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Master thesis

Simulation of complex actuators

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Abstract

Lorem ipsum dolor...

Acknowledgements

I would like to express my sincere thanks to all those who provided me the possibility to complete this thesis.

First of all, I thank the professor B. Boigelot who made this thesis possible and helped me on various occasions.

I also wish to thank Grégory Di Carlo and Guillaume Lempereur, my fellow students who also worked on the robot.

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Chapter 1

Introduction

1.1 Context

For the last ten years, Montefiore has been participating in a robotic contest named *Eurobot*, where wheeled robots battle each other for points in various play environments. After some success, it was decided to move on to a more difficult contest, *Robocup*.

This contest is quite vast and divided into several categories :

- Robocup Rescue : a category where robots are must perform various rescue operations in diverse scenarios.
- RoboCup Industrial : a category with industrially oriented competitions.
- RoboCup@Home : a league for domestic robots. This category has a social aspect to it.
- RoboCupJunior : more of an initiative that aims to foster robotics interest in children rather than a contest, it helps organize various robotics events for younger minds.
- RoboCup Soccer : historically the first category, centred about humanoid robots playing football in small teams. The objective of this category is to have a team of robots beat the world champions by 2050. This is the league we will compete in.

Robocup Soccer is further subdivided into 4 sub-categories :

- Standard platform, where the teams all use the same robot(Nao).
- Adultsize, for the taller robots
- Teensize, for middle sized robots
- Kidsize, for the smaller robots.

This year's team is preparing to participate to the Kidsize subcategory of the Robocup Soccer category. This master thesis is the by-product of that team's activity.

Since Montefiore is participating for the first time we are nearly starting from scratch and we don't really know how to build a good humanoid robot. In order to not

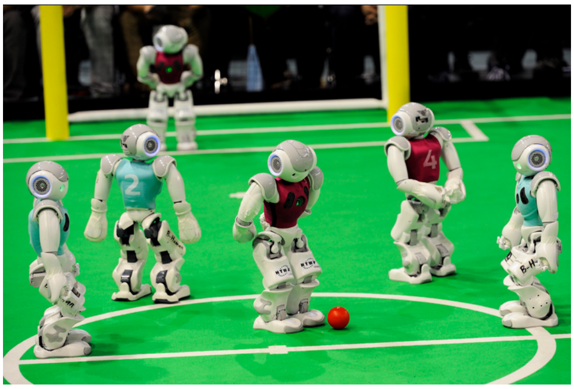


Figure 1.1: Two teams of Nao robots playing against each other in the 2014 edition of RoboCup Soccer standard platform league*[Photo courtesy of RoboCup]*

spend countless hours building and testing different designs we need a tool able of simulating the physics of a robot model.

In particular, we want to use it to :

1. Test different robot designs and choose the best one, faster than it would be done by building the designs in real life.
2. At a later stage, be able to test control algorithms faster because the real robot is not needed.

1.2 Goals of the project

The goal of this thesis is to provide the team with a simulation tool that provides the following features :

- realistically simulate the physics of objects including inertias, frictions, collisions and more.
- receive and process orders incoming at a relatively high frequency. The processing need not be in real-time.
- we want to use this simulator to test the code that would run on the real robot. That is, the simulator should provide the same interface to the code as the robot would.
- visualize the results of the simulation.

1.3 Structure of the report

This report begins with an overview of the basics of physics simulation on computers before moving to the chapter that motivates the choice of V-Rep as the main simulation tool for this project.

Then, an in-depth presentation of V-Rep and Blender will be made in chapter 4, before detailing some experiments that were made to verify and improve the accurateness of the model.

Chapter 6 goes into the core of the subject with some simulations that influenced the design of the robot before being used to explore control strategies.

The last chapter will conclude the work by summing up and laying out future prospects.

Chapter 2

Principles of interactive rigid body simulation

This chapter briefly introduces the basic concepts of physics engines. We restrict ourselves to the simulation of rigid bodies, which is a significant simplification of the problem since rigid bodies are idealized solid objects which never change shape.

2.1 Problem statement

Physics engine trouble themselves with the simulation of classical mechanics in a computer. They model how objects accelerate, move and react to collisions with other objects. They also model how objects can be constrained to each other, for example with a hinge and how that influences them.

2.1.1 Notations and definitions

- $a \cdot b$ denotes the product of scalars a and b.
- $\mathbf{a} \cdot \mathbf{b}$ denotes the product of vectors $\mathbf{a}$ and $\mathbf{b}$.
- $\mathbf{a} \times \mathbf{b}$ denotes the cross product of vectors $\mathbf{a}$ and $\mathbf{b}$.
- A **mesh** is a 3D object made of vertices, edges and faces.
- A **convex mesh** is a mesh whose internal angles are all less or equal to 180°.

