Arms motion of a humanoid inspired by human motion

Marija Tomić[1], Christian Vassallo[2], Christine Chevallereau[3], Aleksandar Rodić[4], Veljko Potkonjak[5]

I. Objective of the work

New generation of humanoid robots are becoming more faithfully copies of the human body. In order to facilitate the integration of humanoid robots in the human environment, our objective is to generate humanoid motions inspired by human motion in the everyday human activities. Human body has many Degrees of Freedom (DOFs), but classical kinematic representation of each arm involves 7 DOF. Thus to achieve a defined task with the hand, even including position and orientation, redundancy exists. The redundancy is increased with the possibility of displacement of the trunk. In robot control, the redundancy is generally solved at the kinematic level by minimization of criterion or definition of several tasks with different priority level [1, 2]. In this context our objective is to define which criterion in IK algorithm leads to human like motion.

In this paper we proposed the nonlinear optimization algorithm for conversion human to humanoid motion. It is based on the Virtual markers which are placed on segments of scaled model of robot. During the movements the position and orientation evolution of Virtual marker match the Real Markers evolution attached to the actor. The algorithm is tested on different type of recorded motion. The obtained generalized coordinates from the imitation algorithm are used to calculate the position and orientation of robot wrists. Following the position and orientation of wrists are the tasks of IK algorithms. To achieve these tasks and generate human like motion the IK algorithms with different criterions are used. The comparative analysis of all IK algorithms is given.

II. Introduction

A. Human to Humanoid motion – State of the Art

A human movement is a unique and coordinated gesticulation resulting from simultaneous muscles contractions generated by an electric nervous signal. The understanding and modeling of human movement and motion is based on observation. Motion observation evolves with the evolution of the available technologies for observation [3]. Today the motion capture technologies are based on: acoustic, magnetic, mechanical, inertial and optical. The differences between motion capture technics can be in positions and size of the active sensors, volume of measurements, resolution, precision of the algorithms, and transfer of data, cost … The most commonly used technique for recording human movement is marker based motion capture system. The information from the markers can be useful to obtain the kinematic characteristics of human. In [4] an algorithm for automatically estimating a subject's skeletal structure from optical motion capture data is presented. This algorithm defined the cluster of markers into segment groups, determines the topological connectivity between these groups and locates the positions of their connecting joints. In [5], a method to identify the geometric parameters of a human skeletal model is presented. The parameters are modeled as the generalized coordinates of virtual mechanical joints. The joint's trajectories are computed from the motion capture data. The method was also applied to obtain a subject-specific musculoskeletal model. In [6], a Cartesian control approach is developed in which a set of control points on the humanoid is selected and the robot is virtually connected to the measured marker points via translational springs. This procedure allows making the robot follow the marker points without the need of explicitly computing inverse kinematics. At the end, the imitation of Jongara-Bushi dance is realized with whole body control of humanoid robot [7]. From recording human dance motions they extracted symbolic representation which is made up of primitive motions: essential postures in arm motions and step primitives in leg motions. A joint angle sequence of the robot is generated according to these primitive motions.

B. IK algorithms – State of the Art

For controlling the movement of robots the inverse kinematics (IK) algorithm is usually used. IK of a robot calculates the generalized coordinates that achieve the desired position of points located on some specific links and/or the orientation of the links. Depending of the structure of robot and level of redundancy the different algorithms of IK can be used. If it is talking about humanoid robots with tree structure and many DOF the calculation of IK is not simple. The numerical approach for solving IK algorithm for redundant robots gives one solution from the set of infinite solutions. There are several methods for solving numerical IK problems for redundant robots: Moore-Penrose pseudoinverse methods, augmented Jacobian, the Levenberg-Marquardt damped least squares methods, task-priority concept, quasi-Newton (QN) and conjugate gradient methods (CG)…

Whitney [8] proposed to use the Moore-Penrose pseudoinverse of the Jacobian matrix. This solution generates the minimum norm of joint velocities. The main

1 Marija Tomić is with the Mihailo Pupin Institute, University of Belgrade, Volgina 15, 11000 Belgrade, Serbia and also IRCCyN, Ecole Centrale de Nantes, 1, rue de la Noe, 44321 Nantes, France (e-mail: marija.tomic@pupin.rs)

2 Christian Vassallo is with the CNRS; LAAS; 7 avenue du colonel Roche, F-31077 Toulouse, France,Université de Toulouse ; UPS, INSA, INP, ISAE ; LAAS ; F-31077 Toulouse, France (e-mail: christian.vassallo@laas.fr)

