

Safe, Reliable and Friendly Interaction Between Humans And Humanoids

Raja Chatila, Rachid Alami, Thierry Siméon, Julien Pettré, Léonard Jaillet
LAAS-CNRS
7, Avenue du Colonel Roche, 31077 Toulouse Cedex 4, France
{Firstname.Lastname}@laas.fr

Abstract

Humanoid robots include a mobile base (walking or rolling) and manipulation devices, usually two arms. By the number of actuators and accessible workspace, they are certainly the most complex robotics systems designed. Unlike classical robots in industry, they have to interact directly with humans, and unlike service robots which have usually only a mobility capacity or limited manipulation, this interaction is a very close one. It is therefore mandatory that the safety and human-friendly aspects of this interaction be addressed as such, considering the problem in its entirety. This paper discusses these issues considering several constraints that must be respected by the robot motion planning system, related to the human-robot interaction distance. It introduces the concepts of safety distance, social distance, manipulation zone, and friendly posture.

1. Introduction

Research on humanoid robots has achieved several results on the issues related to their design and control for walking, navigation, manipulation, etc. On the other hand several issues related to human-friendly robots have also been addressed including the study of human behavior and modeling of human environment. Finally, the dependability issues of robots in terms of the reliability of achieving their tasks and the safety aspects related to their interaction with humans are also subject of investigation. This paper addresses new issues related all these aspects and specifically to the close interactions between humans and humanoid robots from the standpoint of the motion decisions that must be taken by the robot in order to ensure a :

- A *safe* interaction, i.e., that cannot harm the human,
- A *reliable* interaction, i.e., that achieves the task adequately

considering the motion capacities of the robot, and

- A *user friendly* interaction, i.e., that takes into account a motion model and a communication model of the human.

We discuss next these notions that are based on the identification of several models for interaction.

2. Safe Interaction

In human environments, safety issues are of concern. The basic functions for a safe sensory human/robot interaction include for instance compliant motions. But a central point is that robot must be able to take into account the safety of the human body. In [1], the authors address a similar question concerning the robot own body. In this paper we address the interaction with humans. In any of its motions the robot should not be able to harm the human, and therefore it must identify a safety distance to the human. However, the robot must be able to approach the human because of the necessity of their interaction (for example to handle some object to the human). Hence, this distance is not uniform and fixed, but depends on the interaction. Figure 1. depicts a safety distance which is represented by bubbles surrounding the human.

2.1 Human safety distance

The human has an articulated multi-body structure. We can identify a “safety suit” which is attached to the human body, composed of bubbles at a predefined distance from its skin and which represents a forbidden region in the robot configuration space. By permanently computing the minimal distance between its own body and the human safety suit, the robot will produce motions that are safe guarded and will never

collide with the suit, and therefore keep the human body out of robot reach (figure 2).



Figure 1: safety distances. Virtual “bubbles” surround the human.

Even if mechanical safety devices such as touch sensors are built in the robot for safety, it is desirable that the robot plans motion that are safe.

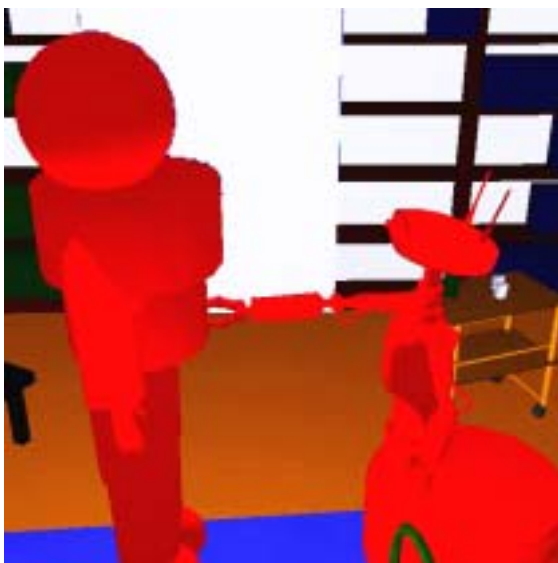


Figure 2: The human safety distance is a forbidden region frontier in the configuration space of the humanoid robot.

The motion planning system of the humanoid robot, considering its whole body, takes into account the geometrical model of the human body and includes a collision checker. The model may include a large number of geometric primitives, and it is well known that the most time consuming operation in motion

planning are interference detection and collision-checking. The motion planning system Move3D that we developed [2,3] is based on probabilistic motion planning techniques [4] and includes an Interference-detector [5] based on algorithms combining techniques proposed in [6] while allowing to process non convex polyhedra together with other volumic primitives (eg. spheres, tubes, torus) as in [7].