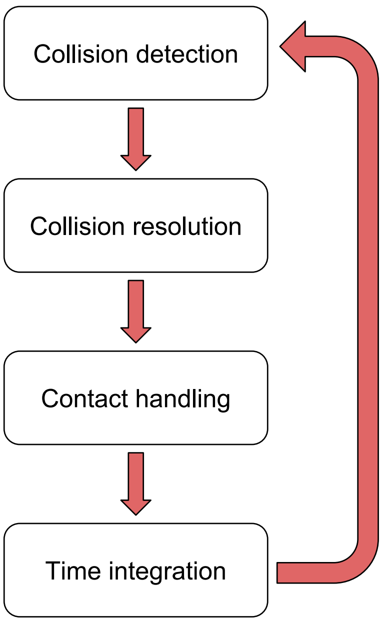
2.2 Principles of rigid body dynamics simulation

The section is heavily inspired by Bender's [?] state of the art paper on rigid body simulation. The simulation of rigid body dynamics is usually built around the loop presented in fig. 2.1a. The simulator begins by finding the collision points between objects (Collision detection). These points are used to derive motion laws which are solved to determine the forces that act on the objects and prevent them from inter-penetrating (Contact handling). Newly found contact points imply collisions, which generate infinite impulse forces, which are handled by collision resolution.

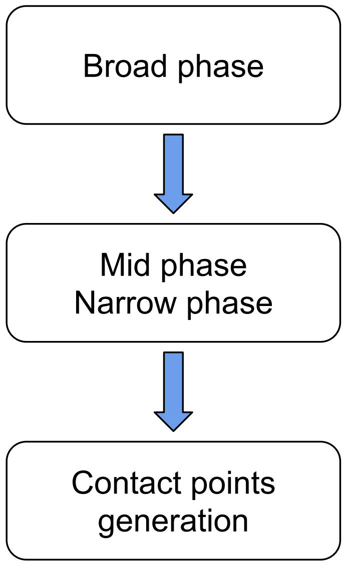
When all the contact forces have been computed, the position and velocities of the bodies are integrated forward in time before a new iteration starts.

Rigid body simulation is achieved through the expression of the Newton-Euler laws as differential equations which are then augmented with equations that express 3 conditions : nonpenetration of bodies, the friction model, and certain disjunctive relationships between variables (a contact force must become zero if two bodies separate, the friction forces acts in the direction that will most quickly stop the sliding).

This yields a differential nonlinear complementarity problem (dNCP) that cannot be solved in closed form. It is discretized in time producing a series of NCPs whose solutions are an approximation of the state of the system. This discrete solution is usually found by linearizing the NCP into a LCP to take advantage of the rich background for that type of problems.



(a) Modular description of the simulation loop of a physics engine



(b) Modular description of the collision detection in a physics engine.

Figure 2.1: Modular phase description of the sub tasks of a rigid body simulator. The mid phase and narrow phase are grouped together because they are often combined for performance reasons

2.3 Collision detection

Collision detect is broken into three phases called the broad phase, the mid phase and the narrow phase.

During the broad phase, objects are approximated by simple geometric primitives. Distances between such geometric shapes are easy to compute. Spheres are usually used. If such spheres do not overlap, then neither do the actual objects.

When an object has a complex shape, an additional phase called the mid phase separates the object into several simpler shapes to detect collisions. Finally the narrow phase uses the exact geometries of the object to find the contact points. These are then returned to the simulation model.

2.4 Kinematics

The position of an object in a 3D space is given by a vector $p \in R^3$ from the origin of an inertial frame to the body fixed frame.

The orientation of an object in a 3D space can be represented in different ways. Usually it represented by either Euler angles or unit quaternions (Q_s, Q_x, Q_y, Q_z)

The translational velocity is usually noted $\mathbf{v} \in \mathcal{R}^3$. The rotational velocity $\mathbf{w} \in \mathcal{R}^3$ describes the rate at which the body rotates.

If $\mathbf{q} = (p, Q)^T$ the differential equation of motion can be written as

$$\dot{\mathbf{q}} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -Q_x & -Q_y & -Q_z \\ 0 & 0 & 0 & Q_s & Q_z & -Q_y \\ 0 & 0 & 0 & -Q_z & Q_s & Q_x \\ 0 & 0 & 0 & Q_y & -Q_x & Q_s \end{pmatrix} \begin{pmatrix} v_x \\ v_y \\ v_z \\ \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$$

2.5 Newton-Euler

The Newton-Euler equations describe how forces and moments modify the velocities of an object.

$$m\dot{\mathbf{v}} = \mathbf{f} \tag{2.1}$$

$$\mathbf{I}\dot{\omega} + \omega \times \mathbf{I}\omega = \tau \tag{2.2}$$

Chapter 3

Choosing the tools

In this chapter we present the reasons for choosing V-Rep as the simulator and Blender as the modelling tool for this project.

