GRIP AND MOVEMENT TOWARDS OBJECTS WITH NAO

FUNCTIONALITY:

This library allows Nao robot to be able to follow a colored ball with his head and move towards it until the ball is stopped (it must be in a place and at a height accessible to the robot). Nao will be able to catch the ball and walk with it if necessary.

The library has a previous stage of recognition and / or calibration of the color of the ball, so that the desired detection range is calculated automatically without having to vary any parameter in the library.

The general operation of the library can be divided into the following stages:

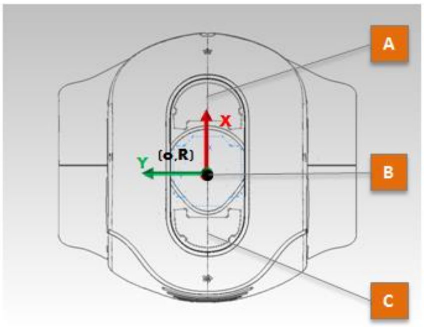
- HSV color range detection.
- Follow the ball with the head and the rest of the body.
- Location of the ball in the 3D space.
- Gripping the ball.

1. HSV COLOR RANGE DETECTION:

This step is done with the help of the tactile buttons included in the upper part of the head of the robot, which are shown in figure 1.

Tactile Head

3 x head capacitive sensors.



Item	Sensor name	X(m)	Y(m)	Z(m)
A	Head/Touch/Front	0.0312	0.0000	0.1014
B	Head/Touch/Middle	0.0010	0.0000	0.1099
C	Head/Touch/Rear	-0.0257	0.0000	0.1045

To access values by using ALMemory key names, see: Head touch Sensors.

Figure 1 - Tactile buttons located on the head.

The operating mode of the tactile buttons of the head is shown in diagram form in figure 4 and is as follows:

- **Button A: Front.**
  By pressing this button deactivates the tracking mode, so the robot stops following the ball. In turn, their arms are placed in “recognition position”, that is, stretched forward, so that the ball is placed between their hands and ensure in this way that the circular shape of the ball is perfectly seen to make more accurate the detection of its color, as can be seen in figure 2.

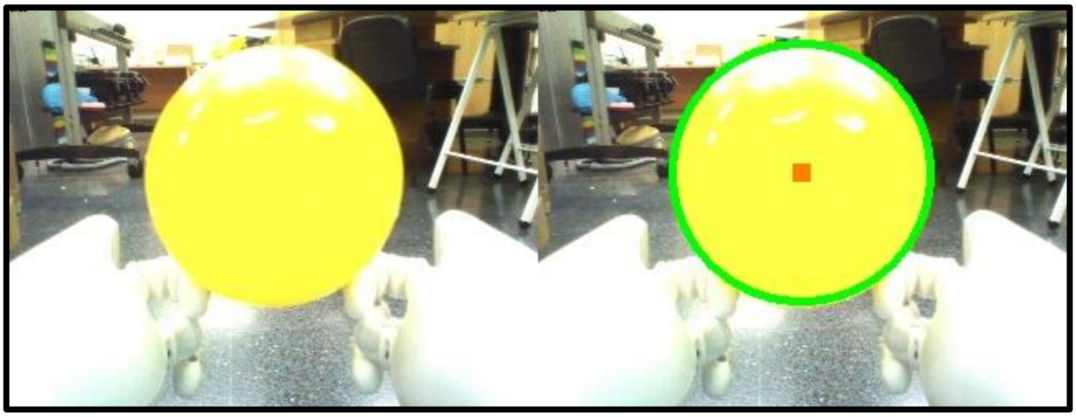


Figure 2 - Ball between Nao’s hands to ensure its recognition.

- **Button B: Medium.**
  By pressing this button, and once the ball is placed between the hands of Nao, a capture of the image seen through the robot's camera is done, so that in this image the ball can be recognized and an estimation of the HSV color of the pixels of the same can be made, as shown in figure 3.

Figure 3 – Representative rectangle of the pixels used for the estimation.

The orange rectangle of the figure 3 would correspond to the pixels taken to calculate the average of the color range, since they occupy the greater percentage of the seen area of the ball. The approximation is done in this way because in the upper part of the ball there may be reflections due to light in the room that distort the measurement and produce a range of false color detection.

