A ROS-based Workspace Control and Trajectory Planner for a Seven Degrees Of Freedom Robotic Arm

Software interfaces for Obstacle Avoidance, OctoMap Visual Sensing and Target Recognition features.

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Abstract

In this Bachelor Thesis I want to provide readers with tools and scripts for the control of a 7DOF manipulator, backed up by some theory of *Robotics* and *Computer Science*, in order to better contextualize the work done.
In practice, we will see most common software, and developing environments, used to cope with our task: these include **ROS**, along with visual simulation by **VREP** and **RVIZ**, and an almost "stand-alone" ROS extension called **MoveIt!**, a very complete programming interface for *trajectory planning* and *obstacle avoidance*.
As we will better appreciate and understand in the introduction chapter, the capability of detecting collision objects through a camera sensor, and re-plan to the desired end-effector pose, are not enough. In fact, this work is implemented in a more complex system, where recognition of particular objects is needed.
Through a package of ROS and customized scripts, a detailed procedure will be provided on how to distinguish a particular object, retrieve its reference frame with respect to a known one, and then allow navigation to that target.
Together with technical details, the aim is also to report working scripts and a specific appendix (A) you can refer to, if desiring to put things together.

Keywords : SHERPA EU Project, 7DOF Manipulator, ROS, MoveIt!, OctoMap, Obstacle Avoidance, Target Recognition

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Abstract (Italiano)

In questo lavoro di tesi verranno forniti tutti gli strumenti, e i codici funzionanti, per il controllo di un manipolatore a 7 DOF, accompagnati da nozioni teoriche di Fondamenti di Robotica ed Informatica.
Analizzeremo i programmi e gli ambienti di sviluppo comunemente usati in questo ambito, per ottenere un "Workspace Control" del robot in questione : passeremo da **ROS**, con simulazione tramite **VREP** e **RViz**, fino a una "estensione" di ROS chiamata **MoveIt!**, un' interfaccia molto completa per il *trajectory planning* ed *Obstacle Avoidance*.
Tuttavia, sarà chiaro fin dal capitolo introduttivo, che non sarà sufficiente essere in grado di modellizzare l'ambiente di collisione nei paraggi del robot ed evitare di conseguenza gli ostacoli. Dovremmo infatti efficacemente riconoscere degli oggetti specifici.
Tramite personalizzazione di un pacchetto ROS, verrà mostrata una procedura dettagliata su come distinguere oggetti particolari, recuperare il loro reference frame rispetto ad uno già noto, e quindi permettere la navigazione verso questo obiettivo.
Oltre ai dettagli tecnici, l'appendice A, allegata alla tesi, servirà da guida per chiunque volesse scaricare gli scripts e i files di questa tesi, e riprodurre le applicazioni riportate.

Keywords : SHERPA EU Project, 7DOF Manipulator, ROS, MoveIt!, OctoMap, Obstacle Avoidance, Target Recognition

To my sister, Letizia

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Chapter 1

Thesis Introduction

1.1 Sherpa Project

The work presented in this document has to be contextualized in a more wide project the University of Bologna, along with other European partners, is involved in: the Sherpa Project [1]. This programme, started in 2013, aims at building a "fleet" of robots, either aerial and grounded, able to **enhance human rescue operations** in hostile environments, such as the alpine one. The many platforms, having the purpose to help humans in these situations, are programmed to be collaborative, autonomous and self-aware.
In few words, every robot knows where it is in the space relatively to the *"human leader"*, its battery-life left, as well as positions and messages from the other units. Once a triggering command is sent, in this case represented by the effective localization of the stricken area, every platform knows how to behave and act, without any need of further specifications by the operators.
Achieving this level of automation, via advanced controls and cognitive capabilities of the robots, allows the system to require minimum supervision by the human team; In fact, this project considers the rescuer as the *"busy genius"*, meaning that is the one really in charge of the operation, although in most cases not able to manage these many devices. Here lies the importance of a *smart* implementation in terms of collaborative strategies towards the achievement of a common goal among both the group of robots, and the rescuers.

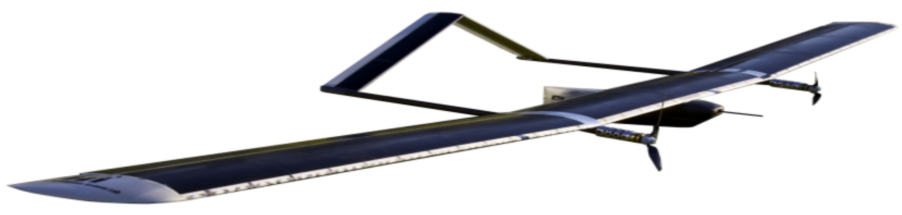
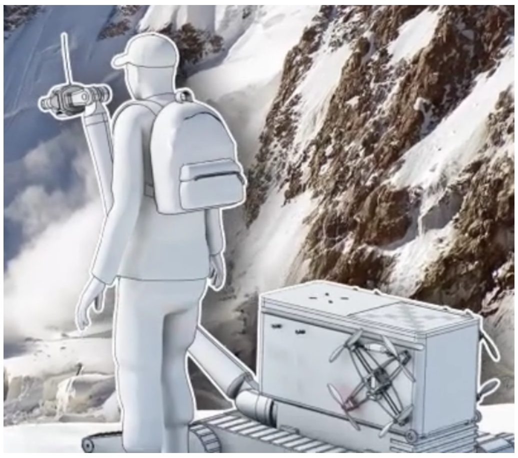


Figure 1.1: The senseSoar, fixed-wing UAV

This group of devices includes a fixed-wing UAV and an RMax rotary-wing, with cutting-edge technology for vision and detection of targets, however, due to their structure, constrained to fly at high altitudes. It includes also multiple quad-rotors UAVs,

characterized by agility and ability to reach most inhospitable places, although having as a main drawback a short life in terms of batteries. Finally, this "robotic-team" includes a ground rover with a multi-purpose arm mounted on it, that carries the main computational unit, has high level of autonomy and a long battery life.
Hereafter some illustrations are reported.


(a) Representation of rescuer and ground rover

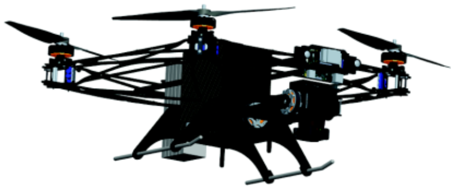

(b) The quad-copter UAV

Figure 1.2: Drone and Rover Representations

This work is centred on the ground robot, which is the one physically following the operator, able to plan its own path behind him, carrying the computational unit and the drones that are going to be detached once around the critical zone. As previously said, in order to set a certain level of autonomy, it has to be able to process gestural as well as vocal commands given by its leader. This stand-alone capability includes also the management and elaboration of the data flow coming from the devices, that use the *Sherpa-BOX* as a central *"common brain"*; this is what practically makes the system so self-supporting.

In particular, I had the opportunity to work on the 7 DOFs rover arm, which has been designed to pick up landed copters and place them in their respective slots on the rover. The main features we are going to add to the system are: *work-space* control and *motion planning*, given a desired end effector pose, an elaboration of joint trajectories takes place to reach the final desired point; communication between camera data and planning core, in order to detect collision objects, *avoid obstacles* and keep refreshing the always changing surrounding environment; Eventually, *recognize the landed quad-copter*, retrieve its reference frame relative to the ground rover, essentially giving to it a target for the navigation, until the UAV is reachable by the arm itself.

1.2 ROS - Robot Operating System

The Robot Operating System [2], best known as ROS, is a very powerful collection of libraries and tools aimed at configuring and writing robots' software. In this work, ROS Indigo, LTS version, has been installed on Ubuntu Trusty 14.

The reason why this operating system is spreading more and more, is because of its innovative way of describing and handling the many parts that are going to characterize the final behaviour of the intended robot: industrial manipulators, drones as well as other mobile platforms up to highly complex humanoids with state-of-the-art AI capabilities. In practice, this result has been achieved with a modular programming method, stimulating collaborative work. As a matter of fact, ROS is organized mainly in **nodes**, **topics** and **messages** (plus other many elements for the moment I avoid telling for sake of explanation). What is being done, is that a programmer builds a node, a mini-core of the overall structured software, that adds one or more particular capabilities and is able to send and receive messages through *channels* called topics. To keep communication organized, a master node handles the most basic functions such as subscriptions and publications on topics.

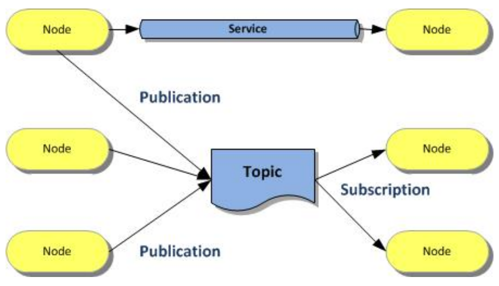


Figure 1.3: ROS concepts

In broad terms, our particular application requires to read mechanical values from the arm, to elaborate suitable trajectories, to collect data from an RGB camera and eventually to detect a specific object. All of these will be the main cores of the software, and they will exchange information or services thanks to proper messages that the sender is able to write and the listener is able to receive and process.
Due to the high readability of the nodes and topics graphs that we can extrapolate from ROS, I will make use of them to show in a detailed manner how the pieces work together, scope and features of each software block and the way in which a simulating engine fits in the scheme, to give us the possibility to experiment and test functionalities of the introduced "code-brick".
Finally, a GUI will be an additional node that listens to topics such as "joints trajectories" and position of "collision objects", and graphically helps us in appreciating the actual underneath software implementation.

1.3 7DOFs Manipulator Specifics

Entering in the technicalities, a description of the arm must be done. Even though low-level implementation is not our final purpose, it clearly is the starting point of a *workspace control*. Indeed, physical components such as actuators, regulators and wiring (fieldbuses, power cables), are the constraints we have to keep into account in planning the motion for our end-effector.

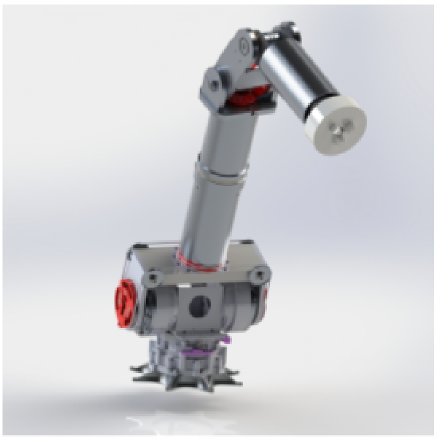


Figure 1.4: Rover Manipulator

The mechanical structure is composed by a 3DOFs shoulder, a single DOF elbow and a 3DOFs wrist. In particular, the elbow actually contains two joints at a distance of about $15cm$; Even if the DOF is only one, because the two revolute connections are dependent with a fixed gear ratio $1:1$, this little separation allows reaching particular poses and, when needed, rest in a folded-arm position. The end-effector has three fingers, dependent on each other since actuated with a single motor.
This design, allows determination of multiple solutions in the joint-space for gripper poses in the reach of the arm; Indeed, it is redundant ($DOFs > 6$) leaving some margin for particular motion planning applications, such as obstacle avoidance and replanning capability, when the desired pose is not reached due to an obstacle, or not reached in the most suitable way.

Communication is managed through CAN interface and proper ROS configuration. More in depth, what we are really interested in, is the method the arm uses to process a given trajectory, namely, how it handles joint-states and joint-controllers commands. Each motor is equipped with an absolute plus an incremental encoder in order to accurately perform our motion requests; The incremental one is directly readable from the velocity regulators, however, without an absolute encoder it wouldn't know its exact position with respect to the TF tree of the arm's kinematic chain.

Knowing the very basics of actuation and communication between controllers and arm, we can enter more in detail concerning the proper ROS programming of the tasks we want it to accomplish.

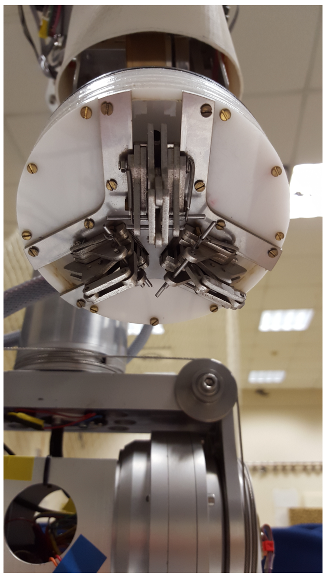


Figure 1.5: Gripper of the Arm

Chapter 2

Basics of Control Theory and Robotics

2.1 Structure of a Manipulator

Robot manipulators, from a physical point of view, are intended as a set of interconnected link and joints, that, strongly depending on their design, are able to perform certain tasks rather than others. For example, we may distinguish between manipulators that are *redundant* or not, parallel or serial structures, or just characterize robotic arms depending on the kind of joints used in their construction.