3.1 Problem statement

We want to find a simulation tool able of simulating physics elements such as inertias, frictions, collisions, joints (hinge, spring-dampers). We also want to get some feedback from the simulation, like acceleration of the objects and their position. Simulation of vision sensors would be a plus, but is not the primary selection criterion. We also want to keep the control code separated from the simulation.

3.2 Available tools

3.2.1 Barebone physics engines

The physics engine is the cornerstone of a physics simulation tool. There exist a quantity of them, we present here the most popular ones that have the the following features' set : multi rigid body dynamics, collision detection, joints (hinge, spring-dampers, generic 6DOF[1]).

1. **Bullet:** As of now, it is the most popular open source physics engine. Primarily used for games[2] it is also used in more serious applications such as Blender, V-Rep or NASA's tensegrity robotics toolkit.

2. **ODE:** Open source, a little older that Bullet. As it was already mature when simulators started to be developed, it is present in a lot of robotics simulation tools (V-Rep, Webots, Gazebo...). It was also designed with games in mind but was influenced by its success in more serious applications.

3. **Newton:** Another open source engine, not quite as popular as Bullet and ODE but nevertheless used for commercial games and simulation. What makes it

[1]DOF : degree of freedom

[2]Most notably in the Grand Theft Auto(GTA) games series

stand out in the crowd is its deterministic constraint solver, as opposed to iterative solvers used by Bullet and ODE.

4. **PhysX & Havok:** Both are proprietary engines used primarily for games. They won't be further discussed because their focus is on speed rather than accurateness and as such they cannot be used in a simulation that aims to be realistic, as stated by Erez *et al* in [**?**].

3.2.2 Simulators

In this section we will speak of software that provides a higher level interface to the physics engines we presented earlier. That interface usually adds a visualization and some other useful features.

1. **Blender**[3] is 3D modelling software suite and as such has integrated the Bullet engine to help make more realistic animations. It features the ability to make Python scripts that use that engine to make games or physics simulations.

   It is open source and cross platform.

2. **Gazebo**[4] is the official simulator for the DARPA Atlas challenge. It features multiple physics engines (Bullet ,Simbody, Dart and ODE), allows custom plugins and uses the SDF format for its models.

   It is open source and runs natively on Linux systems but needs to be compiled in order to run on Windows or OSX.

3. **V-Rep**[5] is another simulator that lets you choose the physics engine(Bullet, ODE, Newton, Vortex) and it also allows custom plugins in the form of LUA scripts. It uses its own format for storing models but can import standard formats(COLLADA, 3ds, etc...).

   It is cross-platform and free to use for educational purposes.

4. **Webots**[6] has virtually the same features as V-Rep.

   It is cross platform but not free.

5. **Matlab** is not a dedicated robotics simulator *per se* but can be used to model the robot analytically and to write simulation code for it.

A summary of the features of each simulator is present on table 3.1.

3.3 Tested software

In this section we try some of the proposals presented previously and give our thoughts on them. We will mainly look at the modelling facilities and the access to the underlying simulation options as all the proposed tools possess the required simulation capabilities and are able to deliver similar looking results.

[3] https://www.blender.org/ [Accessed 21/05/2016]
[4] http://gazebosim.org/ [Accessed 21/05/2016]
[5] http://www.coppeliarobotics.com/ [Accessed 21/05/2016]
[6] https://www.cyberbotics.com/ [Accessed 21/05/2016]

Simulator	License	Physics engine(s)	Integrated editor	Modelling
Blender	Free	Bullet	Fully fledged	Internal
V-REP	Free	Bullet, ODE, Newton, Vortex(10s limit)	Limited	Can import .COLLADA
Gazebo	Free	Bullet, ODE, Simbody, DART	Limited	SDF format
Webots	Proprietary	ODE	None	SDF format
Matlab	Proprietary	None	None	Mathematical

Table 3.1: Comparison of simulators

3.3.1 Blender

Blender is pleasant to use because the robot's model can be easily changed inside it and the fact that the scripting language is Python make for faster development. Support for a socket allows an external program to control the simulation and the robot inside it. The internals of the physics are obscured and some interesting object properties, such as inertias, are hard to reach. It is also hard to change the simulation parameters making it difficult to obtain stable results when using a higher number of objects and constraints. Furthermore, support for the game engine, the basis of a simulation project, is uncertain, as stated in this development [?].

Pros :

- Easy modelling of the elements.
- The Python API is well documented.

Cons :

- Bullet's simulation parameters are hidden behind an incomplete interface, making it impossible to modify the timestep or the number of iterations for constraint solving.
- Friction parameter not a physical value but a value between 0 and 1.
- Inertias are approximated by the principal values Ixx, Iyy and Izz.