The actions to be taken by pressing this button can be summarized as follows:

- Image acquisition from the NAO camera.
- Delimitation of the contour and center of the ball to delimit in which area to take the pixels.
- Calculate the HSV mean of the chosen pixels.
- Determination of the detection range from the calculated HSV value.

- **C button: Rear.**

By pressing this third button concludes the stage of color recognition and detection range and it begins the tracking of the identified colored ball. In turn, the robot puts his arms back into the initial position (stretched out next to his body) to start with the tracking stage.

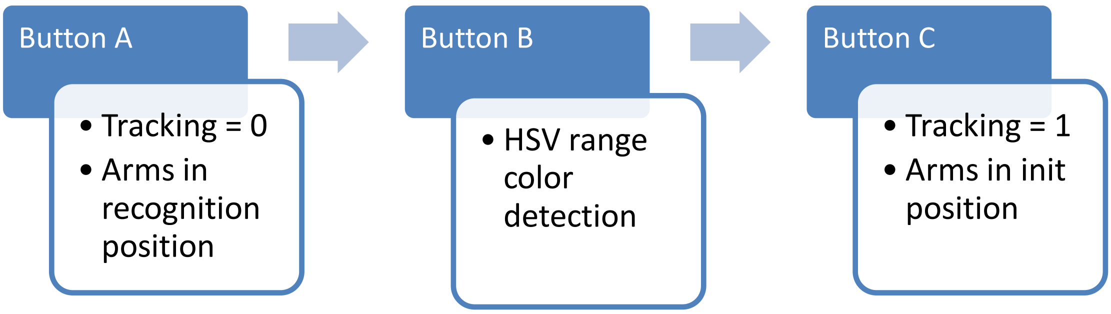


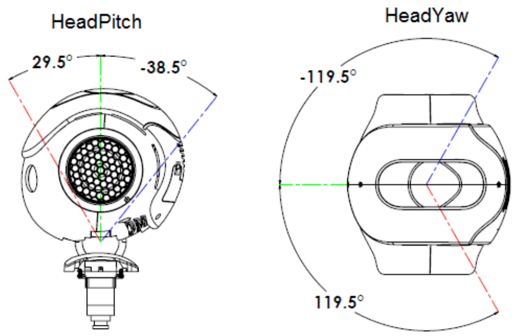
Figure 4 - Operating mode of the tactile buttons.

2. BALL TRACKING:

- **Head movements.**

The head movement necessary to track the ball is calculated so that the ball is always kept in the center of the image being obtained in real time through the camera of the Nao robot.

Head joints



Motion range

Joint name	Motion	Range *(degrees)*	Range *(radians)*
HeadYaw	Head joint twist (Z)	-119.5 to 119.5	-2.0857 to 2.0857
HeadPitch	Head joint front and back (Y)	-38.5 to 29.5	-0.6720 to 0.5149

Click the joint name to see all related ALMemory key names.

Figure 5 - Head movement ranges.

Some movements of the head are restricted, figure 6, to prevent this one from colliding with the shoulders of the robot and to avoid its wear. For this, in each iteration is made a prediction of which will be the new position of the head and, if this is conflicting, its movement is restricted to avoid the shock.

Anti collision limitation

Due to potential shell collision at the head level, the **Pitch** motion range is limited according to the **Yaw** value.

HeadYaw	HeadPitch Min	HeadPitch Max	HeadYaw	HeadPitch Min	HeadPitch Max
(degrees)			*(radians)*		
-119.52	-25.73	18.91	-2.086017	-0.449073	0.330041
-87.49	-18.91	11.46	-1.526988	-0.330041	0.200015
-62.45	-24.64	17.19	-1.089958	-0.430049	0.300022
-51.74	-27.50	18.91	-0.903033	-0.479965	0.330041
-43.32	-31.40	21.20	-0.756077	-0.548033	0.370010
-27.85	-38.50	24.18	-0.486074	-0.671951	0.422021
0.0	-38.50	29.51	0.000000	-0.671951	0.515047
27.85	-38.50	24.18	0.486074	-0.671951	0.422021
43.32	-31.40	21.20	0.756077	-0.548033	0.370010
51.74	-27.50	18.91	0.903033	-0.479965	0.330041
62.45	-24.64	17.19	1.089958	-0.430049	0.300022
87.49	-18.91	11.46	1.526988	-0.330041	0.200015
119.52	-25.73	18.91	2.086017	-0.449073	0.330041

Figura 6 – Head movement restriction.

