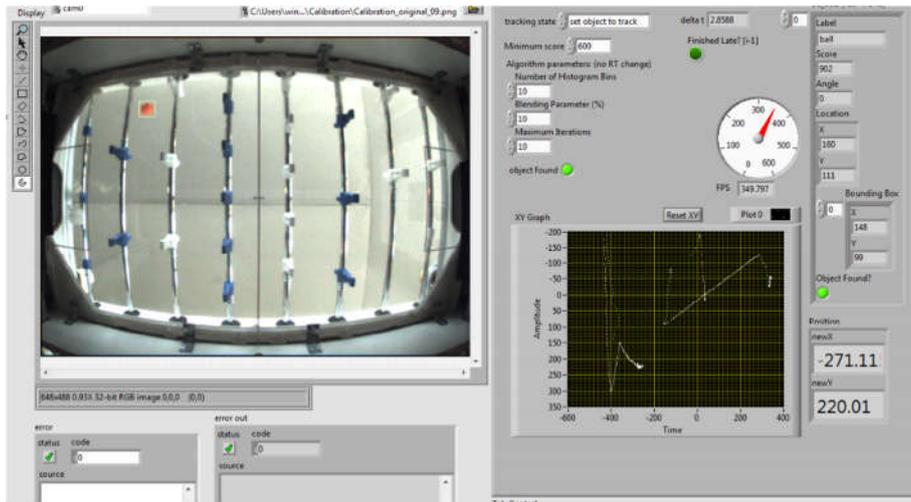


The system starts to move and performs the homing movement by reaching the limits of the motion range and returning to the initialized position. Once the homing sequence is finished, the program asks you to place all rods in the initial angular position. You can click OK once all rod are as vertical as possible.



Once the calibration is completed, the system is ready to operate and displays the main interface:

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2.3 Normal operation fault

It can occur during the system operation that the linear or rotary motion of one of the rods stops. Most of the time this is due to an overcurrent fault in motors. As drives are configured to protect motors they go to fault mode and need to be disabled and re-enabled. This can be achieved as follow:

Set to true the boolean control used to switch between automatic and manual mode (red arrow)

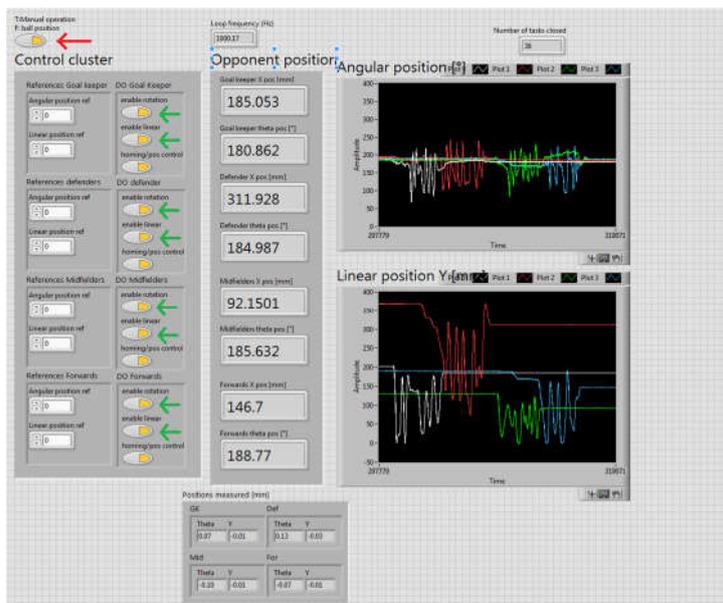
Set all references to 0

Set to false the boolean control used to enable the drive under fault (green arrows)

Set to true the boolean control used to enable the drive under fault (green arrows)

Set to false the boolean control used to switch between automatic and manual mode (red arrow)

The system should then continue its operation normally.



If the drive has not recovered from the fault, it could mean that the fault is serious and further investigations should be made. By opening the configuration program (CME2 for Xenus drive or ESCON studio for Maxon drive) you should have the description of the fault quickly.

2.4 In case of emergency stop

The baby-foot has two emergency stop buttons. Do not hesitate to use them if human or material integrity is threatened.