3.3.2 Gazebo

Gazebo is attractive because it has the support of DARPA and handles multiple physics engines. The main drawback lies in the modelling of the robot to be simulated. It does feature an internal modelling tool but it is too limited to be usable. That would not be a problem if it could import models easily but that is not the case, it uses an xml file to store the parameters of the robot and the only tool that can export models to that format is 3ds max, a commercial product. The team behind Gazebo seems to be well-aware that this is an issue since as of May 2015 it is focusing on developing an internal model editor.

Pros :

- Gives the choice of the physics engine.
- Inertias definable as a matrix.
- Friction represented in physical values.

Cons :

- Internal model editor prohibitively limited, cannot be used to create a complicated model. It cannot import popular CAD formats.
- Uses the SDF[7] format to store models, making it hard to iterate over robot designs.

3.3.3 V-Rep

V-Rep also has multiple physics engines available and has a user-friendly interface. It also has an internal modelling tool but there is not much use for it since it allows the import of models in the COLLADA format. It also supports socket communication and even provides code for a client thread in the custom application. The options of the physics engines are also pretty accessible and lots of sensor types are natively supported by the simulator.

Pros :

- Gives the choice of the physics engine.
- Inertias correctly definable.
- Friction represented in physical values.
- Already used at the university.

Cons :

- Limited internal editor, can hardly be used for modelling.

3.4 Choice

The first choice to be made is whether we go for a barebone physics engines or a simulator: the former has the advantage of being a highly customizable solution but a simulator provides features a physics engines does not :

- 3D visualization
- code handling the import of models
- a remote API

All these functionalities would eventually be necessary so a simulator is preferred.

From the available simulators(Blender, Gazebo and V-Rep) the best seems to be V-Rep. This choice is further confirmed by Ivaldi in [**?**] who shows that V-Rep is the highest noted tools amongst roboticists.

[7] A XML file

Inside V-Rep, we chose Newton Dynamics as the physics engine because simple tests showed it to be the most stable with a high number of joints[8]. That choice is further confirmed by Hummel *et al* in [**?**] where Newton Dynamics is stated to be the best engine when it comes to handling a high number of constraints.

Although Blender was not chosen as the primary simulation tool for the project, it shall be used as a modelling tool for the robot, as a complement for V-Rep.

[8]with the exception of Vortex but it requires a license to run more than $10s$

Chapter 4

Modelling the basic elements of a robot

This chapter covers the modelling of the building blocks of the robot.

4.1 Problem statement

Our robot will be made from a number of elements that all need to be represented in the simulation :

– cameras

– hands, feet, electronics

– servos

4.2 Basic Modelling

4.2.1 Convex elements

A convex element is an element which has a convex shape, that is, all its interior angles are less or equal to 180°. Our humanoid robot will have some number of them since a lot of elements can be approximated as cubes, which are convex.

The modelling consists in creating a mesh with the right dimensions, setting the mass and setting the inertia (V-Rep does not feature matrix inertias, only principal axes inertias). Friction of the material can also be set and will influence how much an object will slide.

4.2.2 Concave elements

A shape is concave if it is not convex. It is not recommended to use concave shapes in a simulation as they make collision detection more expensive and the simulation is generally more unstable.

Therefore, the modelling consists in approximating such a shape by several convex shapes, linked together.

4.3 Applied to the building of a humanoid robot

4.3.1 Feet

The shape of the feet is not fixed yet but it is safe to approximate them by a convex shape with high friction.

4.3.2 Frames

The frames in use, FR07-H101 are convex and are thus decomposed into into convex shapes that are linked together.

4.3.3 Eletronics

Electronics

4.3.4 Cameras

Cameras are modelled as cubes. Their function is performed by vision sensors handled by V-Rep.

Figure 4.1: LI-USB30-M021C camera, to be used in the robot.

4.3.5 Servos

The robot will mainly be made from MX-28R servos, manufactured by Dynamixel. Their size and power make them an good choice for a humanoid robot. The goal of this section is thus to reproduce as accurately as possible the behaviour of this servo in our simulation.

The MX-28R outer shape is convex so we can create a convex mesh to model its appearance. Its mass and inertias can be set to $77g$ and

$$IxxIyyIzz = ($$

(a) MX-28R servo. **(b)** Model of the MX-28R.

Figure 4.2: Side by side of a MX-28R servo and its 3D model. The shape has been simplified but retains outer appearance of the servo. The axis is used as a position marker and will be removed once the joints are in place.