- **Movement of the body towards the ball.**

  As for the movement towards the ball, this is done as a function of the distance to which it is located, so its radius is used as a characteristic parameter to determine this, and depending on the position of the robot head, the robot will move forward or sideways according to the position in which the ball is.

It is taken as a reference a radius of 50 pixels to start walking. This radius corresponds to the one that has the ball seen through the robot's camera when it is at a distance equivalent to the length of the robot arm stretched forward. From there, if the ball moves away, the radius becomes smaller and the robot walks towards it until it is approximately 25cm apart, which is where it is able to catch it by stretching its arms, and if the ball approaches, Nao will move backwards until it is at the corresponding distance to take the ball.

As for the position of the head, such as this on the X axis (HeadYaw) can move from -2.0857 to 2.0857 radians, as shown in figure 5, it is considered that the ball is centered when the head is in the range of -0.3 to 0.3 radians, in which case the robot will only walk forward. If the head is rotated more than 0.3 radians or less than -0.3 radians, the ball is considered to be on one side and, therefore, the robot will walk forward and turn its body towards the corresponding side.

Once the robot is already at a distance from the ball that allows Nao to reach it by stretching its arms, Nao should orient its body so that it is sure to be able to catch it. For this, the following conditions must be fulfilled:

- The head and body of the robot must be aligned so that the grip is always performed in the direction of the head and this can avoid possible errors. The desired position is shown in figure 7.

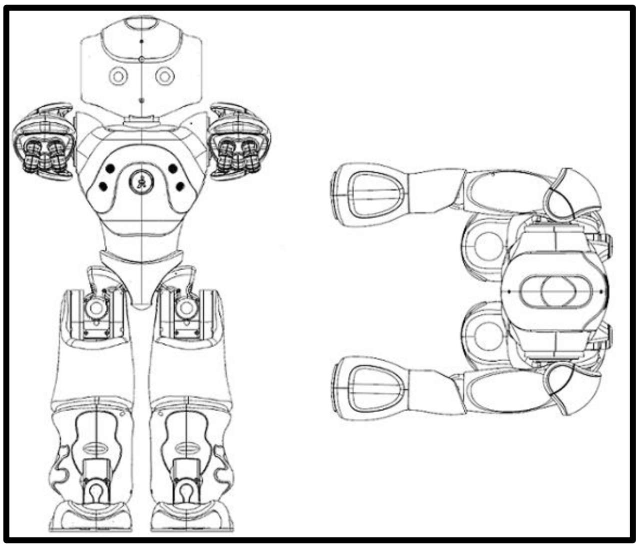


Figure 7- Nao position with body and head aligned.

- The center of the ball should be in the central area of the image seen through the upper camera of the robot, this will ensure that the robot does not hit the ball by stretching its arms to catch it as this could happen if the robot sees the ball in a corner of the image. Figure 8 shows a case in which the center of the ball is in the center of the image and another case in which it is slightly to the left.

Figure 8- Examples of positions of the ball center.

As previously stated, the robot will perform slight lateral displacements and rotations until it is in the optimum position, in which both conditions will be fulfilled. This is achieved by a proportional controller that allows the robot to make shorter shifts as it approaches the target.

Then it will proceed to the stage of locating the ball in 3D space.

3. LOCATION OF THE BALL IN THE 3D SPACE:

The ball should be about 25cm from the robot, since it is the distance at which the robot is able to catch it by stretching its arms. Therefore, as the center of the ball and its radius are known, this position must be converted to real-world coordinates with the robot as its origin, where the X axis is positive towards the front of the Nao, the Y from right to left and Z is vertical, all measured from the torso of the robot, as shown in Figure 9.