The SHERPA Rover Arm has the following characteristics:

- It is a serial chain, meaning that, moving from the end-effector down to the base, higher torques motors have to be adopted, due to the fact that in a serial structure each joint must *support*, and allow the *motion*, of the following links.
- It is only formed by 1 DOF joints, that are way simpler to manage in terms of computational power needed and mathematical modelling, yet not introducing any particular constraint on the trajectories and motions we can achieve with that arm.
- In particular, it only consists of *revolute* joints. These kinds of manipulators are for this reason called *anthropomorphic*, recalling their structural similarity with human arms.
- Eventually, it is said to be *redundant*, having dimension of the joint-space (7DOF) greater than the dimension of the work-space (imposed by our physical world and equal to 6).

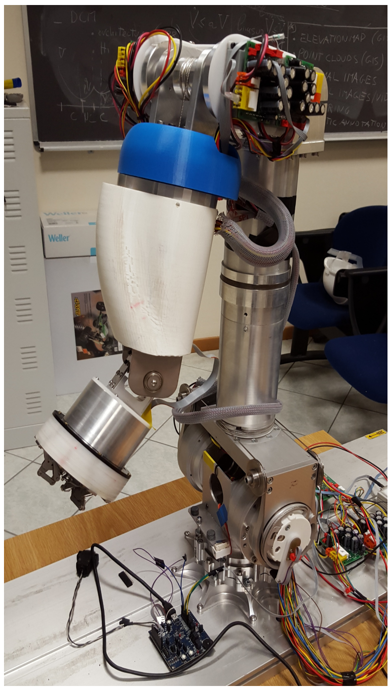


Figure 2.1: SHERPA Rover Arm

2.2 Physical Interpretation

Motion Control for such a robot is all about properly mapping *Jointspace* and *Workspace*, so that either direct and inverse kinematics can be carried out.
We will see that our Software Tools are actually able to extrapolate such a map from the model of our manipulator, however, for the sake of completeness, let's go a bit through these mathematical and geometric concepts.

Joint Space According to the number of independently actuated joints, we would define a vector of joint values :

$$\mathbf{q} = [\theta_1, \theta_2, \cdots, \theta_7] \qquad \text{so that} \qquad \mathbf{q} \in \mathbb{R}^7$$

In our application it has dimension 7, coincident with the number of DOFs of the arm, and contains angles due to the fact that it has an anthropomorphic structure.
In order to perform tasks with it, we can just act at the "low-level" that is the joint-space; Indeed, giving values to the vector q (that is give setpoints to each joint) we would define a position for our end-effector.

Work Space However, the most interesting (and most frequent) operation we want such an arm to carry out, is to elaborate a proper set of joint values in order to place the end-effector in a desired point in space: in our case, even with a certain orientation.
With the word *Workspace* we indicate the set of possible configurations the end-effector may assume in our space that, for a rigid body, has dimension 6.
Hence, a vector $\mathbf{x}$ would contain 3 position parameters (e.g. Cartesian coordinates) and 3 orientation parameters (e.g. Euler angles):

$$\mathbf{x} = [p_x, p_y, p_z, \phi, \theta, \psi] \qquad \text{where} \qquad \mathbf{x} \in \mathbb{R}^6$$

Map Workspace $\leftrightarrow$ Jointspace At this point we want to find a mapping between this two spaces. In other words, a function f that holds :

$$f : \mathbb{R}^7 \rightarrow \mathbb{R}^6 \qquad , \qquad \mathbf{x} = f(\mathbf{q})$$

Such a function would bond together the end-effector and the joint angles, with a mathematical map.

2.3 Inverse Kinematics

The function f above, is in charge of the so-called "*Direct Kinematics*", that is the problem of defining the end-effector configuration-vector $\mathbf{x}$, once known the joint parameters $\mathbf{q}$.
However, as pointed out before, in this thesis we face the task of solving Inverse Kinematics (IK), that is mapping :

$$g : \mathbb{R}^6 \rightarrow \mathbb{R}^7 \qquad , \qquad \mathbf{q} = g(\mathbf{x}) \qquad \text{hence} \qquad g = f^{-1}$$

Both maps are obviously *non-linear* functions. To solve the *Inverse Kinematic* problem, that is finding proper joint values known a desired $\mathbf{x}$, we would definitely prefer a linear relationship.
The Jacobian would be our "solving engine" exactly for this reason.

Jacobian Matrix If the functions above represent a "position mapping", we will the define through the Jacobian, the derivative of that map, that would be a relationship at the "velocity level", from a physical point of view.
We define the *Jacobian Matrix* as follows:

$$\mathbf{J}(\mathbf{q}) = \frac{\partial \mathbf{f}(\mathbf{q})}{\partial \mathbf{q}} = \begin{bmatrix} \frac{\partial f_1}{\partial q_1} & \frac{\partial f_1}{\partial q_2} & \cdots & \frac{\partial f_1}{\partial q_7} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_6}{\partial q_1} & \frac{\partial f_6}{\partial q_2} & \cdots & \frac{\partial f_6}{\partial q_7} \end{bmatrix}$$

By exploiting this matrix we can now define :

$$\tfrac{d}{dt}\mathbf{x} = \tfrac{d}{dt} f(\mathbf{q}) \qquad \Rightarrow \qquad \dot{\mathbf{x}} = \mathbf{J}(\mathbf{q}) \cdot \dot{\mathbf{q}}$$

This equation is *no more* non-linear. In fact, now velocities of the joints and end-effector's linear and angular velocities are *linearly* correlated, thanks to the Jacobian Matrix $\mathbf{J}(\mathbf{q})$.
Since it goes $\mathbb{R}^7 \rightarrow \mathbb{R}^6$, then it would be *not square*, hence an inverse $\mathbf{J}^{-1}(\mathbf{q})$ shouldn't exist.
For this purpose, our solving engines will instead make use of the *pseudo-inverse* that, as an additional advantage, are mathematically proven to give the "best solution": technically speaking, the solution with the *minimum norm.*
Given the vector $\dot{\mathbf{x}}$ and called the pseudo-inverse with $\mathbf{J}^{+}$, we get:

$$\dot{\mathbf{q}} = \mathbf{J}^{+} \cdot \dot{\mathbf{x}} \quad , \qquad \text{the solution having minimum} \qquad \|\dot{\mathbf{q}}_s\|$$

The fact that with this method we have the "*optimal solution*" is because, having a *redundant* manipulator, whenever a solution for the inverse kinematics exists, then we actually will have infinite solutions.
This is possible because we still have 1 dimension, that is 1 DOF (in practice nothing but 1 joint variable) that we may still exploit to change the arm configuration but not the gripper pose.
Having such a possibility will be key in our obstacle avoidance tasks : in these cases we want the arm to re-plan its trajectory to the "goal pose"; If the solution had been unique, it would have just been impossible to do so.

Singularities At the moment, we just overcame the problem of finding the inverse of a non-square matrix by using the pseudo-inverse.
Still, if the matrix above wouldn't be *maximum rank*, the procedure in the last equation, that is deriving $\dot{\mathbf{q}}$ from $\dot{\mathbf{x}}$, would not hold.
Due to the fact that $\mathbf{J}(\mathbf{q})$ is built with functions of the joints, there would exist particular arm's configuration that do not make $rank(\mathbf{J}) = min(6, 7) = 6$.
Whenever the Jacobian Matrix has not maximum rank we are in a *Singular Configuration* that, from a physical point of view, is translated in loosing one or more Degrees of Freedom.

These configurations are coincident, for example, with the alignment of 2 (or more) different joints. In fact, in that exact instant of time, and for an infinitesimal displacement dx, the two joints that are independently actuated, would rather just define a motion (rotating motion due to the revolute joints in our case) around *coincident axes*.
In our application, we will take particular care in avoiding *Boundary* singularities (done via not working at the edge of the arm's reaching space) and *Internal* singularities, more difficult to detect and avoid (still doable via our software tools).

Chapter 3

VREP - Virtual Robot Experimentation Platform

3.1 General Configuration

VREP [3] is a simulation platform developed by *Coppelia Robotics*. It exploits LUA language for its API functions and makes use of threaded or non threaded scripts to manage behaviour of the mechanical parts under experimentation. The difference between threaded and non-threaded is that the last one is nothing but a script elsewhere known as a function, that means, executes the code and returns control; Moreover, it is executed in a cascade way, so we are going to respect the TF tree hierarchy of our system. It has to be preferred, whenever possible, to a threaded script, that may induce in infinite loops and waste computational power.

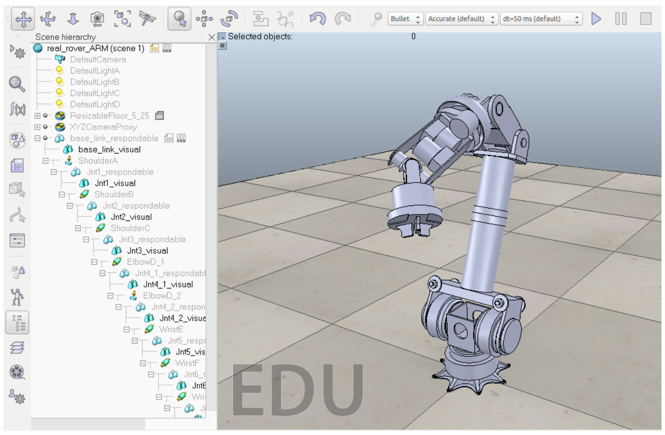


Figure 3.1: URDF model Configuration in VREP

VREP has the capability to import URDF models, that we use to represent our arm in virtual environments. Once uploaded the respective meshes, the program recognizes joints, links, the overall children-parents structure and is ready for simulations, using powerful physics engines (I have chosen BULLET). First of all, to make the system able to withstand its own weight, we set the joints' actuators in *torque/force mode* with suitable maximum torque $[N \cdot m]$ and a simple PID controller on position (since not looking for high performances in this part of the configuration, a Proportional controller with $K_p = 0.1$ will be enough).

3.2 Interfacing VREP and ROS

This simulation environment has the intrinsic capability of connecting with ROS. In fact, specific libraries (such as `libv_repExtRos.so`) add particular API functions for the intercommunication between them. On the other side, ROS is able to manage VREP as a node and interact with it through topics.
Hereafter, I want to show a simple publisher and subscriber between these two programmes; A node-topics graph will be reported as well.
At VREP's side I want to enable subscription to ROS topic /setJointPosition that will broadcast float64 messages containing position setpoints for a joint. The simulation environment will be able to catch those messages through the command `simros_strmcmd_set_joint_targe`

```
    if (sim_call_type==sim_childscriptcall_initialization) then
    --testing if roscore is on
    local moduleName=0
    local moduleVersion=0
    local index=0
    local pluginNotFound=true
    while moduleName do
      moduleName,moduleVersion=simGetModuleName(index)
      if (moduleName=='Ros') then
        pluginNotFound=false
      end
      index=index+1
    end

    if (pluginNotFound) then

      -- Display an error message if the plugin was not found:
      simDisplayDialog('Error','ROS plugin was not found.&&
     nSimulation will not run properly',sim_dlgstyle_ok,false,nil
     ,{0.8,0,0,0,0,0},{0.5,0,0,1,1,1})
    else

      --handle of the elbow joint we want to control
      elbowHandle = simGetObjectHandle('ElbowD_1')
      subscriberID = simExtROS_enableSubscriber('/setJointPosition',
     1, simros_strmcmd_set_joint_target_position, elbowHandle, -1, ''
     )


    end
end
```

Listing 3.1: VREP subscriber to /setJointPosition ROS topic - (LUA)

On the counterpart, ROS must create a node publishing those desired positions on the common chosen topic; In practice, we will send cyclic positions around the rotation axis of the revolute joint. For this application we will use Python because, to experiment a little bit, we are going to change often this setpoints, and a *.py* script doesn't need to be recompiled through commandline `catkin_make` each time a variation in the code occurs.