	Data	**Unit**
Weight	77	g
Dimension	$35.6 \times 50.6 \times 35.5$	mm^3
Inertia around main axes	$\begin{pmatrix} 33,765 & 12,900 & 28,821 \end{pmatrix}$	$g \times mm^4$
Stall torque	2.5	Nm
Nominal torque	0.7	Nm

Table 4.1: Characteristics of a MX-28R type servo. Data taken from [**?**]

The torque of the servos is computed from the maximal torque of the DC motor and the reduction ratio of the gears.

$$\begin{aligned} Torque &= TorqueMotor \times ReductionRatio \\ &= 3.67e^{-3} \times 193 \\ &= 0.7083Nm \end{aligned}$$

4.3.6 Springs

```lua
-- init: true when this callback is called for the first time
-- revolute: true if the joint is revolute
-- cyclic: true if the joint is revolute and cyclic (i.e. no lower/upper limits)
-- currentPos: the current position of the joint
-- targetPos: the desired position of the joint
-- errorValue
-- effort: the last force or torque that acted on this joint along/around its axis
-- dynStepSize: the step size used for the dynamics calculations
-- lowLimit: the joint lower limit
-- highLimit: the joint upper limit
-- targetVel: the joint target velocity
-- maxForceTorque: the joint maximum force/torque
-- velUpperLimit: the joint velocity upper limit

if not PID_P then
    PID_P=0.1
    PID_I=0
    PID_D=0
end

if init then
    pidCumulativeErrorForIntegralParam=0
end
ctrl = errorValue*PID_P

if PID_I ~=0 then
    pidCumulativeError = pidCumulativeError+errorValue*dynStepSize
else
    pidCumulativeErrorForIntegralParam=0
end

ctrl=ctrl+pidCumulativeError*PID_I
if not init then
    ctrl=ctrl+(errorValue-pidLastError)*PID_D/dynStepSize
end
pidLastError=errorValue

velocityToApply=ctrl/dynStepSize
if (velocityToApply>velUpperLimit) then
    velocityToApply=velUpperLimit
end
if (velocityToApply<-velUpperLimit) then
    velocityToApply=-velUpperLimit
end
forceOrTorqueToApply=maxForceTorque

return forceOrTorqueToApply,velocityToApply
```


Listing 4.1: Control code of the servo

Chapter 5

Physical validation

In this chapter experiments with real servos will be conducted in order to, firstly, tune the parameters of the simulation (servo's characteristics) and, secondly, verify that the simulation correctly predicts the behaviour of a real-life configuration.

5.1 Problem statement

Before using our simulator to test control algorithms it is useful to first verify that it gives physically accurate results. It would be a waste of time to conduct tests on a model that does not behave in the same way as the original does.

5.2 Experimental set-up

The set-up is explained on fig. 5.1. In later experiments a camera will be used to film the motion of the servos and compare it to the results of the simulation that is supposed to predict it.

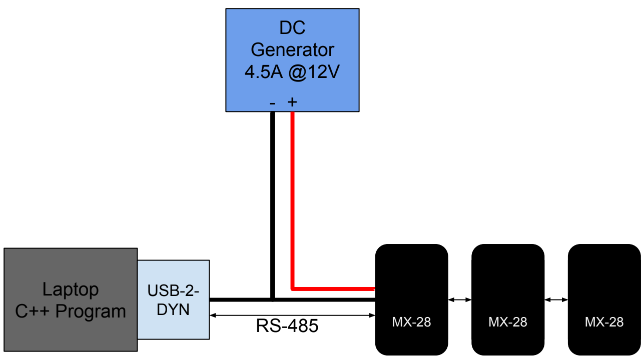


Figure 5.1: Experimental setup : The MX-28 servos are powered by a DC generator and controlled by a laptop equipped with a USB2DYNAMIXEL(USB-2-DYN) device. It converts an USB port into a serial port.

5.3 Experiment 1

The purpose of the first experiment is to test the torque : to that end, a frame is fixed onto a single servo and weighted. The setup is represented on fig. 5.2.

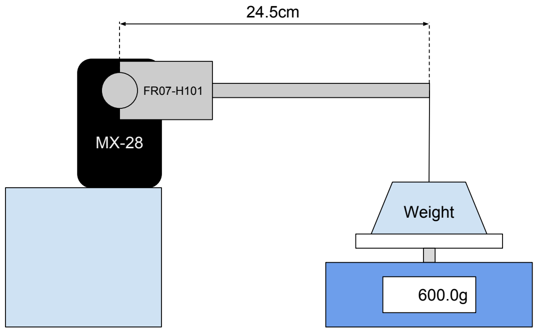


Figure 5.2: Experimental setup for torque testing. A weight w of is suspended at a distance d from the servo, resulting in a applied torque of $w \times g \times d$. The goal consists in finding the weight w for which the servo is unable to lift the arm.

In our case, d was equal to $22.5cm$ and we could reach a weight w of $740g$ at $14.8V$. This equals to a torque of $1.64Ncm$. The complete results are listed in table 5.1.

	Stall torque @11.1V $[N.m]$	**Stall torque @12V** $[N.m]$	**Stall torque @14.8V** $[N.m]$
Theoretical	2.1	2.5	3.1
Experimental			1.6

Table 5.1: Experimental stall torques at different tested voltages. Theoretical values taken from [?]

