

# HUMAN-SCALE VIRTUAL REALITY CATCHING ROBOT SIMULATION

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**Abstract:** This paper presents a human-scale virtual reality catching robot simulation. The virtual robot catches a ball that users throw in its workspace. User interacts with the virtual robot using a large-scale bimanual haptic interface. This interface is used to track user's hands movements and to display weight and inertia of the virtual balls. Stereoscopic viewing, haptic and auditory feedbacks are provided to improve user's immersion and simulation realisms.

## 1 INTRODUCTION

Robotic researchers tried to solve the problem of catching moving object (dynamic problem) while basing themselves on the use a priori of the trajectory of the object to limit the calculating time.

Most of the proposed methods generally rest on the following stages:

- 1) the detection of the ball,
- 2) the determination since it is in flight,
- 3) the follow-up and the prediction of its trajectory
- 4) the economic planning and the execution of a movement of interception.

Indeed, the prediction of balls trajectories in a controlled environment (no wind, etc.) is based on a priori knowledge of characteristics of this type of movement and, on the collection of information about the displacement of the ball, before beginning to make a prediction on the trajectory followed by the object.

Virtual Reality (VR) is a computer-generated immersive environment with which users have real-time interactions that may involve visual feedback, 3D sound, haptic feedback, and even smell and taste (Burdea, 1996 ; Richard, 1999 ; Bohm, 1992 ; Chapin, 1992 ; Burdea, 1993 ; Sundgren, 1992 ; Papin, 2003). By providing both multi-modal

interaction techniques and multi-sensorial immersion, VR presents an exciting tool for simulation of (real) human – (virtual) robot interaction or cooperation. However, this requires a large-scale Virtual Environments (VEs) that provide efficient and multi-modal interaction techniques including multi-sensorial feedbacks.

## 2 HUMAN-SCALE VE

Our multi-modal VE is based on the SPIDAR interface (Figure 1). In this system, a total of 8 motors for both hands are placed surrounding the user (Sato, 2001). Motors mounted near the screen and behind the user; drive the strings attachments. One end of string attachment is wrapped around a pulley driven by a DC motor and the other is connected to the user's hand.

By controlling the tension and length of each string, the SPIDAR-H generates an appropriate force using four string attachments connected to a hand attachment. Since it is a string-based system, it has a transparent property so that the user can easily see the virtual world.

It also provides a space where the user can freely move around. The string attachments are soft, so there is no risk of the user hurting himself if he would get entangled in the strings. This human-scale

haptic device allows the user to manipulate virtual objects and to naturally convey object physical properties to the user's body. Stereoscopic images are displayed on a back-projected large screen (2m x 2,5m) and viewed using polarized glasses. A 5.1 immersive sound system is used for simulation realism, auditory feedback and sensorial immersion. Olfactory information can be provided using a battery of olfactory displays.

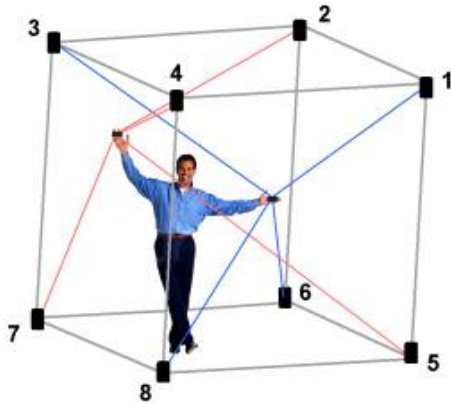


Figure 1: Workspace of the SPIDAR device.

### 3 CATCHING SIMULATION

#### 3.1 Virtual Room

The virtual room in which simulation takes place is a right-angled parallelepiped which consists of a ground, a left wall and a right wall. The ceiling is left open. A wood texture was added on each face to increase the depth perception, as well as the ball shadow.

This virtual room contains objects such as a virtual ball, virtual hands (right and left), and a virtual robot (a Kuka KR6).

All calculation are made in cartesian co-ordinates X, Y, Z, according to an orthonormed reference frame whose origin O is located at the middle of the floor. The Z axis is directed towards the user. The Y axis is directed upwards. The X axis is directed towards the right compared to the user view.



Figure 2: Snapshot of the robot reaching for the ball.