Note : Remember to make the script executable through *sudo chmod* `<users>` *+x* `<file.py>` command from terminal.

```python
#!/usr/bin/env python
#joint_position_publisher.py
import rospy
from std_msgs.msg import Float64

def joint_position_publisher():

  pub = rospy.Publisher('setJointPosition', Float64, queue_size=10)
  rospy.init_node('joint_position_publisher', anonymous=True)
  #anonymous gives unique name to nodes in case of an homonymy

  rate = rospy.Rate(1) #once per second, 1Hz

  #init variables
  count=4    #we start from a middle position
  sign=1     #used to go back and forth with the arm
  desired_joint_position = 0

  while not rospy.is_shutdown():

    desired_joint_position += sign*(3.1415/12)
    count += 1
    if (count%6) == 1 :
      sign = sign*(-1)

    pub.publish(desired_joint_position)
    rate.sleep()    #keeps the desired 1Hz transmission frequency

if __name__ == '__main__':
  try:
    joint_position_publisher()
  except rospy.ROSInterruptException:
    pass
```

Listing 3.2: ROS publisher to VREP - (Python)

To launch the application, once built and compiled a proper `catkin_pkg` with relative *CMakeLists.txt* and *Package.xml*, we want to run the publishing node and then start the simulation. The following steps will guide us into it. From terminal's commandline execute:

- Launch the master : `roscore`
- `rosrun set_joint_position_vrep joint_position_publisher.py`
- Monitor topic messages with `rostopic echo /setJointPosition`
- Open VREP scene previously created with the non-thread child script above
- Run the simulation either from VREP GUI or via ROS service : `rosservice call /vrep/simRosStartSimulation`

Clearly, depending on the joint's constraints, the controller used and the torque of the motor, the achieved result varies. Remember also to set the base link "not dynamic", indeed, in the real case, it is fixed on the rover base.
As we said, through command `rosrun rqt_graph rqt_graph` we can get a map of nodes and topics in our system. This time it turns out to be a very simple one, however, we will have the opportunity to appreciate this tool later on in more complex applications of our project.
Our scheme is :

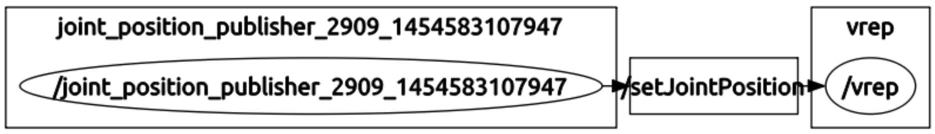

joint_position_publisher_2909_1454583107947
/joint_position_publisher_2909_1454583107947
/setJointPosition
vrep
/vrep

Figure 3.2: RQT Graph in VREP - ROS communication

3.3 Limits of VREP

What we achieved is the control of a single joint, however, it's easy to understand, that the trajectory of a kinematic chain is something more complex. By trajectory (that we will physically define and describe in the next section) we intend a stream, namely an array float64[], containing velocities and accelerations of the specific joints in multiple instants of time : as a result, we obtain the *trajectory* in terms of positions.

VREP, despite being very accurate and graphically elegant, would require unpacking and assignment for each trajectory stream, to every single joint. That's because, through ROS, we elaborate JointTrajectory.msg types that VREP is not yet able to process.
The final choice as a Graphical Simulation Engine will be RVIZ (ROS-Visualization) environment.

Chapter 4

MoveIt! Interface

4.1 MoveIt! Architecture

The software MoveIt! [4] will be the central core of this thesis application, since gives us tools that span from motion planning to 3D perception. The most fundamental point, is that it is naturally linkable with ROS through methods explained in the Introduction chapter (nodes, topics...).
MoveIt! has been originally developed by Willow Garage, becoming very soon of public domain thanks to its open-source license. It has a very powerful system architecture, is able to process scripts in either Python or C++ and it's readily possible to interface it with RVIZ.

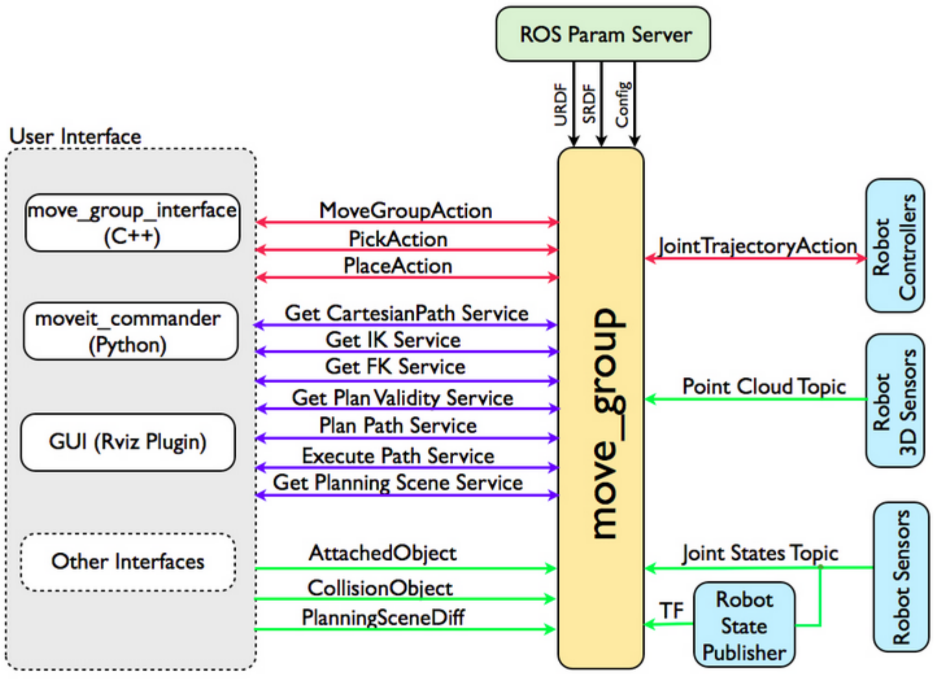


Figure 4.1: MoveIt! System Architecture

From the Fig. 4.1 it's very easy to understand why and how this software will be pivotal in our implementation.

4.1.1 Robot Model

In the very top section of the scheme, we notice that the node *move_group* reads 3 parameters : they represent the model of our robot, in a format that this software is able to understand. The URDF (Unified Robot Description Format) lists all the details of the kinematic chain (in our application with the rover arm), links and joints, TF tree hierarchy and whichever constraint we may set (effort, position, velocity, acceleration). Its correspondent SRDF (Semantic Robot Description Format) is generated after the first configuration is completed, and contains the most useful information on our robot: joint limits, pre-defined positions (I defined an *home* position, for example), planning groups, end-effector structure and finally a list of *links* that are *always* or *never* in collision, in order to slim computations.

4.1.2 Robot Feedback and Controllers

From the robot sensors, the central "high-level" node always keeps track of the overall structure's position and orientation. Indeed the TF tree is refreshed at high-frequencies to cope with dynamic environments, with obstacles spawning in the arm's workspace, and to allow planning around them, respecting chain's design limits and avoiding self-collisions. Once a trajectory is successfully planned, we may execute it. The Robot Controllers are interfaced with the move_group node to perform this task. By using *rqt_plot*, we can see that they are actually transmitting commands for the motion of our arm.

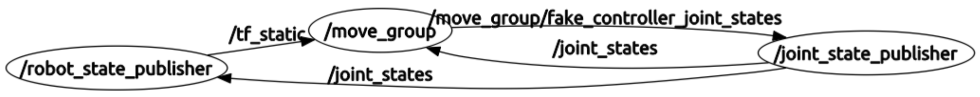


Figure 4.2: Communication between move-group and Joint States

4.1.3 3D Perception

Another very useful capability of this MoveIt! structure is the one of reading real time camera sensors' data through *point cloud topics*. We will make use of this kind of communication when configuring a kinect sensor for the arm. Essentially, the point cloud updates the *Occupancy Map* in the World Geometry of the robot; Thus, is possible to make a direct translation from depth and RGB data into collision objects. At this point, we will be able either to plan around them and to keep "listening" to the point cloud topic for updates of the surrounding environment.

4.1.4 Moveit! User Interface

The way in which a programmer can interact with this Moveit! architecture is basically described by the topics, actions or messages we can exploit to communicate with the move_group node. There exist particular actions for a *pick and place* application, the user may define collision object by script and place them in the map or attached to the robot: in the latter case, the planner keeps that object into account in elaborating trajectories. Moreover, we can exchange information on Inverse Kinematics calculations, generated paths (planned and/or executed) and planning scene structures.

Note : A GUI (we choose RVIZ, as already said) has to be like a simple listener to the TF tree, planning scene and path generation topics, so that it can graphically represent what the move_group node has processed from our ROS script request.

4.2 Setup for the SHERPA Arm

4.2.1 MoveIt! Setup

The linkage between MoveIt! and the real robot, we said, is the URDF. Actually, due to some peculiarities in our model, a couple of modifications have to be done.

1DOF elbow The elbow of our arm has one degree of freedom, however, it is built by 2 revolute joints. In general, they should add 2DOF but in this case they are linearly dependent with a fixed gear ratio. This value is $1 : 1$ so we want to insert in the model a *mimic function*, with multiplier 1, between `Jnt4` and `Jnt4_2`. Moveit! will be able to read this information and plan accordingly.

```
<joint
    name="Jnt4_2"
    type="continuous">
    <mimic
      joint="Jnt4" />
```

Listing 4.1: Mimic function on the elbow

In addition, from the planner point of view, the joint `Jnt4_2` is seen as *non actuated*; To explain it better, in the real case as well as in the model, it follows movement of `Jnt4` then MoveIt! must not take it into account in motion planning.
To implement this feature, `Jnt4_2` is set to *passive*.
One last consideration is for the elbow constraints. Once determined in Laboratory the range of positions it can assume due to its wiring, we must take action in setting joint limits.
Note that the planner will take actions itself for position limits when auto-collision may occur, but in this case we have an external constraints due only to the cables passing through the arm. The planner wouldn't know of these connections, so we need to "impose" them in the URDF model. Code is reported in the following page.

```
<joint
    name="Jnt4"
    type="revolute">
<limit
    lower="0.0"
    upper="1.509" />
```

Listing 4.2: Jnt4 URDF constraints

Note : "Joint Type" is now revolute. This is the kind of joint that allows us to set position limits (as well as velocity or effort ones). With type "continuous" we are not setting any external constraint. Planning would be limited to avoiding obstalces and self-collisions.

Kinematic Solver As explained in Chapter 2.3, we are going to solve our IK problems with the Jacobian. That's because we saw that it makes possible to have a *linear* relationship between Work-space and Joint-space velocities.
Upon completion of the initial set-up, we will have a configuration file, named `kinematics.yaml`, containing the following information :

```
arm:
  kinematics_solver: kdl_kinematics_plugin/KDLKinematicsPlugin
  kinematics_solver_search_resolution: 0.005
  kinematics_solver_timeout: 0.005
  kinematics_solver_attempts: 3
```

Listing 4.3: MoveIt! Kinematic Solver

Let's analyse the single parameters :

- The **kinematic_solver** chosen is the one provided by MoveIt! that works with the jacobian principle
- The value for **search_resolution** is the resolution the solver uses to search over the redundant space. In our application this is very important for obstacle avoidance, hence an accurate resolution is needed.
- With **timeout** we mean the maximum time allotted to solve the IK problem once started a certain solution cycle.
- The "complementary" parameter to the one above would be the **attempts**. With this number we specify how many solution cycles we want the solver to go through.

The values given to those entries above have proven to be a good trade-off between computational weight and speed in the determination of a solution.

Semantic Robot Description Format - SRDF Once brought to an end the initial configuration of our robotic platform in MoveIt!, a very useful SRDF file will be created, containing the most important information on the arm. MoveIt! will deal just with it, from now on.

```xml
<robot name="SHERPA_ARM_1.4">

<!--GROUPS: Representation of a set of joints and links. This can
    be useful to specify the DOFs considered in planning tasks,
    defining arms, end effectors, etc-->
  <group name="arm">

    <joint name="virtual_joint"/>
    <joint name="Jnt1"/>
    <joint name="Jnt2"/>
    <joint name="Jnt3"/>
    <joint name="Jnt4"/>
    <joint name="Jnt4_2"/>
    <joint name="Jnt5"/>
    <joint name="Jnt6"/>
    <joint name="Jnt7"/>
  </group>

<!--GROUP STATES: Purpose: Define a named state for a particular
    group, in terms of joints values.-->
  <group_state name="home" group="arm">

    <joint name="Jnt1" value="0.0353"/>
    <joint name="Jnt2" value="0.0353"/>
    <joint name="Jnt3" value="0.2118"/>
    <joint name="Jnt4" value="0.15"/>
    <joint name="Jnt4_2" value="0.15"/>
    <joint name="Jnt5" value="0.0353"/>
    <joint name="Jnt6" value="0.1765"/>
    <joint name="Jnt7" value="0.2118"/>
    </group_state>

<!--END EFFECTOR: Purpose: Represent information about an end
    effector.-->
  <end_effector name="end_eff" parent_link="Gripper" group="arm"/>

<!--VIRTUAL JOINT: Purpose: this element defines a virtual joint
    between a robot link and an external frame of reference (
    considered fixed with respect to the robot) we need this joint
    to fix the arm to the simulation environment map in RVIZ.-->
  <virtual_joint name="virtual_joint" type="fixed" parent_frame="
    odom_combined" child_link="base_link"/>

<!--PASSIVE JOINT: Purpose: this statement is used to mark joints
    that are not actuated. Jnt4_2 mimics Jnt4, hence...-->
  <passive_joint name="Jnt4_2"/>

<!--For the sake of easing readability, I avoid reporting all the
    list of joints always or never in collision, that, as said in
    the previous chapter, are an indication to the motion planner to
     save computational power and time-->

</robot>
```

Listing 4.4: SHERPA arm SRDF model

Let's now move to the simulation environment RVIZ and understand more in detail how we can use our model there.