3 Christine Chevallereau is with the IRCCyN, Ecole Centrale de Nantes, 1, rue de la Noe, 44321 Nantes, France(e-mail: christine.chevallereau@irccyn.ec-nantes.fr)

4 Aleksandar Rodić is with the Mihailo Pupin Institute, University of Belgrade, Volgina 15, 11000 Belgrade, Serbia (e-mail: aleksandar.rodic@pupin.rs)

5 Veljko Potkonjak is with the School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia (e-mail:potkonjak@yahoo.com)

disadvantage of this method is that produces discontinuous in joint velocities near the singularities [9]. For adding multiple tasks Park [13] proposed the weighted pseudoinverse algorithm. This algorithm can be used for minimization the kinetic energy.

Another method of solving redundancy, conceptually different from the above methods, is that of imposing an additional constraint task in the null space of Jacobian to be executed along with the original (end-effector) task. Therefore the search directions and the solutions are determined by evaluation of chosen optimization criteria function. The optimization criteria can be the joint limit avoidance, obstacle avoidance, mathematical singularity avoidance and the latter considers dexterity, energy minimizing and other criteria [10, 11 and 12]. Including these optimization criteria in null space of Jacobian the algorithm of IK finds a joint configuration which satisfies both the end-effector and the constraint task at the same time.

III. Imitation process

The model of 140-cm humanoid robot Romeo developed by Aldebaran company (see Fig. 1.b.) is used in this paper [14]. The human motions are recorded using marker-based capture system Advance Real-time Tracking system (ART). The system consists of a hybrid suit of 17 targets with 6 DOF relative to the feet, shins, thighs, shoulders, upper-arms, forearms, hands, head, hip, back and torso (see Fig. 1.a.). A set of 8 infra-red (IR) cameras are used. The ART software acquires the 2D information of each IR camera and provides the transformation matrices relative to the different local frames attached to the body parts [15].

The basic ideas for the human to humanoid motion conversion is to scale the robot segment dimensions to the human limbs size and to attach to the model of robot Virtual Markers such that during the movements their position and orientation evolution match the Real Markers evolution attached to the actor. Based on this principle the optimization algorithm gives the humanoid imitation of motion in joint space. In practice, to limit the use of orientation information that are quite noisy, the position of the marker frame and position of joint frame are used, only the orientation of the distal marker frame (hands and head) are used. On this way the generalized coordinates of robot are calculated without explicitly computing inverse kinematics. If the task is not related to the environment such as hello motion, this imitation of joint motion is converted to desired Cartesian hand motion based on the direct kinematic model of the humanoid robot (see Fig. 1.c.). For the task related to the environment, such as rotation of a steering wheel, this step is not useful.

IV. Criterions of the kinematic control law

Starting from the Cartesian definition of tasks for the hands, IK algorithms will be used to define the joint motion of the upper part of the humanoid robot [15]. The pseudo inverse approaches with different criteria function are used. The criteria functions are:

1. Minimize the norm of joint velocities $\|\dot{q}\|^2$
2. Minimize the distance between current position and ergonomic configuration of human $\left|q-q_{ergonomic}\right|^2$
3. Minimize the distance between current position and a constant configuration q_n adapted for each trajectory $\left|q-q_n\right|^2$
4. Minimize the kinetic energy $\dot{q}^T A(q)\dot{q}$ where $A(q)$ the Inertia matrix of the robot.
5. Minimize a weighted distance to the ergonomic configuration. The weight matrix is defined to include the energetic cost of the displacement, W_A is a diagonal part of the inertia matrix at the initial configuration: $\left(q-q_{ergonomic}\right)^T W_A \left(q-q_{ergonomic}\right)$

Studies of the human motion have led to the definition of ergonomic configuration $q_{ergonomic}$ which seems preferred by human to be comfortable during his task [2]. Based on the known joint motion of the imitation process q_d, q_n is defined using the optimization algorithm with criteria function:

$$\min \sum_{t=1}^{T} (q_d(t) - q_n)$$

while satisfying the Cartesian desired motion. For each experiment q_n is different.

In the joint space, comparison analyses of the results obtained from each algorithm are done (see Fig. 1.d.). Additional analyses of results of the IK algorithms are also done in Cartesian space. The positions of joints obtained from imitation process are compared with position obtained from each IK algorithms. From these analyses the conclusion about advantages and disadvantages of IK algorithms are given.