.

5.4 Experiment 2

In this experiment we will test some simple dynamics. The setup is on fig. 5.3.

5.5 Conclusion

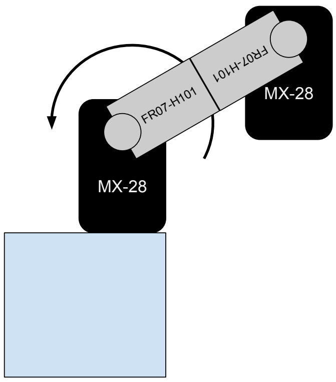


Figure 5.3: Experimental setup for dynamics testing. Two servos are connected together

Chapter 6

Applications

In this chapter we explain how to use the simulator and it influenced the design of our humanoid robot.

6.1 Overview of the simulation setup

V-Rep is used to simulate the physics of the robot but the control code runs alongside and not inside V-Rep. This is possible because V-Rep runs a server thread which can process specific instructions[1] sent by a client thread. This gives us great implementation flexibility and we can substitute the real robot by the simulation model easily. This is represented on fig. 6.1.

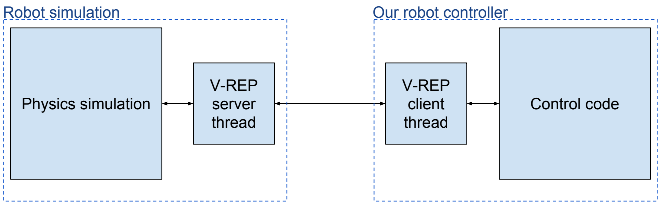


Figure 6.1: V-Rep simulates the robot while an external program sends order to the robot over TCP/IP thanks to the client/server thread provided by V-Rep.

Furthermore, the simulation will operate in the synchronous operation mode. That is, each simulation timestep must be triggered by the control code, allowing precise control of the robot. Figure 6.2 presents how V-Rep and the control code interact in synchronous mode.

The instructions available can execute a number of different actions. The following proved most useful for this project :

- simxGetObjectHandle : this function is used to retrieve a handle on an object. A handle is necessary if a user wants to perform operations on an object.
- simxSetJointTargetPosition : this function sets a target position for a joint.

[1]An alphabetical list of those instructions can be found on http://www.coppeliarobotics.com/helpFiles/en/remoteApiFunctionListAlphabetical.htm

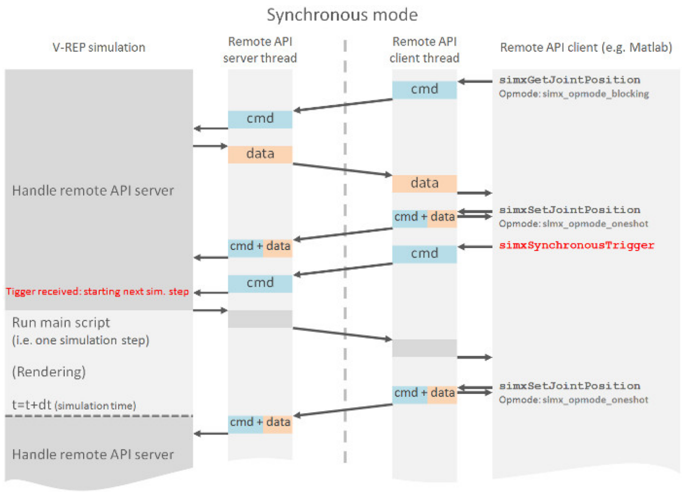


Figure 6.2: Typical interaction between the simulator and the control code. The simulation runs on two threads : the simulation and the server thread. The server threads can receive orders from a client thread which is controlled by a custom application of our own. The simulator waits for a trigger before simulating the next timestep.

- simxSetFloatSignal : this function gives the possibility of setting the value of a signal inside V-Rep. This is useful if we want to extend the interface that V-Rep provides.
- simxGetFloatSignal : this function retrieves the value of a float signal.

6.2 Applications

6.2.1 Static stability

The first application is simply to build a model of the robot and test if it is able to stand upright on its own.

The modelling begins in Blender where pieces are simplified/made convex and placed to create the structure of the robot. The model is then exported (in COLLADA) and imported into V-Rep.

The feet are approximated by a thicker block in order to help with the collision detection. They are also given a high friction.