4.2.2 RVIZ Setup

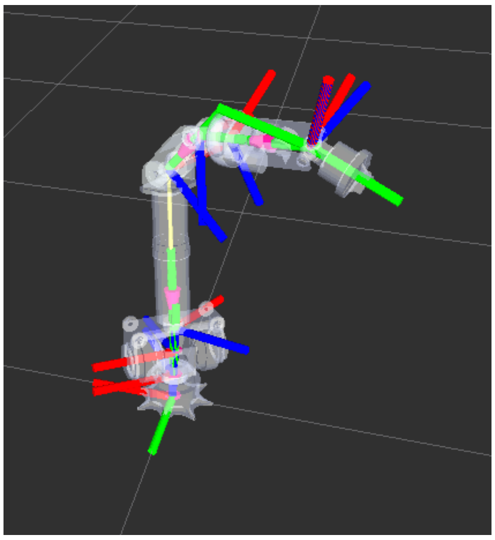
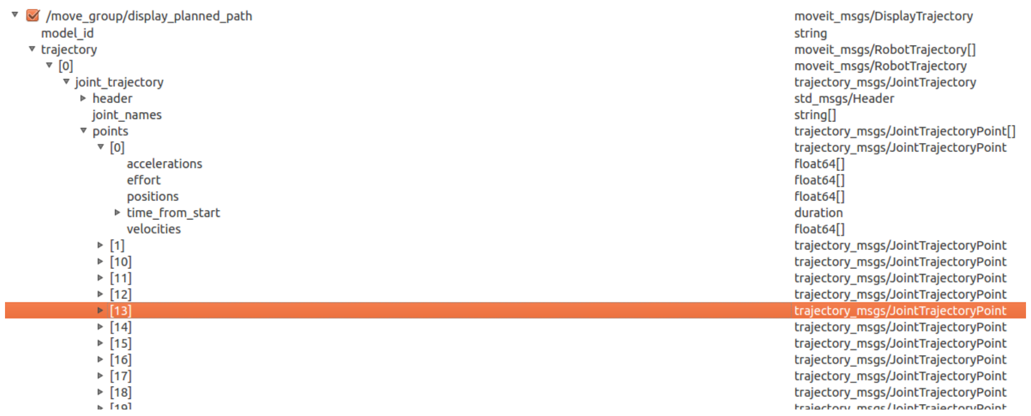


Figure 4.3: Arm's TF tree in RVIZ

RVIZ [5] is a powerful GUI used to have graphical feedback of our ROS - MoveIt! applications.
It listens to various topics in order to visualize results coming from motion planning algorithms. The most basic ones are the topics shown in Fig: 4.2, that allow sending commands as well as retrieve information on the overall structure of the robot, that means, kinematic chain parent-children relationships and reference frames from all the rigid bodies. This last one is the TF tree, that RVIZ shows in the Fig:4.3 here on the side.
Eventually, the trajectory is reported by MoveIt! through a topic readily understandable by RVIZ, that is named "/move_group/display_pla
It is transmitted as a series of "waypoints" (in Fig : 4.4 are shown only some points to keep the image quickly to glance at) that are velocity and acceleration values for some given intervals of time measured in $[ns]$.
From the figure we can appreciate the ability of this simulation engine to read Float64[] arrays, that were the inability and limit of VREP environment.
In practice, they are transmitted via a custom MoveIt! message called `moveit_msgs::DisplayTrajectory`.



```
▾ ☑ /move_group/display_planned_path                moveit_msgs/DisplayTrajectory
    model_id                                        string
  ▾ trajectory                                      moveit_msgs/RobotTrajectory[]
    ▾ [0]                                           moveit_msgs/RobotTrajectory
      ▾ joint_trajectory                            trajectory_msgs/JointTrajectory
        ▸ header                                    std_msgs/Header
          joint_names                               string[]
        ▾ points                                    trajectory_msgs/JointTrajectoryPoint[]
          ▾ [0]                                     trajectory_msgs/JointTrajectoryPoint
              accelerations                         float64[]
              effort                                float64[]
              positions                             float64[]
            ▸ time_from_start                       duration
              velocities                            float64[]
          ▸ [1]                                     trajectory_msgs/JointTrajectoryPoint
          ▸ [10]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [11]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [12]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [13]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [14]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [15]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [16]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [17]                                    trajectory_msgs/JointTrajectoryPoint
          ▸ [18]                                    trajectory_msgs/JointTrajectoryPoint
```

Figure 4.4: Display Planned Path topic

Other two fundamental aspects of RVIZ have to be cited : The *OMPL* and the *OctoMap*.
The former is the acronym of Open Motion Planning Library [6] , a collection of algorithms used in planning: in other terms, is the main tool in our arm obstacle avoidance feature, that may even require multiple solving attempts, through the *kinematic solver* we chose and explained in a couple of paragraphs back.
On the other hand, the latter is a schematic representation of a *pointcloud* topic. In fact,

we will need to superpose to the "world" of RVIZ, what our kinetic sensor will be able to detect in following chapters' applications. This is done via this OctoMap [7] service that places collision objects in the space according to the camera data-stream.
In the next pages we will effectively exploit this functionality.

4.3 Scripts and Applications in MoveIt!

In this section I report the actual work done concerning the use of MoveIt! on the rover arm, still without camera kinect sensor. I will bring two examples : a simple *joint space control* sending setpoints, testing if the communication through robot state and joint publisher works fine; And an obstacle avoidance piece of software, where at first I set an end-effector desired pose, than I insert collision objects in its trajectory, and the arm smartly re-plans its path to the same point in space (with the same orientation too) as before.

4.3.1 Joint-Space Goal

The code is reported hereafter :

```
#include <moveit/move_group_interface/move_group.h>
#include <moveit/planning_scene_interface/planning_scene_interface.
   h>

#include <moveit_msgs/DisplayRobotState.h>
#include <moveit_msgs/DisplayTrajectory.h>

#include <moveit_msgs/AttachedCollisionObject.h>
#include <moveit_msgs/CollisionObject.h>

int main(int argc, char **argv)
{
    ros::init(argc, argv, "rover_arm_joint_space_goal");
    ros::NodeHandle node_handle;
    ros::AsyncSpinner spinner(1);
    spinner.start();

    //wait some time to load RVIZ
    sleep(15.0);

    moveit::planning_interface::MoveGroup group("arm");
    moveit::planning_interface::PlanningSceneInterface
   planning_scene_interface;

    //publisher for RVIZ
    ros::Publisher display_publisher = node_handle.advertise<
   moveit_msgs::DisplayTrajectory>("/move_group/
   display_planned_path", 1, true);
    moveit_msgs::DisplayTrajectory display_trajectory;

    ROS_INFO("Reference frame for the robot: %s", group.
   getPlanningFrame().c_str());
```

```
    ROS_INFO("Ref. frame for the End Effector : %s", group.
    getEndEffectorLink().c_str());

    //planning to a joint space GOAL
    std::vector<double> group_variable_values;
    //I'm writing in the new array defined above the current values
    of the robot's joints
    group.getCurrentState()->copyJointGroupPositions(group.
    getCurrentState()->getRobotModel()->getJointModelGroup(group.
    getName()), group_variable_values);

    //now I change some values
    group_variable_values[1] = -0.8;
    group_variable_values[2] = 1.2;
    group_variable_values[3] = 0.7;
    group_variable_values[6] = -1.2;
    group.setJointValueTarget(group_variable_values);

    //Plan with the new setpoints in group_variable_values[]
    moveit::planning_interface::MoveGroup::Plan my_plan;
    bool success = group.plan (my_plan);
    ROS_INFO("Visualizing plan (joint space goal... %s)", success ?
    "":"==FAILED==");
    sleep(10.0); //give time to RVIZ to plan


    if(success)   //making use of moveit_msgs::DisplayTrajectory to
    display trajectory
    {
        ROS_INFO("let's see it once again");
        display_trajectory.trajectory_start = my_plan.start_state_;
        display_trajectory.trajectory.push_back(my_plan.trajectory_
    );
        display_publisher.publish(display_trajectory);

        sleep(10.0);
    }

    ros::shutdown();
    return 0;
}
```

Listing 4.5: Joint Space Goal - (C++)

Breaking down the code :

- Definition of a ROS node `rover_arm_joint_space_goal` and its handle.
- Instantiation of the planning group *"arm"*, registered in the SRDF, and of a planning-scene object.
- A proper message `moveit_msgs::DisplayTrajectory` is the mean of communication between MoveIt! and RViz. The publisher broadcasts this kind of messages to the topic `/move_group/display_planned_path`, of which our simulator is a subscriber.

- A vector group_variable_values customized as a *double* one, collects all joint names and values. (Note that this is done through topics shown in Fig: 4.2)
- User desired values are substituted in this array and a plan object *my_plan* is created.
- The group.plan method is used, that either plans and shows the trajectory. For sake of completeness, this path is also displayed through the *display_trajectory* msg created above.