The re-start the system after an emergency stop proceed as follow:

- Stop the Global_main VI

- Unlock the emergency bumper (Warning, power will be up)

- Restart the VI and perform the position calibration

3 Appendix

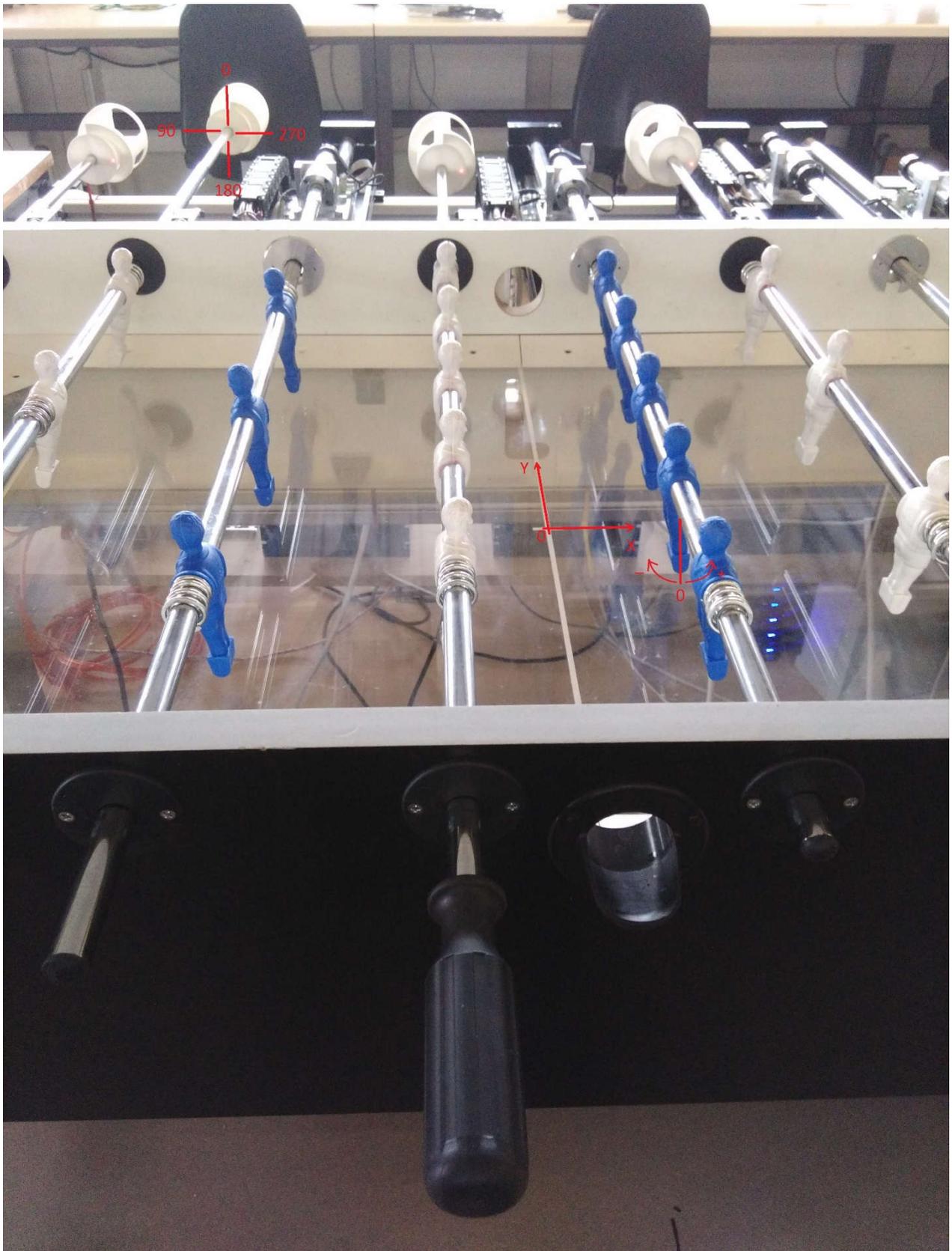


Figure 6: Coordinates references