The torque of the servos is computed from the maximal torque of the DC motor and the reduction ratio of the gears.

$$\begin{aligned} Torque &= TorqueMotor \times ReductionRatio \\ &= 3.67e^{-3} \times 193 \\ &= 0.7083Nm \end{aligned}$$

In section 5.3 we determined that the maximum torque the servo was actually able to produce was $1.7Nm$ so to represent this we choose to set the maximum torque of the servos to $1Nm$.

```
function simulation_client_vrep()

disp('Program started');
vrep = remApi('remoteApi'); % use the prototype file
vrep.simxFinish(-1); % close all opened connections
clientID = vrep.simxStart('127.0.0.1', 19997, true, true,
    5000, 5);

if clientID < 0
    disp('Failed connecting to remote API server. Exiting
       .');
    vrep.delete();
    return;
end
disp('Connected to remote API server');

% Make sure we close the connexion whenever the script is
    interrupted.
cleanupObj = onCleanup(@() cleanup_vrep(vrep, clientID));

% Set the remote mode to 'synchronous'
vrep.simxSynchronous(clientID, true);

% retrieve handles to servos, joints
h = robot_init(vrep, clientID);

% start the simulation
vrep.simxStartSimulation(clientID, vrep.
   simx_opmode_oneshot_wait);

t = 0;
dt = 0.1; %timestep of the simulation
while true && t < 3
    instructions = standup_prone(h, t);
    send_instructions(vrep, clientID, instructions);
    t = t + dt;
end

% Before closing the connection to V-REP, make sure that
   the last command sent out had time to arrive.
vrep.simxGetPingTime(clientID);

% Now close the connection to V-REP:
vrep.simxStopSimulation(clientID, vrep.
   simx_opmode_oneshot_wait);
vrep.simxFinish(clientID);
vrep.delete(); % call the destructor!
disp('Program ended');
end
```

Listing 6.1: Minimal example code that connects to the server, gets the handles and implements a basic control loop

In V-Rep the different elements of the robot are dynamically enabled and given mass, accordingly to the values listed in table 6.1. Then, joints (motor controlled with control loop activated) are added to simulate the behaviour of the servos. Their maximal torque is set to 1.6, the maximum torque developed my Mx-28 servos as shown by our earlier experiments (table 5.1).

Module	**Weight** $[g]$	**Density** $[kg/m^3]$	**Dimensions** $[mm \times mm \times mm]$
Odroid C-2	40		85.0 x 56.0 x 10.0
Li-Po battery	188	2304	103.0 x 33.0 x 24.0
Mx-28R	72	1150	35.6 x 50.6 x 35.5
LI-USB30-M021C	22	2200	26.0 x 26.0 x 14.7
Frame Fr-07		1200	
Frame Fr-101-H3	7	1200	

Table 6.1: Weights and dimensions of the pieces of the robot. The density is useful for the automatic computation of the weight and inertia of the pieces in V-REP.

The springs on the leg are simulated by two spherical joints and one prismatic joint set to spring-damper mode.

The servos of the robot are simply ordered to hold their initial angle and the simulation determines that the robot can indeed stand upright without any active stabilization.

6.2.2 Standing up routines

This section is heavily inspired by [?]

6.2.3 Walking

6.3 Influence on robot's design

The simulator helped shape the robot through simulations that unveiled serious design problems (inability to stand after a fall, inability to walk).

The first design is visible on fig. 6.3. It was plagued by stability problems, overcomplicated arms and simulation difficulties.

The final design, visible on fig. 6.4 has better stability, wider movement possibilities and can stand up and walk more easily.

The final dimensions of the robot respect the rules of the contest:

- Height : $61.3cm$
- Height of COM : $34cm$
- Height of legs : cm
- Height max is $< 1.5 \times 61.3$.

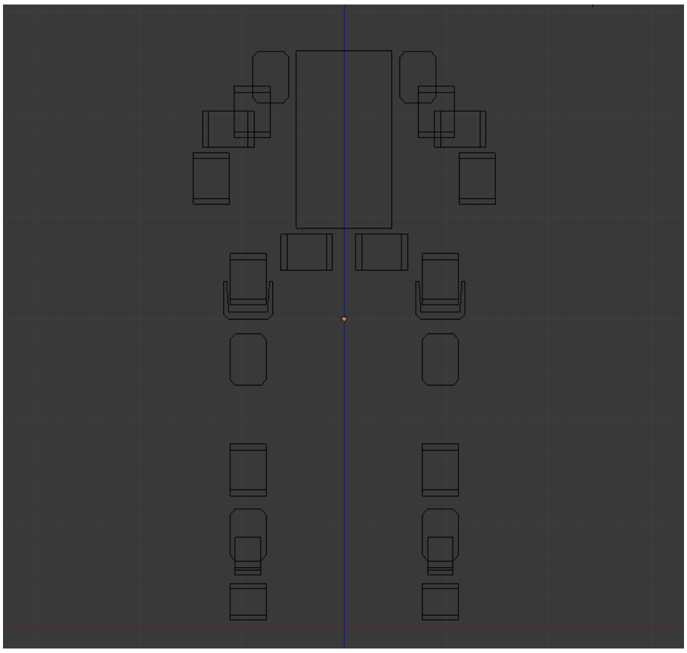


Figure 6.3: First robot design. Arms use 4 servos each, making it quite heavy.