4.3.2 End-Effector Pose with Obstacles

The script reported here, has the purpose of showing the capability of MoveIt! to do exactly what we desire : *Obstacle Avoidance*.
Through code and figures we will be able to better appreciate this feature.

```
#include <moveit/move_group_interface/move_group.h>
#include <moveit/planning_scene_interface/planning_scene_interface.
   h>

#include <moveit_msgs/DisplayRobotState.h>
#include <moveit_msgs/DisplayTrajectory.h>

#include <moveit_msgs/AttachedCollisionObject.h>
#include <moveit_msgs/CollisionObject.h>

int main (int argc, char **argv)
{

    ros::init(argc, argv, "rover_arm_obstacle_avoidance");
    ros::NodeHandle node_handle;
    ros::AsyncSpinner spinner(1);
    spinner.start();

    //sleeping to load rviz
    sleep(15.0);

    //the move group interface allows me to control and plan only
   for the desired group, in my case the group "arm" defined in the
    SRDF
    moveit::planning_interface::MoveGroup group("arm");
    group.allowReplanning(true);

    //now the planning scene interface deals with the world
    //coordinates, objects..
    moveit::planning_interface::PlanningSceneInterface
   planning_scene_interface;

    //hereafter we create a publisher in order to display
   trajectories on rviz.
    ros::Publisher display_publisher = node_handle.advertise<
   moveit_msgs::DisplayTrajectory>("/move_group/
   display_planned_path", 1, true);
    moveit_msgs::DisplayTrajectory display_trajectory;

    //printing out ref.frame for the robot and end-eff name
   ROS_INFO("Reference frame: %s", group.getPlanningFrame().c_str
  ());
   ROS_INFO("Reference frame: %s", group.getEndEffectorLink().
  c_str());

   //I use the home position designed in the SRDF
   group.setNamedTarget("home");
   moveit::planning_interface::MoveGroup::Plan my_plan;
   bool success = group.plan(my_plan);

   if (success)
   group.execute(my_plan);
   else ROS_INFO("Was impossible to plan for the home position,
  keep planning from singular position")

   //we plan now from this position. if(success) the current state
   is NON-SINGULAR
   group.setStartStateToCurrentState();

   //==================================
   //=====Planning to a pose goal======
   //==================================
   //Desired position and orientation for the eef

   geometry_msgs::Pose target_pose1;

   //here I define the message
   target_pose1.orientation.w = 1.0;
   target_pose1.position.x = 0.132;
   target_pose1.position.y = 0.545;
   target_pose1.position.z = 0.647;

   //now i give this setpoint to my group object
   group.setPoseTarget(target_pose1);

   //let's call the planner to compute and visualize this plan
   success = group.plan(my_plan);

   ROS_INFO("Visualizing plan 1 (pose goal for the eef) %s",
  success? "":"FAILED");

 //give time to rviz to visualize
   sleep(10.0);

 /****************************************************************/

   //now we are going to introduce collision objects and see how
  trajectory changes
   //I define a collision object message first
   moveit_msgs::CollisionObject collision_object1;
   collision_object1.header.frame_id = group.getPlanningFrame();
   collision_object1.id = "obstacle1";

   shape_msgs::SolidPrimitive primitive1;
   primitive1.type = primitive1.BOX;

   primitive1.dimensions.resize(3);
   primitive1.dimensions[0] = 0.3;
```

```
    primitive1.dimensions[1] = 0.1;
    primitive1.dimensions[2] = 0.3;

    //I place the box in the space, relatively to frame_id selected
     above
    geometry_msgs::Pose obstacle1_pose;

    obstacle1_pose.orientation.w = 1.0;
    obstacle1_pose.position.x = 0.0;
    obstacle1_pose.position.y = 0.3;
    obstacle1_pose.position.z = 0.75;

  //my shape message
    collision_object1.primitives.push_back(primitive1);
    collision_object1.primitive_poses.push_back(obstacle1_pose);
    collision_object1.operation = collision_object1.ADD;

    moveit_msgs::CollisionObject collision_object2;
    collision_object2.header.frame_id = group.getPlanningFrame();
    collision_object2.id = "obstacle2";

    shape_msgs::SolidPrimitive primitive2;
    primitive2.type = primitive2.BOX;

    primitive2.dimensions.resize(3);
    primitive2.dimensions[0] = 0.3;
    primitive2.dimensions[1] = 0.3;
    primitive2.dimensions[2] = 0.1;

    geometry_msgs::Pose obstacle2_pose;

    obstacle2_pose.orientation.w = 1.0;
    obstacle2_pose.position.x = 0.0;
    obstacle2_pose.position.y = 0.5;
    obstacle2_pose.position.z = 0.2;

    collision_object2.primitives.push_back(primitive2);
    collision_object2.primitive_poses.push_back(obstacle2_pose);
    collision_object2.operation = collision_object2.ADD;

    //now i customize a vector, making it of type moveit_msgs::
   CollisionObject
    //I push back in it the two messages I created for the
   collision objs
    std::vector<moveit_msgs::CollisionObject> collision_objects;
    collision_objects.push_back(collision_object1);
    collision_objects.push_back(collision_object2);

    //now we effectively add the objects into the world
    ROS_INFO("Obstacles spawn in the world");
    planning_scene_interface.addCollisionObjects(collision_objects)
   ;

    //sleep to see the obstacles in rviz
    sleep(5.0);

    //let's increase allotted time for planning when obstacles are
   present
```

```
    group.setPlanningTime(8.0);

    //now we give THE SAME pose setpoint and the arm avoids the
   obstacle
    group.setPoseTarget(target_pose1);
    success = group.plan(my_plan);

    ROS_INFO("Visualizing same target pose avoiding obstacles...%s"
   , success ? "" : "FAILED");

    sleep(20.0);
    return 0;
}
```

Listing 4.6: Obstacle Avoidance given End-Eff desired pose - (C++)

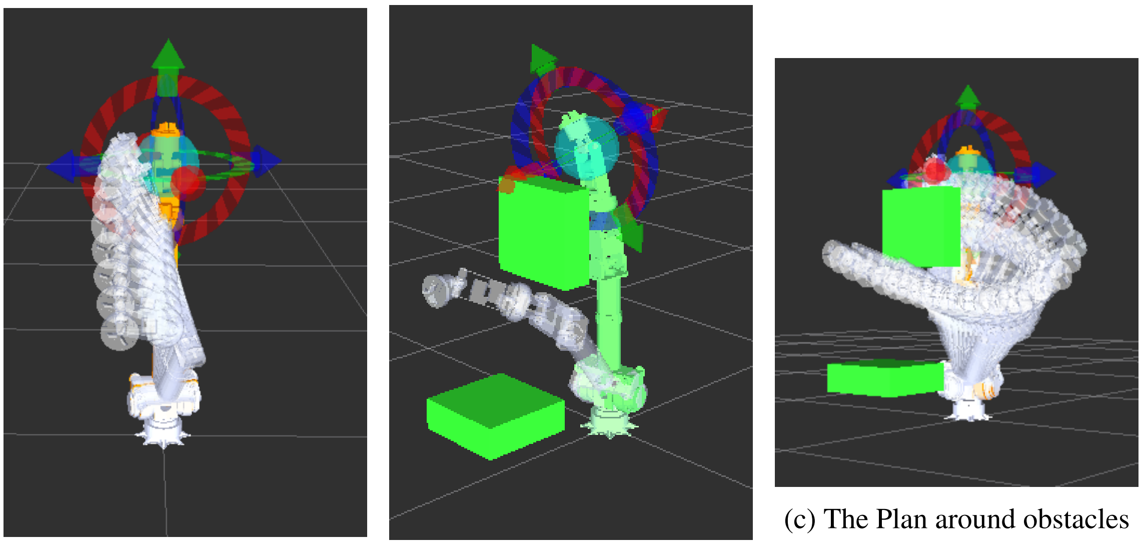

(a) Original Path to Goal Pose (b) Collision Objects added (c) The Plan around obstacles

Figure 4.5: Obstacle Avoidance

Breaking down the code (skipping parts already seen, such as `#include < .h>`, definition of nodes...) :

- Since the original position of the arm is *singular*, we plan to the home position we defined in the SRDF. The arm simply slightly moves into a more favorable configuration. We do it through `group.setNamedTarget("home")` that if doesn't find an *"home"* in the script above, looks into the SRDF.
- Through a *geometry message* we define a desired pose for the end-effector.
- Plan takes place, as already seen in the joint-space goal application.
- MoveIt! has particular message types for the definition of collision objects. I exploit them and define two obstacles and their relative positions.
- Once a vector incorporating the two object is created, we make use of *methods* of the planning scene interface to add them in the world.

- After having increases a little bit the planning time, we re-plan with the same `target_pose1`. The trajectory is now *around* those obstacles.

However, in real cases, we are not able to set "a priori" obstacles in the rover world, thus we need to make use of the on board depth and RGB kinect sensor.

Chapter 5

Interfacing a Kinetic Sensor with our System

5.1 Camera Sensor Setup

Among the whole range of kinetic sensors available, the choice for our rover system was an *ASUS Xtion PRO Live*. This camera is inherently built to be used in software programming and it is easy to connect thanks to drivers available on-line (`PrimeSense.com`).

Most important, `openni` package [8] allows the *communication* of this visual-data stream with ROS.
It has both Depth and RGB Sensors; Through ROS, we are able to *register* detection points. Due to the fact that this two streams come from different cameras with some offset,they will give slightly imprecise information on the same point. In fact, a depth point wouldn't have its actual RGB color, and vice versa. That "points registration", through the driver of the camera, compensates for the little displacement between the camera "eyes" and actually bonds the color of a point with its respective depth point in space.

Figure 5.1: ASUS Xtion PRO Camera

Although depth sensing could be enough for obstacle detection, our system will be asked to recognize a certain target; Therefore an RGB detection, along with the depth one, is the best option.
A proper configuration, has to deal with :

- Setting camera parameters to make MoveIt! aware of its implementation
- Subscribe RViz to the same *PointCloud* topic
- Subscribe the OctoMap Updater to a *PointCloud* topic to let it work
- Compose a proper .launch file, including frames' transformations between rover arm and camera link

5.1.1 Kinect Parameters

MoveIt! can be made aware of the connection of a sensor through a file called "<robot-model-name>_moveit_sensor_manager.launch.xml". In here we define a call to a *.yaml* configuration file (that we are analyzing in Listing 5.1), the link that the OctoMap takes as a reference, the resolution of the map and the max range of the sensor, that will coincide with the far clipping plane of our camera.

The file (referred to my packages) is attached:

```
<launch>
  <rosparam command="load" file="$(find rover_arm_moveit_config)/
   config/sensors_kinect.yaml"/>
  <param name="octomap_frame" type="string" value="camera_link"/>
  <param name="octomap_resolution" type="double" value="0.025"/>
  <param name="max_range" type="double" value="1.5"/>
</launch>
```

Listing 5.1: Sensor Manager file

Note : Parameter `octomap_resolution` value represents the dimension of the basic collision units that will combine together to create a proper collision scene based on the kinect's data; The value chose is, once again, a good trade-off between details and computational speed.
The other one, `max_range`, is set to 1.5 m, just some more with respect to the actual reach of the arm, taking into account motion of the rover structure and giving a little bit more feedback from the scene. An higher value, although allowed by the far clipping plane of the camera, would result being too heavy on the computational unit (above being not useful).

5.1.2 PointCloud for RViz

The new standard adopted in ROS programs is the use of PointCloud2 type. PointCloud is deprecated because it cannot represent *n-dimensional arrays* (just 3D) and handles only floats. Once said that, in our RViz environment we are going to add a PointCloud 2 Panel, subscribing it to `/camera/depth_registered/points`. A proper base frame switch to the *camera_link frame* (if not already done) is needed to have the image displayed correctly.
Figures are reported in the next paragraph.

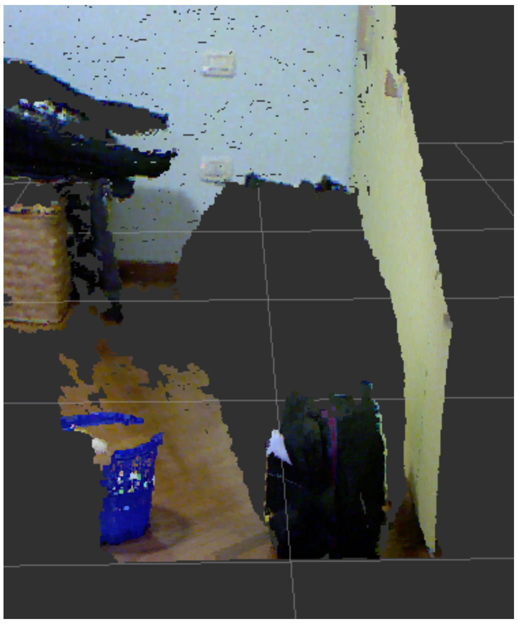
5.1.3 OctoMap Updater

This feature allows the "conversion" of kinect sensor data into collision objects. We could either use the point clouds or images as a source topic for our OctoMap Updater to work, however, each one has a main advantage as well as a drawback.
A kinect sensor inherently reconstructs the image coming from a point stream, indeed, each pixel is basically one single ray emitted from the camera, that is able to give back information on depth of the pointed object and its color spectrum. Said that, an Image, being the reconstruction of a point cloud, results in a more complete and "fluid" stream, however takes more time due to the optimization of a stream of points into an Image.

On the counter part, a pure PointCloud is surely less "visually smooth", however is a very quick input that will produce, clearly, a quicker output with respect to the Image topic OctoMap Updater.
The reason why I chose to supply this Updater with the PointCloud topic, is because I really need the most quick response; In fact the OctoMap is also able to output another topic (That I arbitrarily called `filtered_cloud`) containing the original PointCloud from the camera sensor *excluded the robot arm structure itself.*
This is extremely important, we don't want the arm to act like if it sees itself as an obstacle. Thus, to have this filtering action, a rapid exchange of information between *robot state* and camera *point cloud data* is very much needed. That's why I selected a point cloud OctoMap Updater.
The following images, show its principle of action :

```
sensors:
  - sensor_plugin: occupancy_map_monitor/PointCloudOctomapUpdater
    point_cloud_topic: /camera/depth_registered/points
    queue_size: 10
    max_range: 1.5
    shadow_threshold: 0.2
    padding_scale: 1.0      #info on the camera support
    padding_offset: 0.02
    filtered_cloud_topic: filtered_cloud
```

Listing 5.2: Kinect Sensor yaml file


(a) Original scene in RViz

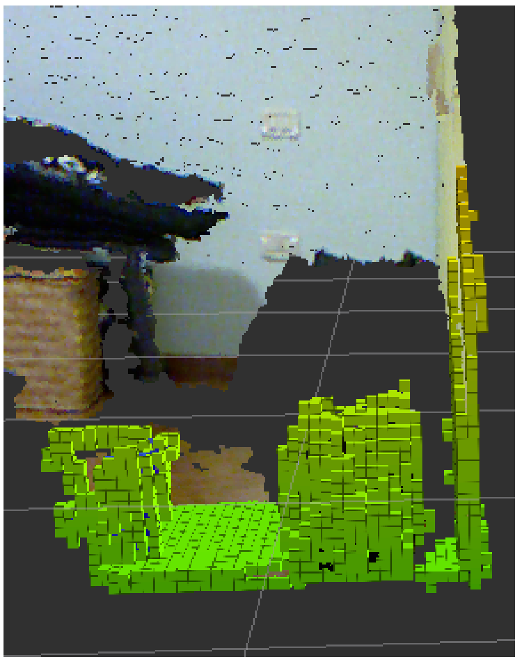

(b) OctoMap Updater working on the same scene

Figure 5.2: OctoMap Updater on RViz

It can be seen that, despite the image being displayed in the full range allowed by the particular sensor used, the OctoMap Update takes place only in the reduced space of 1.5 meters defined in the `sensor_manager` file.