#### 3.2 Robot Modelling

The robot chosen here is Kuka KR6 model. It is an arm manipulator with 6 degrees of freedom, having only rotoids axes. It is placed at the bottom of the virtual room. Each part of the model was modelled in Discreet 3D Studio Max 7.0 and then imported into OpenGL. The robot consists of 6 rotoids axes whose angles are respectively  $q_1, q_2, q_3, q_4, q_5, q_6$ .

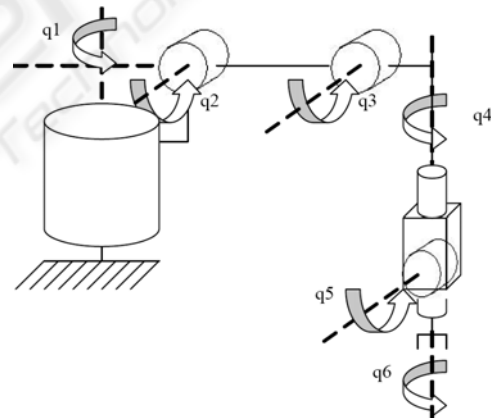


Figure 3: Illustration of the parameters used for the geometrical modelling of the Kuka KR6 robot.

To animate each robot part, elementary geometrical operations such as translations and rotations around the frame reference is used.

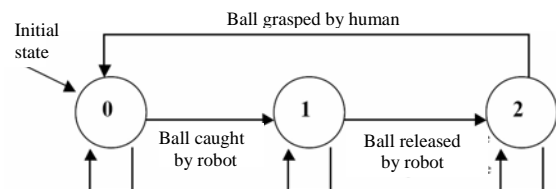


Figure 4: Finite state machine of the robot.

The virtual robot is subjected to the finite state machine given in figure 4. The various states are defined as follows:

**State 0:** the robot tries to catch the ball if in its workspace.

At the beginning of simulation, the robot waits until the ball is seized by the human operator, via the virtual hand, or till an external force is generated on the ball, to return to state 0.

**State 1:** the robot catches the ball if in state 0.

**State 2:** the robot releases the ball automatically, after a certain amount of time, and returns in its initial configuration.

The robot waits until the ball is grasped by the user (using one of the virtual hand) or till an external force is generated on the ball to return to state 0. Once the ball is caught, the robot automatically drops the ball and the simulation is reinitialised in its initial configuration.

The virtual ball is represented by a sphere and has a given mass "m", a given radius "R" and a given velocity "Vb" (or a Velocity Vector).

Assimilated to a single point which is the centre of the sphere, the ball is animated according to the fundamental law of dynamics:  $F=mA$ , i.e. the sum of the external forces  $F$  applied to the ball, is equal to the mass of the ball multiplied by acceleration.

Thus, the animation engine of the ball uses the following formulas:

$$\begin{aligned} \text{Force} &= \text{truncate}(\text{Force}, \text{max\_force}) \\ \text{Acceleration} &= \text{Force}/m \\ \text{Velocity} &= \text{Velocity} + \text{Acceleration} \\ \text{Velocity} &= \text{truncate}(\text{Velocity}, \text{max\_velocity}) \\ \text{Position} &= \text{Position} + \text{Velocity} \\ \text{Or Force} &= (F_x, F_y, F_z), \text{ Acceleration} = (A_x, A_y, A_z), \\ \text{Velocity} &= (V_x, V_y, V_z), \\ \text{Position} &= (P_x, P_y, P_z) \end{aligned}$$

"max\_force" is defined by the developer. It represents the maximum force that could be applied to the ball. Similarly, "max\_velocity" represents the maximum velocity that could be set to the ball. Thus one truncates the force by "max\_force" and velocity by "max\_velocity" to avoid reaching a force or velocity of oversized magnitudes.

In this way, a new position of the ball could be calculated at any time (more precisely according to the main loop of the simulation), when the ball is free (not caught by the robot or grasped by the user). The ball is subjected to the finite state machine given in fig.5.

