Stabilize humanoid robot teleoperated by a RGB-D sensor

Andrea Bisson*, Andrea Busatto*, Stefano Michieletto, and Emanuele Menegatti

Intelligent Autonomous Systems Lab (IAS-Lab)
Department of Information Engineering (DEI)
University of Padova
{bissonan,busattoa,stefano.michieletto,emg}@dei.unipd.it
http://robotics.dei.unipd.it

Abstract. An easy way to let a robot execute complex actions is to let the robot copy human moves. Useful information are read by sensors and elaborated to convert them into robot movements.
This work focuses on keeping the robot balanced while it is performing an action: grasp an object laying on the ground in front of the robot. Experiments are performed with a human user moving in front of the sensor using a humanoid robot performing the same action, the Vstone Robovie-X.

1 Introduction

In this paper we describe a laboratory experience involving a humanoid robot an its behaviours. This work follows to some similar experiences [1] already developed in our lab. The proposed system elaborates online human movements in order to control the robot joints. The goal is to make robot picking up an object teleoperated by an human actor. The robot has to avoid unstable situations by automatically balancing the input movements could make it fall down. *Robot Stabilization* is the key step of the complete process (Fig. 1) used to compute suitable joint values: the algorithm elaborates a feedback signal to keep the robot balanced during the movement.

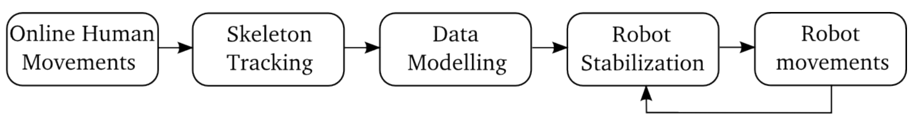

Fig. 1. Overview of the entire system proposed in this paper.

The robot used in this work is a humanoid: the Vstone Robovie-X. Robovie-X is a flexible and economic platform already used in robotics courses to make

* These authors contributed equally to this work.

students familiar with humanoids. Our lab also provided us a simulated version of this humanoid in order to prevent robot damages during the tests.

The remainder of the paper is organized as follows: in Section 2 the data acquisition system is explained, while the robot structure is illustrated in Section 3. The stability algorithms used, math and physics behind them and some specific tests performed are described in Section 4. Finally, Section 5 contains conclusions.

2 Data acquisition

In this paper, data are acquired from a low cost RGB-D sensor: a person can perform the desired actions in front of the sensor without any need of additional equipment. A skeleton tracking system is used to extract human joints positions and angles from the raw data provided by the sensor, namely a Microsoft Kinect. The skeleton information (Figure 2) is subsequently remapped to the robot model, so that the person acting in front of the camera could simply teleoperate the robot by his own body, similarly to the systems described in [2], [3], and [4].

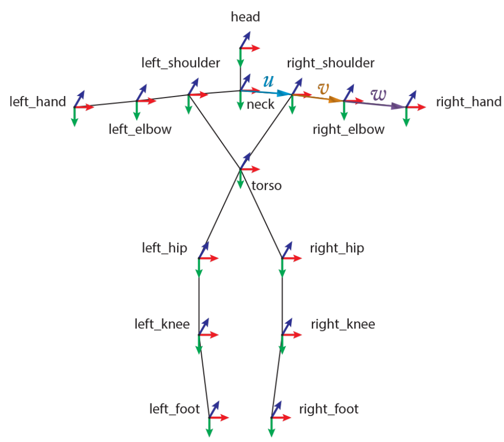

Fig. 2. Skeleton joints provided by the tracker.

3 Robot structure analysis

The robot used in this work is a Vstone Robovie-X (Fig. 3). It is a small humanoid robot with 17 DoF (Head 1, Arms 6, Legs 10). In this work the whole robot body has been used to get it stable. In particular the upper body is also involved in a grasping action so arms and shoulders can't be enforced to completely keep the stability. The lower body is mainly controlled in order to maintain balance but it is also important to let the robot reach objects easily.

Fig. 3. The small humanoid used in this work: the Vstone Robovie-X.

4 Robot stability

In the following subsections are described the stability algorithms and optimizations for the robot movement.

4.1 Base strategy

As we said before, our primary goal is to make a robot pick up an object laying in front of it by imitating the human movements coming from a skeleton tracking system. The main challenge is to keep the robot stable while it is crouching and grasping the object.

A consolidated method to maintain the robot stability [5] is to keep the Center of Mass (CoM) projection point inside the contact area of the feet with the ground. The CoM projection point of the robot should be calculated in order to reach two different purposes: maintain the point inside the safe balanced area and keep the robot movements as similar as possible to the user motions.

At each instant, the CoM is equal to:

$$CoM_x = \frac{\sum_{k=1}^{N} m_k\, x_k}{M}; \quad CoM_y = \frac{\sum_{k=1}^{N} m_k\, y_k}{M}; \quad CoM_z = \frac{\sum_{k=1}^{N} m_k\, z_k}{M} \tag{1}$$

where $N = 17$ is the number of joints, m_k is the k^{th} joint inertial mass, M is the mass of the robot, and x_k, y_k, z_k are the coordinates of the k^{th} joint with respect to the Torso joint.

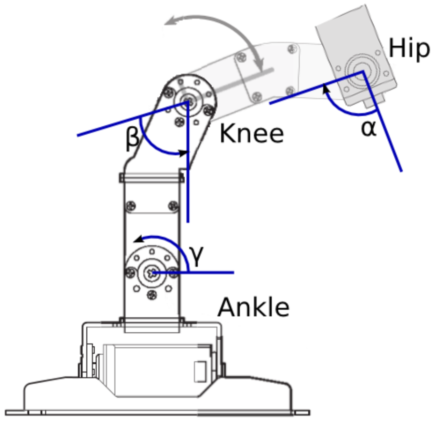

Fig. 4. Main joint angles involved in balance.