5.1.4 The Launch File

In wrapping up all these features together, we need a `.launch` file that includes running Rviz and camera driver nodes, that states a *transformation* between link `sherpa_arm_base` and `camera_link` (this last one will be our reference frame, as explained before), and contain basic info, such as the robot model, for the simulation to work.
The launch file is attached :

```
<launch>

  <!-- By default, the database db is not started-->
  <arg name="db" default="false" />
  <!-- Allow user to specify database location -->
  <arg name="db_path" default="$(find rover_arm_moveit_config)/
   default_warehouse_mongo_db" />

  <!-- By default, debug mode is switched off -->
  <arg name="debug" default="false" />

  <!-- Load the URDF, SRDF and other .yaml configuration files on
   the param server -->
  <include file="$(find rover_arm_moveit_config)/launch/
   planning_context.launch">
    <arg name="load_robot_description" value="true"/>
  </include>

   <!-- Including openni launch to get camera streams (really
   depends on the driver we want to use) -->
    <include file="$(find openni_launch)/launch/openni.launch">
    <arg name="depth_registration" value="true" />
   </include>

   <!-- static_transform_publisher x y z qx qy qz qw frame_id
   child_frame_id  period_in_ms -->
    <node pkg="tf"
    type="static_transform_publisher"
    name="camera_link_tf_broadcaster"
    args="0.3 0.2 0 0 0 0 1 camera_link sherpa_arm_base 100" />

  <!-- In simulation, we are going to need the FAKE controller to
   execute trajectories-->
  <node name="joint_state_publisher" pkg="joint_state_publisher"
   type="joint_state_publisher">
    <param name="/use_gui" value="false"/>
    <rosparam param="/source_list">[/move_group/
   fake_controller_joint_states]</rosparam>
  </node>

  <!-- Given the published joint states, publish tf for the robot
   links -->
  <node name="robot_state_publisher" pkg="robot_state_publisher"
   type="robot_state_publisher" respawn="true" output="screen" />
  <!-- Run the main MoveIt executable -->
  <include file="$(find rover_arm_moveit_config)/launch/move_group.
   launch">
    <arg name="allow_trajectory_execution" value="true"/>
    <arg name="fake_execution" value="true"/>
    <arg name="info" value="true"/>
    <arg name="debug" value="$(arg debug)"/>
  </include>

  <!-- Run Rviz and load the default config to see the state of the
    move_group node -->
  <include file="$(find rover_arm_moveit_config)/launch/moveit_rviz
   .launch">
    <arg name="config" value="true"/>
    <arg name="debug" value="$(arg debug)"/>
  </include>

</launch>
```

Listing 5.3: RViz simulation with OctoMap Updater - (Launch file)

Note : When adopting an RGB-depth camera, is very useful to activate *depth_registration* to obtain an optimized camera stream (explained at the beginning of the chapter).
From the package `tf` coming with ROS-desktop installation, we include in the lauch file the *static* transformation that is nothing but the position of the camera with respect to the arm base (and thus the rover structure).

5.2 Applications and scripts

With the GUI itself, we are already able to experiment the OctoMap Updater feature that comes from the implementation of a kinect sensor in our system. Still, our purpose is to give the arm commands through a script.
This one, speaking of pure code, wouldn't be so complex. What we are going to do is set a `geometry_msgs::Pose` message with the desired *end-effector* pose. MoveIt! will plan a trajectory around the obstacles that, this time, are real time updated with the visual camera data stream (formerly we had to define a collision objects vector and add it into the planning scene).
Code of the application "`rover_arm_obstacles_on_camera.cpp`" :

```
#include <moveit/move_group_interface/move_group.h>
#include <moveit/planning_scene_interface/planning_scene_interface.
   h>

#include <moveit_msgs/DisplayRobotState.h>
#include <moveit_msgs/DisplayTrajectory.h>

#include <moveit_msgs/AttachedCollisionObject.h>
#include <moveit_msgs/CollisionObject.h>

int main (int argc, char **argv)
{
    ros::init(argc, argv, "obstacle_camera_detection");
    ros::NodeHandle node_handle;
    ros::AsyncSpinner spinner(1);
    spinner.start();

    //sleeping to load rviz
    sleep(15.0);

    //the move group interface allows me to control and plan only
    //for the desired group, in my case the group "arm" defined
    //in the moveit setup config files

    moveit::planning_interface::MoveGroup group("arm");
    group.allowReplanning(true);
    group.setPlanningTime(10.0); //incremented a little due to
   obstacles presence

    //now the planning scene interface allows us to deal with the
   world
    //coordinates, objects..
    moveit::planning_interface::PlanningSceneInterface
   planning_scene_interface;

    //hereafter we create a publisher in order to display
   trajectories on RViz
    ros::Publisher display_publisher = node_handle.advertise<
   moveit_msgs::DisplayTrajectory>("/move_group/
   display_planned_path", 1, true);
    moveit_msgs::DisplayTrajectory display_trajectory;

    //printing out ref.frame for the robot and end-effector name
    ROS_INFO("Reference frame: %s", group.getPlanningFrame().c_str
   ());
    ROS_INFO("Reference frame: %s", group.getEndEffectorLink().
   c_str());

    //I use the home position defined in the SRDF
    group.setNamedTarget("home");
    moveit::planning_interface::MoveGroup::Plan my_plan;
    bool success = group.plan(my_plan);
    if (success)
    {
  group.execute(my_plan);
  //now we plan from this NON-SINGULAR config
  group.setStartStateToCurrentState();
    }

    //==================================
    //=====Planning to a pose goal======
    //==================================
    //we plan now for a desired motion for the eef
    geometry_msgs::Pose target_pose;
    //here i define the message
    target_pose.orientation.w = 1.0;
    target_pose.position.x = 0.565;
    target_pose.position.y = -0.0745;
    target_pose.position.z = 0.143;

    //now i give this setpoint to my group object
    group.setPoseTarget(target_pose);

    //let's call the planner to compute and visualize this plan
    success = group.plan(my_plan);
    ROS_INFO("Visualizing plan (pose goal for the eef) %s", success
   ? "":"FAILED");
    sleep(10.0); //give time to RViz to visualize

    return 0;
}
```

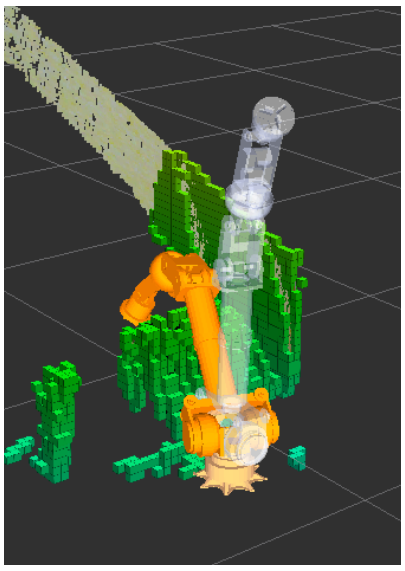
Listing 5.4: Obstacle avoidance with a configured kinetic sensor - (C++)

Assuming that the setpoint given is appropriate (not inside an obstacle, not out the reach of the arm) MoveIt! will give us in `/move_group/result` topic the desired trajectory. Clearly, thanks to this way of detecting obstacles, each time the trajectory is allowed to change although given the same `target_pose`.
Moreover, if an object is suddenly inserted in the planned path of the arm, MoveIt! would block the execution and prevent an hit. Last but not least, another launch file has to be crafted for this application. Luckily, the one in section 5.1 will do most of the things (launch RViz, camera, configurations and OctoMap), this last one is only need to launch the node we just wrote.

A launch file may be:

```
<launch>
    <!-- I gave to the launch file in section 5.1 the name
   RViz_camera_OctoMapUpdater -->
    <include file="$(find rover_arm_moveit_config)/launch/
   RViz_camera_OctoMapUpdater.launch"/>

    <node name="rover_arm_obstacles_on_camera" pkg="
   rover_arm_moveit_applications" type="
   rover_arm_obstacles_on_camera" respawn="false" output="screen">
    </node>

</launch>
```

Listing 5.5: Obstacle avoidance for an End-Effector setpoint - (Launch file)


(a) Start state and Goal state, given through "target pose"

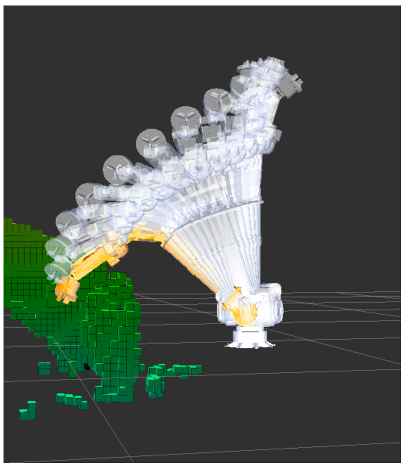

(b) Trail of the arm trajectory, avoiding collision objects represented by the OctoMap

Figure 5.3: Obstacle Avoidance with Camera Sensor Configuration

Chapter 6

Visual Detection and Identification

The final step, in order to give the system full autonomy from human rescuers, is to implement detection and navigation to a quadrotor landed somewhere, with empty battery.
The aim is to pick it up through a ring placed on the top: our arm's end-effector has a three-finger system able to do it. More in details, the fingers are inter-dependent since actuated by just one motor, as it's shown in Fig. 1.5 . The rest position of the gripper is with closed fingers, in fact, it is going to pick quadrotors "unconventionally" with respect to the way we imagine and actually grab objects: The fingers would go all inside the quadcopter's ring, the motor would be actuated and the "hand" would grasp the object from the inner part of the ring. In this way, the fingers are basically behaving as hooks.
In practice, even if present, it is not enough a GPS sensing (even though extremely precise) because we need to know either the position and the *orientation* of the small UAV. That's because, in a real scenario, although the quadrotors have the ability to estimate their battery-life left and plan a controlled landing flight to the most suitable spot nearby, it can hit a bush, could sink a little bit laterally on the snow, or whatever other situation, just to say that the orientation is not always the one we expected it to be.

6.1 Find Object Package

One more esteem of ROS is its community. In the vast sea of packages either created and uploaded by ROS creators and developers, or by users like us, I found a very suitable one for our particular application, called "Find-Object" [9].
Once did a `git clone` of it, I added this package in my *catkin workspace* and started analyzing it. It works with camera streams and is able to memorize an object once shown it to the camera for a first time. Its principle of action is keeping track of a finite number of characterizing points of that particular object in order to recognize it.
To achieve the best performance, I first registered the PointCloud stream (as already done in previous applications) and then set the refresh and detection rate to 100Hz. Once again, the choice I made was the best trade-off, in my opinion, between computational weight and smoothness of the images.
Consider that with this object recognition we want to *retrieve the frame* of the landed copter, that means its position and orientation with respect to another known frame. For this purpose, an high frequency rate is very much desired too.

6.2 Customization and Configuration

6.2.1 Pattern Detection

As one can understand, the capability of a camera to recognize an object has a limitation on the spatial range, mostly due to the dimension of the object to detect.
Directly, we cannot detect a quadcopter: it has too few peculiarities, has a general black color and simple structure that may be easily confused with something else. For this reason, a characterizing pattern is applied to every quadrotor. With a dimension of the symbol of $20cm$ x $15cm$, our detection system is able to properly work in a radial distance of up to 2 meters from the camera, which is satisfying.
As a matter of fact, the first "rough" localization of the landed UAV is done by the rover through a GPS sensing. This kind of operation, given the sensors chosen by the rover designers, feeds back the position of the rotor in the space with an error up to 10 meters. Now the rover can navigate to that spot and start the search.
In the very worst case, the rover is 10 meters away from the copter, clearly out of the camera detection feature. Working in collaboration with the rover navigation developers, it will be able to scan the nearby area having 10m radius from the fed back position; while doing this, the camera will detect the object. However, with a bit of luck it may also happen that the quadrotor is readily in the range of the rover, or that it is detected on the path of the rover to the GPS position spot.
In any case, note that this retrieval procedure is *completely human-commands free*.