Computation is performed in two stages: selection of possibly colliding pairs based on simple bounding volumes that approximate the geometry of the objects, and a precise interference detection limited to the pairs selected at the first stage.

A hierarchical structure based on OBB-trees is constructed on top of the convex primitives (or facets), instead of the triangular decomposition required by [8]. This allows to reduce the size of the data structures in large models where most of the objects are modeled by simple primitives.

The Collision-checker developed for determining whether a given path is collision-free or not, is currently performed by multiple calls to the interference detection algorithms, using a dichotomic sampling of the path and a non uniform step computed from the distance to the obstacles.

2.2. Human interaction distances

In usual interactions between humans, some non written rules are respected that determine the distance between two persons (see the controversial proxemic theory of E. T. Hall [9]). Hall has proposed that four interpersonal distances were respected in society : *Intimate* distance (0 to 1.5 feet) for very close relationships, *Personal* distance (1.5 to 4 feet) for most usual friendly interactions and conversations, *Social* distance (4 to 12 feet) for more formal social interactions, and finally *Public* distance (over 12 feet) with minimal interactions. Of course these figures are approximate and related to culture and several other factors. However in human-robot interaction distances will also be defined because humans are used to respect such distances and would be surprised or would not feel at ease if a humanoid robot does not respect them. In addition, if the interaction with the humanoid

robot is similar to the interaction with other humans, i.e., through speech, vision and touch, then such distance will be very natural to the human. Our purpose is to make them also natural for the robot. Hence, when a robot must listen to a human or speak to him or her, or when it moves along the human or when a human approaches the robots (figure 3) etc., it must be always keep the adequate distance. Again, distance checking in the robot motion planning and control system plays a central role.



Figure 3: The forbidden distance represents the human intimate distance. The robot must move away when in contact with it.

3. Reliable interaction

In some situations, the robot and the human must exchange objects that are manipulated and handed from one to the other. In this case, the safety distance must be adapted to this kind of interaction, as well as the proximity of the robot and human bodies.

But in order to actually be human friendly and reliable, the robot must understand what is the adequate position or motion to adopt so that the object manipulation task is feasible by the human in a manner that is the most comfortable for them. For this a **human motion model** is required, as well as a **human-robot manipulation model** for object exchange. Here again, the motion planning system plays a central role in checking the adequate constraints. Figure 4. shows how a specific zone can be defined for object exchange, which enables to violate

the constraint of the safety distance. However, a closer safety distance is then defined to forbid direct contact (figure 5). For object exchange, the safety region can be defined closer to the human body. We can note that in such exchanges, the robot motions are more local and slower.



Figure 4: An exchange zone related to the human manipulation model is defined for direct interaction.



Figure 5: The forbidden region during object exchange is closer to human body.

4. Friendly Interaction

In order to feel safe, the human must be able to see the robot and to expect its motions. This in turn means that the robot must have

a model of human communication behavior . For example, when the robot speaks to the human it is more adequate to face him or her at, or when it must hand something to him/her, it is again better that the robot comes to face the human, even if this requires it to avoid obstacles or to plan a complex motion [10]. The robot should be endowed with a **human communication model** defining its capacities and adapted to the human which the robot interacts with (e.g, handicapped or not). Figure 6 shows an example of robot reaction when understanding the human “calling” gesture requiring a service from the robot.



Figure 6: Even if the robot has gesture recognition capacities the glass is shown for service), it must produce also understandable motions in cluttered environments.

If the human requires some action from the robot, the robot motion must be adapted to the human behavior. Figure 7 shows the robot pouring water in the glass handed out by the human. Here the motion planning system must reason on the human reachable workspace and on the obstacles in the environment to compute a path of the whole robot body so that the pouring operation is possible **and** seems natural for the human.

5. Conclusion

In this paper we have introduced the requirements on the humanoid robot motion system for producing safe, reliable and friendly motions during its interaction with

humans. These requirements translate into an efficient motion planning system with permanent collision checking of the robot whole body with the human body using the notion of safe distance and models of human interactions related to interaction distances, object manipulation, human motion and human communication. Work is in progress for experimenting these concepts in the motion planning system MOVE 3D.



Figure 7: The motion planner must plan a position of the robot and of the pouring gesture that look natural and are safe for the human.

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