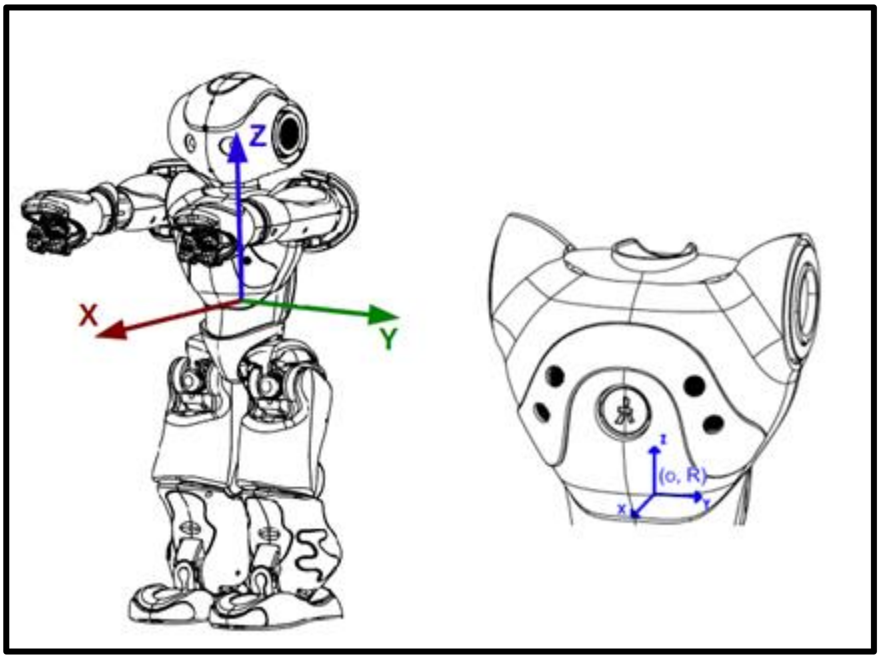


Figure 9 - Coordinate system with the robot as its origin.

- **X COORDINATE:**

To calculate the X coordinate, an image of the ball at 25 cm distance is taken and is calculated the radius on that image, which are 55 pixels. Thus, a converter 'radiusToMeters' can be used, which is:

$$0.25\ cm \cdot\ 55\ px\ =\ 13.75\ cm \cdot px$$

Therefore, to know the distance to which the ball of the robot (X coordinate) is located, it will suffice to know the radius of the ball and divide it by this converter 'radiusToMeters'. Figure 10 shows a schematic representation of this X coordinate, marked 'Xrobot', so that it is not confused with the 'x' coordinate of the ball's center.

- **Y COORDINATE:**

For the Y coordinate there are 2 possibilities: that the ball is on the left of the center, then the Y coordinate is positive, or it is on the right, where Y is negative.

The ball has a real diameter of 8 millimeters. With this value you can also create a 'pixelToMeter' converter that is obtained by dividing this value of the actual diameter between the diameter of the ball in pixels, in this way it is possible to know the distance of a pixel in meters.

On the other hand, in order to know in which side the ball is located, it will suffice to subtract the value in pixels from the center of the image (in this case 160 because the image has a width of 320 pixels) the value 'x' of the center of the Ball, also in pixels. This gives a positive Y coordinate if 'x' is smaller than 160 and therefore is on the left of the center of the image, and a negative Y coordinate if the center of the ball is on the right. Finally, by multiplying the value obtained for the Y coordinate in pixels by the 'pixelToMeter' converter, is possible to know how far the ball is (in meters).

As before, figure 10 shows a schematic representation of this Y coordinate, marked 'Yrobot', so that it is not confused with the 'y' coordinate of the ball's center.

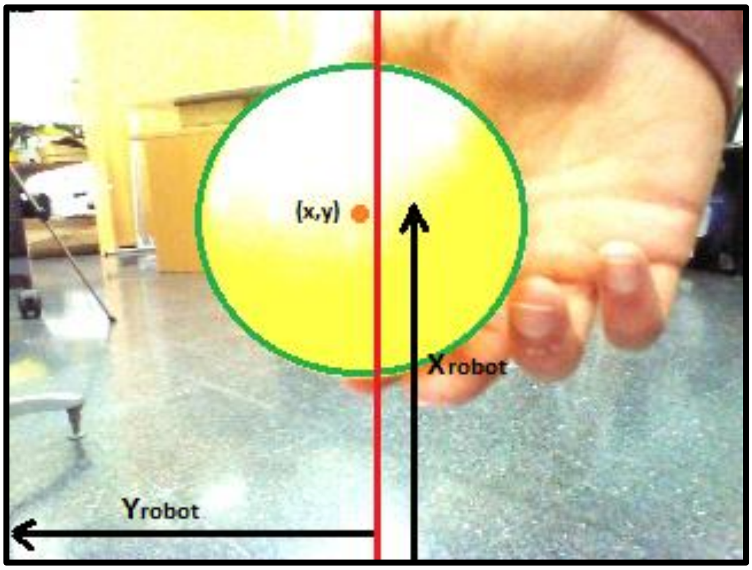


Figure 10 – X and Y coordinates representation.