6.2.2 Scripts and Files

Mainly, we are going to need a node that is in charge of scanning and detecting the desired object and a node having the purpose of retrieving the object's frame with respect to a desired one. Obviously, the first step is to have the object's TF linked with the camera link but, at the end, to ease navigation, I'm going to send coordinates with respect to the `/rover_structure`.

Find Object Node I attach the script here after:

```
#include "CameraROS.h"
#include "FindObjectROS.h"
#include <QApplication>
#include <QDir>
#include "find_object/MainWindow.h"
#include "ParametersToolBox.h"
#include "find_object/Settings.h"
#include <signal.h>

using namespace find_object;

bool gui;
std::string settingsPath;

void my_handler_gui(int s){
  QApplication::closeAllWindows();
  QApplication::quit();
```

```
}
void my_handler(int s){
  QCoreApplication::quit();
}
void setupQuitSignal(bool gui)
{
  // Catch ctrl-c to close the gui
  struct sigaction sigIntHandler;
  if(gui)
  {
    sigIntHandler.sa_handler = my_handler_gui;
  }
  else
  {
    sigIntHandler.sa_handler = my_handler;
  }
  sigemptyset(&sigIntHandler.sa_mask);
  sigIntHandler.sa_flags = 0;
  sigaction(SIGINT, &sigIntHandler, NULL);
}

int main(int argc, char** argv)
{
  ros::init(argc, argv, "find_object_2d");

  gui = true;
  std::string objectsPath;
  std::string sessionPath;
  settingsPath = QDir::homePath().append("/.ros/find_object_2d.ini"
   ).toStdString();
  bool subscribeDepth = true;
  std::string objFramePrefix = "quadrotor";

  ros::NodeHandle nh("~");

  nh.param("gui", gui, gui);
  nh.param("objects_path", objectsPath, objectsPath);
  nh.param("session_path", sessionPath, sessionPath);
  nh.param("settings_path", settingsPath, settingsPath);
  nh.param("subscribe_depth", subscribeDepth, subscribeDepth);
  nh.param("obj_frame_prefix", objFramePrefix, objFramePrefix);

  ROS_INFO("gui=%d", (int)gui);
  ROS_INFO("objects_path=%s", objectsPath.c_str());
  ROS_INFO("session_path=%s", sessionPath.c_str());
  ROS_INFO("settings_path=%s", settingsPath.c_str());
  ROS_INFO("subscribe_depth = %s", subscribeDepth ? "true":"false")
   ;
  ROS_INFO("obj_frame_prefix = %s", objFramePrefix.c_str());

  if(settingsPath.empty())
  {
    settingsPath = QDir::homePath().append("/.ros/find_object_2d.
   ini").toStdString();
  }
  else
  {
    if(!sessionPath.empty())
    {
      ROS_WARN("\"settings_path\" parameter is ignored when \"
  session_path\" is set.");
    }

    QString path = settingsPath.c_str();
    if(path.contains('~'))
    {
      path.replace('~', QDir::homePath());
      settingsPath = path.toStdString();
    }
  }

  // Load settings, should be loaded before creating other objects
  Settings::init(settingsPath.c_str());

  FindObjectROS * findObjectROS = new FindObjectROS(objFramePrefix)
    ;
  if(!sessionPath.empty())
  {
    if(!objectsPath.empty())
    {
      ROS_WARN("\"objects_path\" parameter is ignored when \"
  session_path\" is set.");
    }
    if(!findObjectROS->loadSession(sessionPath.c_str()))
    {
      ROS_ERROR("Failed to load session \"%s\"", sessionPath.c_str
  ());
    }
  }
  else if(!objectsPath.empty())
  {
    QString path = objectsPath.c_str();
    if(path.contains('~'))
    {
      path.replace('~', QDir::homePath());
    }
    if(!findObjectROS->loadObjects(path))
    {
      ROS_ERROR("No objects loaded from path \"%s\"", path.
  toStdString().c_str());
    }
  }

  CameraROS * camera = new CameraROS(subscribeDepth);

  QObject::connect(
      camera,
      SIGNAL(rosDataReceived(const std::string &, const ros::Time
  &, const cv::Mat &, float)),
      findObjectROS,
      SLOT(setDepthData(const std::string &, const ros::Time &,
  const cv::Mat &, float)));

  // Catch ctrl-c to close the gui
  setupQuitSignal(gui);
  if(gui)
  {
    QApplication app(argc, argv);
    MainWindow mainWindow(findObjectROS, camera); // take ownership

    QObject::connect(
        &mainWindow,
        SIGNAL(objectsFound(const find_object::DetectionInfo &)),
        findObjectROS,
        SLOT(publish(const find_object::DetectionInfo &)));

    QStringList topics = camera->subscribedTopics();
    if(topics.size() == 1)
    {
      mainWindow.setSourceImageText(mainWindow.tr(
          "<qt>Find-Object subscribed to <b>%1</b> topic.<br/>"
          "You can remap the topic when starting the node: <br/>\"
   rosrun find_object_2d find_object_2d image:=your/image/topic\".<
   br/>"
          "</qt>").arg(topics.first()));
    }
    else if(topics.size() == 3)
    {
      mainWindow.setSourceImageText(mainWindow.tr(
          "<qt>Find-Object subscribed to : <br/> <b>%1</b> <br/> <b
   >%2</b> <br/> <b>%3</b><br/>"
          "</qt>").arg(topics.at(0)).arg(topics.at(1)).arg(topics.
   at(2)));
    }
    mainWindow.show();
    app.connect( &app, SIGNAL( lastWindowClosed() ), &app, SLOT(
   quit() ) );

    // loop
    mainWindow.startProcessing();
    app.exec();
    Settings::saveSettings();
  }
  else
  {
    QCoreApplication app(argc, argv);

    // connect stuff:
    QObject::connect(camera, SIGNAL(imageReceived(const cv::Mat &))
   , findObjectROS, SLOT(detect(const cv::Mat &)));

    //loop
    camera->start();
    app.exec();

    delete camera;      //deallocating
    delete findObjectROS;
  }
  return 0;
}
```

Listing 6.1: Object Detection - (C++)

A little **code explanation** to highlight central features:

- In the `main`, the *find object* node is defined and some parameters are made explicit to allow modification through, for example, a launch file (which is what we are going to do).
- Session and Settings paths are set to default values.
- Loading pre-saved objects giving their path. This is central, in fact once registered an object, there's no need of the GUI, and we are searching for it on the basis of the picture stored in `objectsPath`.
- Then the core application runs without further modifications.

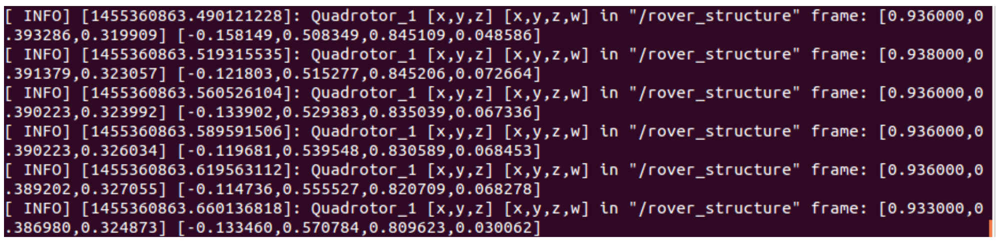
TF tree Once graphically recognized our object, the following code retrieves its frame with respect to the one specified in `mapFrameId_`.

```
#include <ros/ros.h>
#include <tf/transform_listener.h>
#include <find_object_2d/ObjectsStamped.h>
#include <QtCore/QString>

class TfExample
{
public:
  TfExample() :
    mapFrameId_("/rover_structure"),
    objFramePrefix_("quadrotor")
  {
    ros::NodeHandle pnh("~");
    pnh.param("map_frame_id", mapFrameId_, mapFrameId_);
    pnh.param("object_prefix", objFramePrefix_, objFramePrefix_);

    ros::NodeHandle nh;
    subs_ = nh.subscribe("objectsStamped", 1, &TfExample::
   objectsDetectedCallback, this);
  }

  // Here I synchronize with the ObjectsStamped topic to
  // know when the TF is ready and for which objects
  void objectsDetectedCallback(const find_object_2d::
   ObjectsStampedConstPtr & msg)
  {
    if(msg->objects.data.size())
    {
      for(unsigned int i=0; i<msg->objects.data.size(); i+=12)
      {
        // get data
        int id = (int)msg->objects.data[i];
        std::string objectFrameId = QString("%1_%2").arg(
   objFramePrefix_.c_str()).arg(id).toStdString(); // "quadrotor_1
   ", "quadrotor_2"

        tf::StampedTransform pose;
        tf::StampedTransform poseCam;
        try
        {
          // Get transformation from "object_#" frame to target
   frame
          // The timestamp matches the one sent over TF
          tfListener_.lookupTransform(mapFrameId_, objectFrameId,
   msg->header.stamp, pose);
          tfListener_.lookupTransform(msg->header.frame_id,
   objectFrameId, msg->header.stamp, poseCam);
        }
        catch(tf::TransformException & ex)
        {
          ROS_WARN("%s",ex.what());
          continue;
        }

        // Here "pose" is the position of the object "id" in "/
   rover_structure" frame.
        ROS_INFO("Quadrotor_%d [x,y,z] [x,y,z,w] in \"%s\" frame:
   [%f,%f,%f] [%f,%f,%f,%f]",
            id, mapFrameId_.c_str(),
            pose.getOrigin().x(), pose.getOrigin().y(), pose.
   getOrigin().z(),
            pose.getRotation().x(), pose.getRotation().y(), pose.
   getRotation().z(), pose.getRotation().w());
      }
    }
  }

private:
  std::string mapFrameId_;
  std::string objFramePrefix_;
    ros::Subscriber subs_;
    tf::TransformListener tfListener_;
};

int main(int argc, char * argv[])
{
    ros::init(argc, argv, "tf_example_node");

    TfExample sync;
    ros::spin();
}
```

Listing 6.2: Retrieval of Object’s Frame - (C++)

Breaking-down the code :

- In the constructor, we initialize `mapFrameId_` and `objFramePrefix_` to, respectively, "/rover_structure" and "quadrotor". For a different application they could be later on modified with the appropriate *node parameters*.
- Function `objectsDetectedCallback` is responsible of assigning a reference frame to the detected object; Also, makes sure that timestamp matches. In order not to have the error *lookup in the future*, a good choice is to select an high frequency refresh rate. I selected 100Hz for this reason too.
- Posting desired information on terminal output (shown in Fig. 6.1)



```
[ INFO] [1455360863.490121228]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.936000,0
.393286,0.319909] [-0.158149,0.508349,0.845109,0.048586]
[ INFO] [1455360863.519315535]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.938000,0
.391379,0.323057] [-0.121803,0.515277,0.845206,0.072664]
[ INFO] [1455360863.560526104]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.936000,0
.390223,0.323992] [-0.133902,0.529383,0.835039,0.067336]
[ INFO] [1455360863.589591506]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.936000,0
.390223,0.326034] [-0.119681,0.539548,0.830589,0.068453]
[ INFO] [1455360863.619563112]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.936000,0
.389202,0.327055] [-0.114736,0.555527,0.820709,0.068278]
[ INFO] [1455360863.660136818]: Quadrotor_1 [x,y,z] [x,y,z,w] in "/rover_structure" frame: [0.933000,0
.386980,0.324873] [-0.133460,0.570784,0.809623,0.030062]
```

Figure 6.1: Terminal Output, Object Recognition

- Eventually, we launch the node just built.