Thus, the ground projection of the CoM is given by (CoM_x, CoM_y), and it has to satisfy the constraints $-90cm < Com_x < 90cm$ and $-35.5cm < Com_y < 35.5cm$ that is the area covered by the robot foot in the initial standing position. The selected movement is quite simple, so several solutions are feasible to solve the problem. We imposed a strong relation between hip, knee an ankle joints in order to involve all the lower body joints and at the same time adapt to the human natural behaviour.

$$\gamma = \alpha = \frac{\beta}{2}\,, \qquad 0 \leq \beta \leq 157^o \tag{2}$$

where α is the pitch hip angle at instant t, β is the knee angle at instant t, and γ is the pitch ankle angle at instant t. Fig. 4 shows the three described angles in the robot model. The method was tested experimentally on both simulated and real robot.

4.2 Refinement

We refine the described technique applying different strategies in order to avoid some rough robot movements we noticed during the initial tests. Studying the dynamics of the task, we decided to limit roll movements (i.e. lateral movements) in joints not involved in reaching the goal, like hips and ankles.

Fast and sudden movements could threaten the robot stability while performing an activity. Ensuring the smoothness of all robot moves is essential in balancing purpose. Without any focused control, the input data can make the robot move jerkily. This problem is due to the fast human movements compared with the frame rate of the sensor and to the margin of error of the skeleton tracker computing joints positions.

The data acquired by the RGB-D sensor are filtered to remove the noise by calculating the mean value of the last three angle values of every joint in order to avoid rough robot movements and obtain a smoother motion.

The pose feedback equation is:

$$\hat{\xi}_t = \frac{\hat{\xi}_{t-2} + \hat{\xi}_{t-1} + \xi_t}{3} \tag{3}$$

where ξ_t is the raw value given by the skeleton tracker for a certain joint, $\hat{\xi}_t$ is the computed value at the instant t for the considered joint, $\hat{\xi}_{t-1}$ is the computed value at the instant $t-1$ for the considered joint, $\hat{\xi}_{t-2}$ is the computed value at the instant $t-2$ for the considered joint.

Moreover, the movements of the right and left side of the robot body are coordinated in order to make easier for the robot to grasp the object. In this way, we also increase the robot stability and its precision during the motion.

Finally, the proportions between lower body angles are computed according to the equation 2. These refined data are used as input to the algorithm checking if the CoM projection on the ground is inside the stability area.

Again, the whole system has been tested with many users and different objects[1] on both real and simulated environment. The applied refinements significantly improved the performance and the users easily reached the goal. It is worth to notice that a slight delay is introduced by USB connection between the system and the real robot, nevertheless no delay is present in the simulated model, that works at 30 fps. We also can make real and simulated robot work together, so humans can take advantage of the information provided by the virtual model.

5 Conclusions

In this paper, a robot behaviour was developed in order to maintain robot stability during a pinking up task performed by human teleoperation. The system keeps the robot stable using movements as similar as possible to the user ones. Our technique reach real-time performances, the robot is able to move smoothly according to user movements.

The system has been tested with different users and objects and it has also been exposed as a working demo to the "The Researchers Night"[2] in Padova.

The work described in this paper could be used jointly with a Robot Learning from Demonstration (RLfD) framework already developed in our lab [6]. RLfD is a programming paradigm that uses demonstrations in order to make a robot learn new tasks. The system can be applied to improve the stability of the robot while it is performing the learned activity. The idea is to extend our lab

[1] Few videos of some tests realized: `https://www.youtube.com/watch?v=LJyXT6gAyo8` `https://www.youtube.com/watch?v=AOIkVLn3Kng` `https://www.youtube.com/watch?v=GS9A4prXfpI`

[2] http://www.near-nottedeiricercatori.it/

experience by modeling the movements of the person in front of the sensor using a Gaussian Mixture Model (GMM). The GMM will provide us a probabilistic way to to classify a movement as safe or unsafe in order to prevent robot falls.

As future work we also will improve the system by increasing the set of supported actions and applying it to scenarios involving innovative robotic platforms like exoskeletons.

References

1. Michieletto, S., Ghidoni, S., Pagello, E., Moro, M., Menegatti, E.: Why teach robotics using ROS. Journal of Automation, Mobile Robotics & Intelligent Systems (in press)
2. Pollard, N.S., Hodgins, J.K., Riley, M.J., Atkeson, C.G.: Adapting human motion for the control of a humanoid robot. In: Robotics and Automation, 2002. Proceedings. ICRA'02. IEEE International Conference on. Volume 2., IEEE (2002) 1390–1397
3. Dariush, B., Gienger, M., Arumbakkam, A., Zhu, Y., Jian, B., Fujimura, K., Goerick, C.: Online transfer of human motion to humanoids. International Journal of Humanoid Robotics **6**(02) (2009) 265–289
4. Michieletto, S., Chessa, N., Menegatti, E.: Learning how to approach industrial robot tasks from natural demonstrations. In: Proceedings of IEEE Workshop on Advanced Robotics and its Social Impacts ARSO2013, IEEE (2013)
5. Vukobratović, M., Stepanenko, J.: On the stability of anthropomorphic systems. Mathematical Biosciences **15**(1) (1972) 1–37
6. Michieletto, S., Rizzi, A., Menegatti, E.: Robot learning by observing humans activities and modeling failures. In: IROS workshops: Cognitive Robotics Systems (CRS2013), IEEE (Nov 2013)