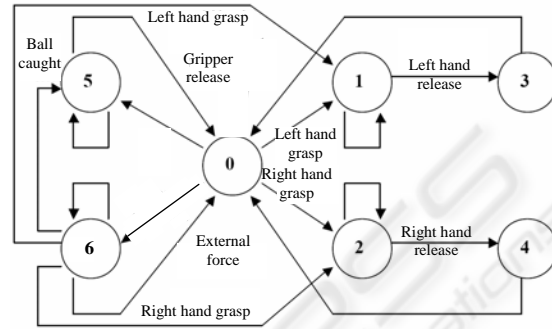


Figure 5: Finite state machine of the ball.

The various states are defined as follows:

**State 0:** the ball is free and is thus subjected to the animation engine described before.

**State 1:** the ball is caught by the left hand. The position of the ball is therefore directly linked to the position of this hand.

**State 2:** the ball is caught by the right hand. The position of the ball is therefore directly linked to the position of this hand.

**State 3:** the ball is released by the left hand. The position of the ball is no more established by the hand, but rather by the animation engine. The external Forces vector is equal, at this moment, to the hand velocity vector  $V_{mx}, V_{my}, V_{mz}$ .

**State 4:** the ball is released by the right hand. The position of the ball is no more established by the hand, but rather by the animation engine. The external Forces vector is equal, at this moment, to the hand velocity vector  $V_{mx}, V_{my}, V_{mz}$ .

**State 5:** the ball is caught by the robot. The position of the ball is no more established by the animation engine, but rather is a function of the robot gripper position.

**State 6:** the ball lies on the ground or closed to the ground. The Velocity vector magnitude is close to zero. The ball automatically moves to state 6, which is the end state and is immobilized on the ground.

User's hands position is tracked using the SPIDAR device.

A gain parameter between the user hand movements and the virtual hands can be introduced in order to enable him to increase his workspace. For example, it can be tuned so that the user can reach any location of the virtual room without moving too far from the centre of the SPIDAR frame of reference.

The closing of the virtual hand is carried out by the closing of a 5dt wireless data glove worn by the user (<http://www.5dt.com>). This could also be achieved using wireless mouses integrated to the SPIDAR device.

Each virtual hand is subjected to the finite state machine given in fig.6. The different states are defined as follows:

**State 0:** the left (respectively right) hand is open: it cannot grasp the ball.

**State 1:** the left (respectively right) hand is closed: it can grasp the ball if the latter is in state 0 or 6 or 1 (respectively 2).

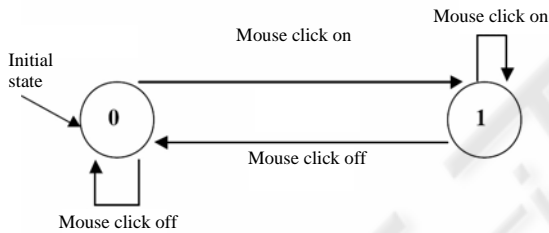


Figure 6: Finite state machine for both hands.

To do the ball grasping, a sphere of detection is used. Its size is defined by the designer and it is invisible during simulation. If the ball and the sphere are in contact, it is considered that the ball is seized, and the position of the ball is readjusted according to the hand.

### 3.3 Ball Launching

The virtual ball is thrown by the human operator, which can grasp and move it using the virtual hands. Once the ball is grasped, a method to launch the ball, corresponding to the animation engine, is proposed and validated. This method allows efficient velocity transfer of a user hand to the virtual ball.

To do this, hand velocity must be calculated. Thus an array of size S (S being defined by the designer),

is created and is used to record the hand position at each loop cycle of the main program loop.

Fig. 7 illustrates an example with an array of size  $S = 4$ . At the initialisation, the array is empty.

This method is easy to implement and is not CPU-time consuming. It gives good results to reproduce realistic "launched balls". However, this requires an optimisation of the size (S) of the array.

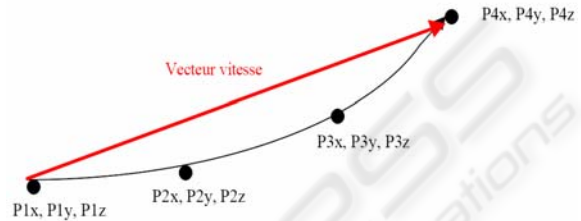


Figure 7: Illustration of the method proposed to efficiently launch the virtual ball with an array size  $S=4$ .