Launch File Just as done in previous chapters, the last step is the composition of a launch file for this application. In here we are starting the nodes needed and we are setting the desired parameters.

```
<launch>
  <!-- Launching the camera. NOTE: using openni2 for our asus
   camera -->
  <include file="$(find openni_launch)/launch/openni.launch">
        <arg name="depth_registration" value="true" />
    </include>

  <node name="find_object_3d" pkg="find_object_2d" type="
   find_object_2d" output="screen">
    <param name="gui" value="false" type="bool"/>
    <param name="settings_path" value="~/.ros/find_object_2d.ini"
   type="str"/>
    <param name="subscribe_depth" value="true" type="bool"/>
    <param name="objects_path" value="~/roverARM_ws/src/
   find_object_2d/saved_objs" type="str"/>
    <param name="object_prefix" value="quadrotor" type="str"/>
    <param name="obj_frame_prefix" value="quadrotor" type="str" />

    <remap from="rgb/image_rect_color" to="camera/rgb/
   image_rect_color"/>
    <remap from="depth_registered/image_raw" to="camera/
   depth_registered/image_raw"/>
    <remap from="depth_registered/camera_info" to="camera/
   depth_registered/camera_info"/>
  </node>
  <!-- script to retrieve TF of the detected object -->
  <node name="tf_example" pkg="find_object_2d" type="tf_example"
   output="screen">
    <param name="map_frame_id" value="/rover_structure" type="
   string"/>
  </node>


  <!-- transformations for our system -->
  <node pkg="tf" type="static_transform_publisher" name="
   rover_base_to_camera_tf"
    args="0.4 0.4 0.3 0.0 0.0 0.0 /rover_structure /camera_link 100
   " />

</launch>
```

Listing 6.3: Find Quadrotors - (Launch file)

Main features launched with the file:

- Start the camera driver with RGB and Depth points registration.
- Launching and setting parameters of our detection node. `"gui"` is set to `false` because we are giving `"~/roverARM_ws/src/find_object_2d/saved_objs"` where the image of the object to detect is stored. Object and Frame codes are set identical to the ones in the original script, so their expression can be avoided.
- Remap to correct desired image topics. Openni2 package gives them in the form `/camera/`<desired/image/topics>.
- Node for the detection of the frame is started, taking as a reference `"/rover_structure"`.
- A static transform from camera link (objects would be detected with respect to this frame obviously) to the main rover_structure frame eases the navigation as explained at the beginning of this section.

Note: I made a variation to this launch file too, avoiding to include the camera driver. In the real case, when we will be looking for a landed copter, the camera driver would be already on and running due to previous launch files shown in section 5, needed for obstacle avoidance and OctoMap Update.

6.3 Testing Object Detection

In this section we test the actual functionality of this piece of software.
Thanks to our characteristic pattern attached to quadrotors, we are able to localize them; In practice, as already said, we want the camera to recognize the image stored in the directory defined above.

6.3.1 Retrieval of the UAV's Reference Frame

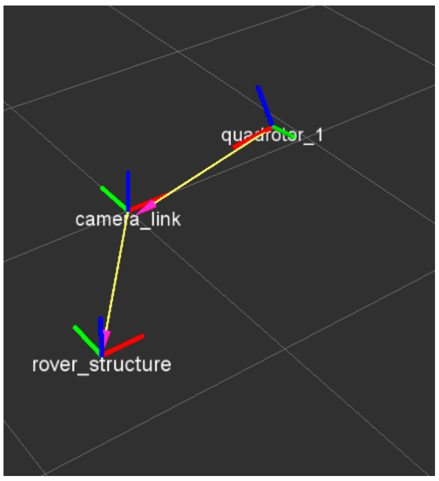


Figure 6.2: Obj Recognition, TF tree retrieved

In broad terms, what we expect to achieve running the scripts above, is to display the frame of the object that carries "on board" (it will be attached on the sides of the quadcopter) the same image as the one in "`objects_path`". In fact, this is actually reported in Fig. 6.2.
The relationships between the frames are represented by RViz just listening to the same stream of data we can see in our terminal output in Fig. 6.1 when an object is correctly identified by the program.
However, we want this application to work in symbiosis with the rest of our visual sensor data: now, we want to combine object detection with point-cloud stream, again with the OctoMap system. In this way, we allow recognition of the copter, we keep track of obstacles, and the actual drone to pick up won't just be seen as a rectangular image, indeed, its actual whole shape will be fed back to the computational unit to elaborate the pick-and-place task.

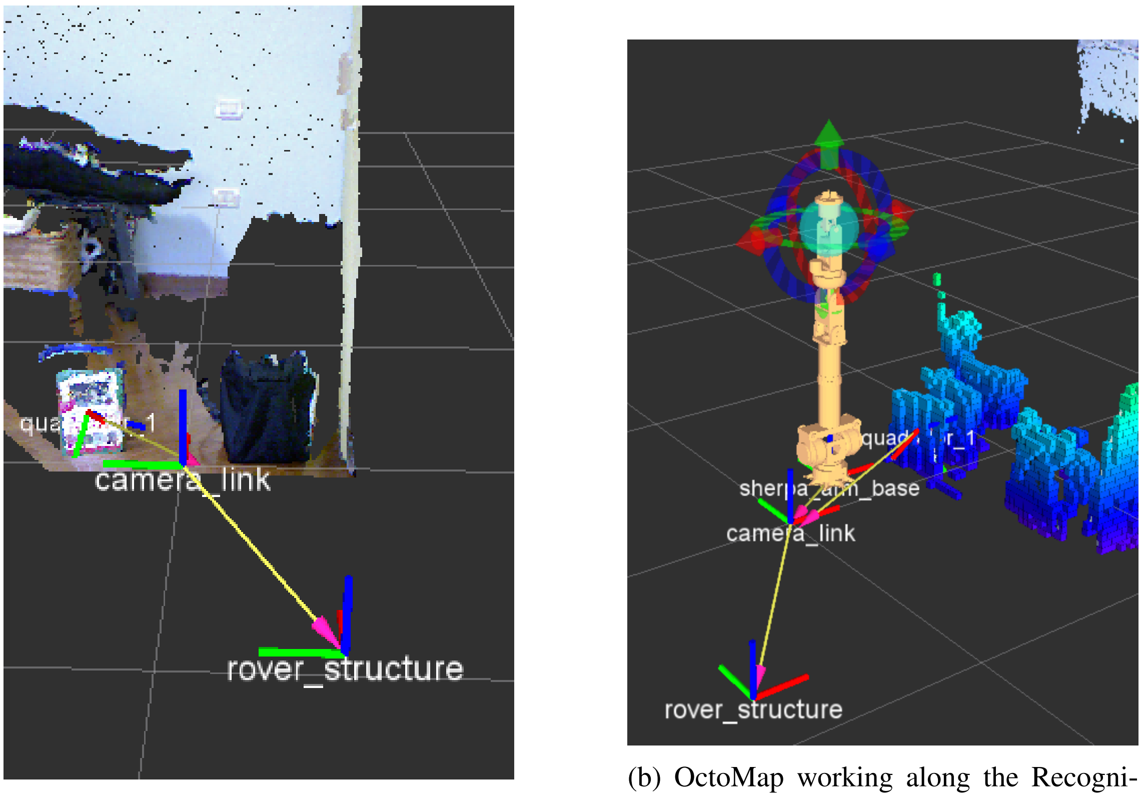
6.3.2 Gathering up Data in the same RViz instance

As reported in Fig. 6.3, we are able to display all important information in a single RViz window. In that figure, picture (a), I simply launched the file in section 6.2.2 and I set RViz listening to a PointCloud2 topic coming out of the camera stream, (through "openni" package).
In the second picture (b), I launch every piece of software we took care of describing in the various chapters.
What appears in the last picture is :

- Robot arm model, used for motion planning tasks.
- The most important reference frames, including the one of the recognized copter and the one used for navigation purposes ("rover structure").
- PointCloud2 stream with the OctoMap Update working.

In practice, to combine those views, we want to launch the file described in the *Listing 5.3* plus a second launch file for the Find-Object pkg, this one reported in *Listing 6.3*.

Note : I actually crafted a launch file, almost identical to *Listing 6.3*, where I avoid calling the camera driver. I named this file `find_quadrotors_online.launch`, meaning that the camera is assumed to be already "online", because launched with the previous file.



(a) PointCloud stream with Object Detection

(b) OctoMap working along the Recognition package

Figure 6.3: Complete Obstacle and specific Target Detection

Chapter 7

Conclusion

To sum up, I want to make considerations and analyse what has been achieved in this thesis work.
A presentation of the SHERPA-Rover Arm used, followed by a "Robotics Introduction", has been reported, in order to define the scope of the project.
Concerning the *Operative Section*, the tools I made us of have been explained; After a careful analysis, we opted for the combination of *ROS* with *RViz* as a simulator engine, everything linked with *MoveIt!* application. Through this last one, we could appreciate how motion planning tasks can be carried out and how *foreseen* obstacles can be avoided, by placing in the script their model.
To go the extra mile, the aim was to effectively detect obstacles in the surrounding environment, make a collision model understandable by the MoveIt! planner, still keeping human commands and GUI not used : to make it possible, proper configuration files have been added to bond together camera data stream and OctoMap Update feature.
Lastly, it was key for the project not to mistake obstacles with the quadcopters; In fact, the most important task the rover has to be able to execute, is the recovery of landed UAVs in total autonomy. By attaching a specific image pattern to the quadrotors, through a customized ROS Package, we defined an application capable of distinguishing the selected target from the whole collection of visual data and output its reference frame with respect to the "basic" one, used for navigation, called *rover_structure*.

Finally, I would like to point out that all the achievements above just required an URDF model, and the addition of some physical constraints, to actually make feasible the motion of the Robotic Arm out of the simulation environment. Hence, the software produced is characterized by a very **high portability**, meaning that it could be proposed in many other fields (in general, wherever obstacle-avoidance and target recognition may be required), and still suitable with different arms' structures; Indeed, by updating the URDF model, along with its specific construction limits, this work can be made **compatible** in other projects where, clearly, other hardware components have been used.

Appendices

Appendix A

Making it Work

Getting Started First of all, complete a proper configuration of ROS and MoveIt! (respective websites available in the Bibliography).
Now, download my collection of files from :

```
https://github.com/AlessandroSantoni/SHERPA-Arm-MoveIt-Controller
```

and "catkin_make" them in the "src" folder where you installed MoveIt! too.
We're now ready to make some tests.

Homing Procedure We will simply ask the arm to plan to the "home" pose, which has been defined in the *.srdf file*. This would make easier the planning into more complex configurations, since at the very beginning the arm stands in a *singular* position.
You can refer to the source file `rover_arm_homing.cpp`.
Execute in the command line:

```
roscore &
roslaunch rover_arm_moveit_applications rover_arm_homing.launch
```

Note : If the planner seems not to display the motion, tick the checkbox "loop animation".

Joint Space Goal With this script, a setpoint in terms of positions is given to some joints.
Refer to the source file `rover_arm_joint_space_goal.cpp` and adjust the position values vector to the desired ones, if needed.
On a terminal, run:

```
roscore &
roslaunch rover_arm_moveit_applications rover_arm_joint_space_go-
al.launch
```

Simple Obstacle Avoidance Hereafter, a simple application of obstacle detection and avoidance is reported. This time, an *end-effector pose setpoint* is given; the trajectory will be computed at first in an obstacles-free environment and then, keeping the same desired pose for the gripper, obstacles will be introduced.
This is a "preliminary" script because, later on, we are going to implement obstacle detection through the camera sensor.
Refer to source code in `rover_arm_obstacle_avoidance.cpp`.
To test this application, execute :

```
roscore &
roslaunch rover_arm_moveit_applications rover_arm_obstacle_avoid-
ance.launch
```

Obstacles Detection with Camera Sensor In order to launch this functionality, we will need to set up a proper "collision scene" and give an end-effector pose that will make the test meaningful.
In my script,the setpoint is given with respect to my "testing-room settings", and it's a point behind an object (as shown in Figure 5.2). You should try to do the same.
The script `rover_arm_obstacle_on_camera.cpp` is similar to the one above, the only difference lies in the launching of `demo_tf_modified_camera.launch` rather than the regular RViz `demo.launch`. In fact, the first one, will make calls to the camera drivers, sensors configuration and OctoMap Update algorithm.
Launch this file:

```
roscore &
roslaunch rover_arm_moveit_applications rover_arm_obstacle_on_ca-
mera.launch
```

Target Recognition As explained in the appropriate chapter, we can also retrieve the reference frame of a desired object, by including its distinctive image pattern in the described path.
In verifying this application, we will practically put all things together. The recognition of an object will be made on top of the collision scene updating and the motion planning capabilities.
Here I list the commands to run the intended nodes:

```
roscore &
roslaunch rover_arm_moveit_config demo_tf_modified_camera.launch
```

After playing a little bit around with this "demo", in a second terminal execute:

```
roslaunch find_object_2d find_quadrotors_online.launch
```

Notes :

- I launch the "online" version of this last script, because I assume the camera drivers already running (those services are called by "demo_tf_modified.launch").
- To save your target image in the specified folder, follow the citation I made of the ROS package "find_object_2d".
- The launch file "find_quadrotors_online.launch" can be obviously called in the previous applications too; I launched the demo just as a test.
- Remember to add the "TF" panel in RViz to display the reference frame of the recognized object.

Appendix B

Code License

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