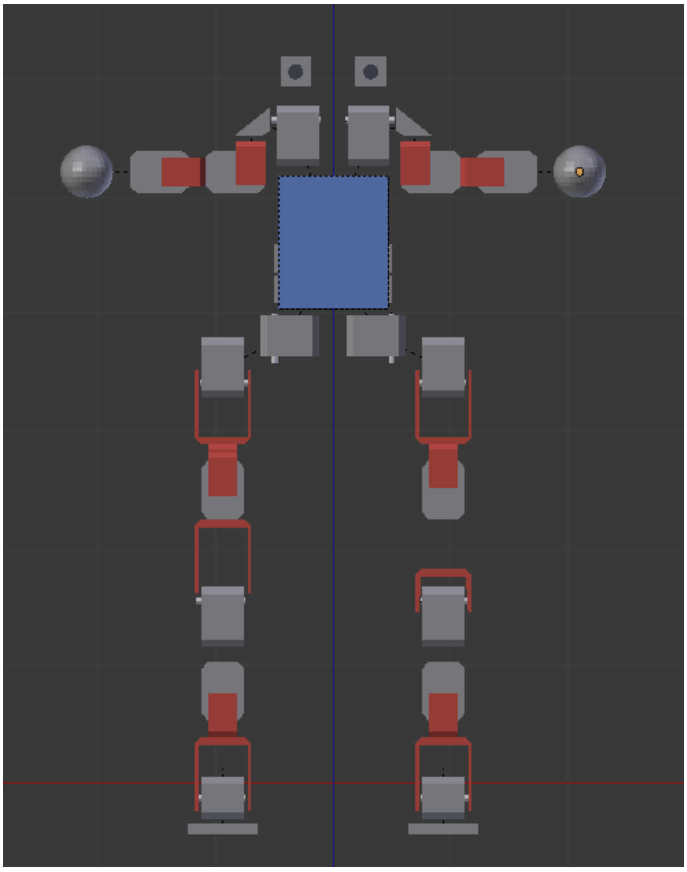


Figure 6.4: Final robot design. Arms now use 3 servos. The feet and the hips use a different configuration to have wider movement possibilities and bring down the center of gravity.

– Foot area is cm^2.

Chapter 7

Conclusion

7.1 Conclusion

This is the conclusion to my work.

7.2 Future work

7.2.1 Modelling

As of now it is still uncertain if Blender shall continue to support the COLLADA format (as explained in [**?**]). In the negative, another tool should be chosen to perform the modelling.

The springs also need some work, as of now they are just there as a proof of concept but their parameters will need to be tuned.

As of now, the model uses simplified inertias, in the belief that a controller should be able to correct minor differences in behaviour between the model and the actual robot. In the case, theses inertias need to be more accurate, we suggest to use Meshlab[1] to compute the inertias of those objects.

[1] http://meshlab.sourceforge.net/

Appendix A

Rules

The robots that participate in the kidsize competition must respect the following characteristics[**?**]:

1. $40cm \leq H_{top} \leq 90cm$.
2. Maximum allowed weight is $20kg$.
3. Each foot must fit into a rectangle of area $(2.2 \cdot H_{com})^2/32$.
4. Considering the rectangle enclosing the convex hull of the foot, the ratio between the longest side of the rectangle and the shortest one, shall not exceed 2.5.
5. The robot must fit into a cylinder of diameter $0.55 \cdot H_{top}$.
6. The sum of the lengths of the two arms and the width of the tor so at the shoulder must be less than $1.2 \cdot H_{top}$. The length of an arm is defined as the sum of the maximum length of any link that forms part of the arm. Both arms must be the same length.
7. The robot does not possess a configuration where it is extended longer than $1.5 \cdot H_{top}$.
8. The length of the legs H_{leg}, including the feet, satisfies $0.35 \cdot H_{top} \leq H_{leg} \leq 0.7 \cdot H_{top}$.
9. The height of the head H_{head}, including the neck, satisfies $0.05 \cdot H_{top} \leq H_{head} \leq 0.25 \cdot H_{top}$. H_{head} is defined as the vertical distance from the axis of the first arm joint at the shoulder to the top of the head.
10. The leg length is measured while the robot is standing up straight. The length is measured from the first rotating joint where its axis lies in the plane parallel to the standing ground to the tip of the foot.

Appendix B

Design guidelines

For a dynamic simulation several design restrictions must be considered :

– use pure convex as much as possible, they are much more stable and faster to simulate. When a more complex shape is used, approximate it with several convex shapes.

– use reasonable sizes, neither not too small nor too big. Thin shapes may behave strangely.

– when using joints, keep the ratio of the masses below 10. Otherwise, the joint may have large orientation/position errors.