### 3.4 Ball Catching

Ball catching is achieved using a detection sphere of predefined size and invisible during the simulation. If the ball and the sphere are in contact, it is considered that the ball is caught. Then the ball position is readjusted according to the robot gripper position.

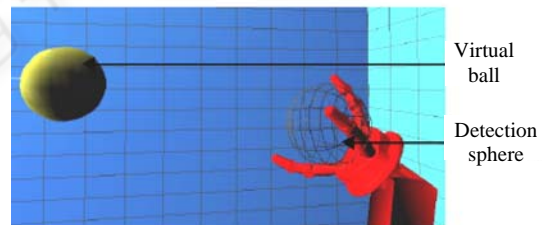


Figure 8: Illustration of the algorithm used for ball catching by the robot gripper.

This requires knowing both the cartesian position of the gripper according to the 6 angles  $q_1, q_2, q_3, q_4, q_5, q_6$  and the dimensions of each part of the robot. The gripper is subjected to the finite state machine illustrated on fig. 9.

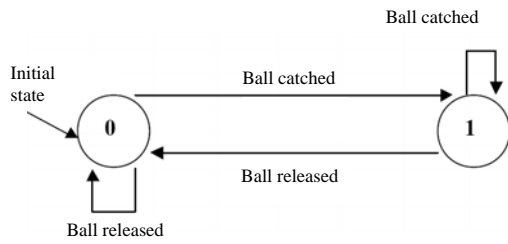


Figure 9: Finite state machine for the gripper.

The states of the gripper are defined as follows:

**State 0:** the gripper is open; the grip is open when the ball is not caught.

**State 1:** the gripper is closed; the grip is closed when the ball is caught.

In order for the robot to catch the ball, it is necessary to know: (1) the cartesian position of the gripper at any time according to the 6 angles  $q_1, q_2, q_3, q_4, q_5,$  and  $q_6$  of the robot and, (2) the Cartesian space reached by the robot (workspace). This is given by the direct geometrical model defined by  $X=f(Q)$ , with  $X=(x,y,z)$  and  $Q=(q_1,q_2,q_3,q_4,q_5,q_6)$ .

It is also necessary to know the value of the 6 angles of the robot, according to the Cartesian position of the gripper  $(X, Y, Z)$ . The inverse geometrical model can obtain these.

Thus, it can be resolved by determining the joint coordinates  $Q$  making it possible to obtain a desired location for the gripper specified by the space coordinates.

Here, we are confronted with a system of 3 equations with 6 unknown variables. To solve this system, the method proposed by Paul (1981) was used. This method allows obtaining the whole solutions set, when they exist.

In our simulation, the robot always faces the ball. However, it will carry out a catching movement towards the ball only if the latter is in its workspace, defined by the whole set of points in the Cartesian space that the robot gripper can reach.

Under the hypotheses that the robot can reach all the points of its workspace at any time, and that there is no constraint on the rotation angles of the joint, the workspace of the robot is a TORE defined by equation 3.

$$(\sqrt{(x^2 + z^2)} - A)^2 + y^2 = R^2 \tag{3}$$

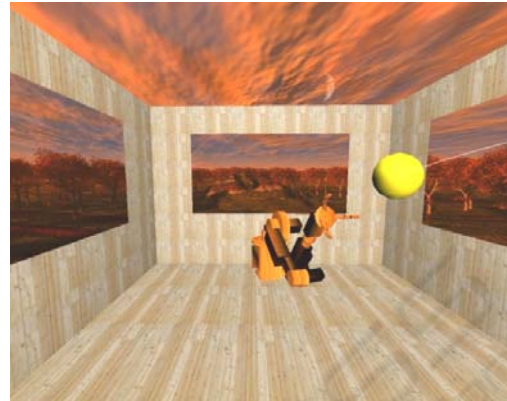


Figure 10: Snapshot of the robot oriented towards the ball.



Figure 11: Snapshot of the robot realising the ball.

## 4 CONCLUSION

We presented a human-scale virtual reality catching robot simulation.. The user interacts with a virtual robot by throwing virtual balls towards it, using a large-scale bimanual haptic interface. The interface is used to track user’s hands movements and to display various aspects of force feedback associated mainly with contact, weight, and inertia. We presented the robot modelling, as well as the ball launching and catching procedures.

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