• Z COORDINATE:

The height at which the ball is located will be estimated based on the inclination of the head of the robot when seeing the ball right in the center of the image. Therefore there is a step before this estimation, in which the robot adjusts the inclination of its head so that the center of the ball matches the image center. This inclination is given by the value of the HeadPitch joint and it varies from the way it was seen in figure 5.

Thus, from this value of inclination, it can be verified that there exists a linear relation with the height at which the ball is. The equation that governs this linear relationship is calculated, so that, from a given value of HeadPitch, the height or coordinate Z is automatically obtained. It must be taken into account that this height will be measured with respect to the coordinate axis located in the torso of the robot (figure 9), and not with respect to the ground.

To know the equation of the line that establishes the relation between the height and the inclination of the head the following has been done:

- Series of various measurements at different heights. The ranges of HeadPitch values obtained for each of the tested heights have been noted.
- The average HeadPitch values are obtained for each of the measured heights.
- Representation of the average values of HeadPitch for their respective values of height in a graph, proving that, when joining all the points, a line is obtained.
- Obtain the equation of the line that joins all the previous points.

Finally, and to finish this stage of location of the ball in the 3D space, all the calculated coordinates will be published as a point, so that that point is accessible for the final stage in which the ball is gripped.

4. GRIP OF THE BALL:

In this stage only the Z component of the published point will be used, due to the final position in which the robot has been placed before, which makes no necessary to make use of the X and Y components, although they are also published with a view to future applications and / or libraries.

The process of catching the ball can be summarized in 3 steps and is represented in figure 11:

• **Movement of the arms towards the ball but without catching it.** The arms are placed on both sides of the ball so that it is placed between both, but only to make a first approximation and verify that there are no localization errors.

• **Gripping the ball.** Movement of the arms towards each other so that the ball is caught between the hands of the robot, therefore, this step begins with the opening of the hands and continues with the approach of the arms until the capture.

• **Separation of the ball from its location.** Nao moves their arms up and towards its chest to avoid colliding with the table, shelf or place where the ball is located, and to gain stability when moving, since from this point it would be prepared to move with the ball caught in his hands.

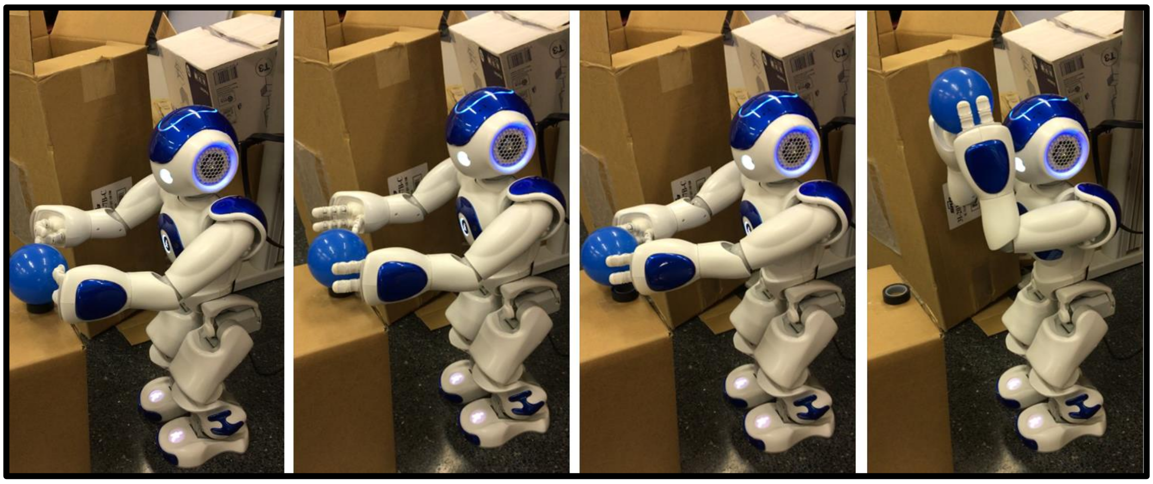


Figure 11 - Sequence of grip of the ball.