V. Results

Using capture motion system the four different motions of actor are recorded. The motions are:

1. Hello motion
2. Rotate horizontal wheel
3. Rotation vertical wheel
4. Rotation of two valves placed in horizontal plane

The ART and Dtrack motion capture software give the position and orientation of Real markers and actor joints. These data are used for scaling dimensions of robot segments to the dimensions of actor limbs and in imitation process. In the imitation process used the Real markers on upper arms, forearms and hands and the shoulders, elbows and wrists joints. Following the position of Real markers with Virtual markers, minimization the distance between position of actor joints and current robot joints and following the orientation of hands Real markers with Virtual markers were enough to obtain good imitation. The results are obtained in joint space. The imitation algorithm gives acceptable errors for the different types of motions studied. Perfect reproduction of human motion is impossible due to the difference between human and humanoid kinematics and characteristics. The tasks of IK algorithms are following the position and orientation of wrists defined based on the generalized coordinate from imitation process. Each IK algorithm achieved the same tasks. The evaluation of the

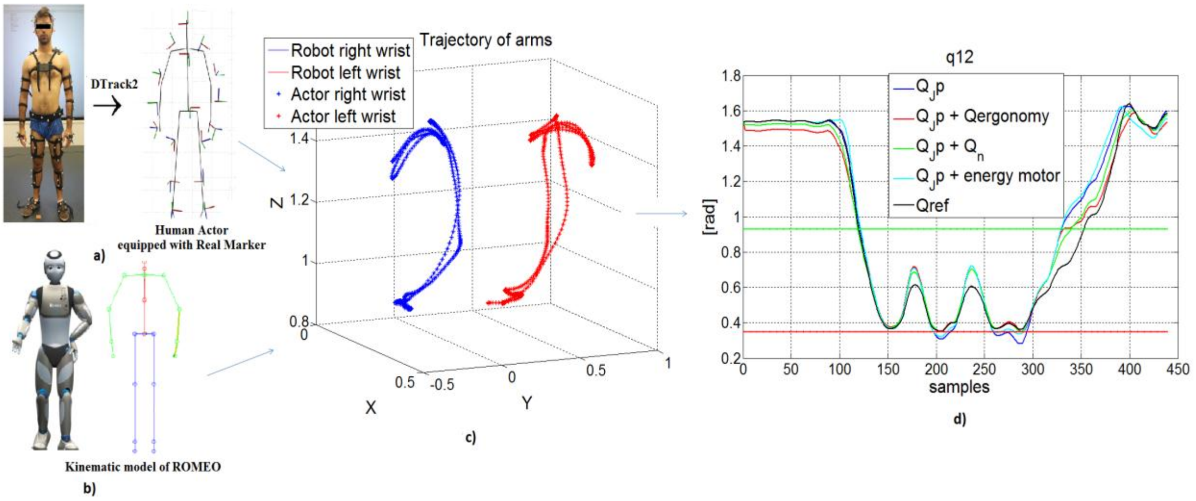

Figure 1. Motion of humanoid inspired by human motion

difference between algorithms is based on the level of achieving the motion like the human. The results of the IK algorithms for different experiments are given on table 1.by comparing the motion of the shoulders and elbows that are not directly controlled by the tasks.

TABLE 1 THE CUMULATIVE NORM OF POSITION ERRORS BETWEEN ACHIEVED AND DESIRED SHOULDERS AND ELBOWS JOINTS

Cum norm	IK Al.1	IK Al.2	IK Al.3	IK Al.4	IK Al.5
Hello motion	24.56	20.64	11.71	27.59	78.28
Horizontal wheel	55.97	121.6	21.67	36.62	34.6
Vertical wheel	68.66	79.99	36.75	63.96	34.85
Two valves	239.9	230.1	90.58	270.1	109.2

From the table 1 we can see that IK algorithm with q_n gives the best results for each experiment. That is logical because q_n is directly calculated separately for each task.

For the first task that does not include contact with the environment, the minimization of the distance with ergonomic configuration provides a motion which is close to the human motion.

For the others task, the introduction of the kinetic energy via a weighted matrix as in algorithm 5 seems to be efficient to reproduce human motion. It makes a compromise between following the ergonomic configuration and minimization energy.

VI. CONCLUSION

In this paper two contributions are developed. First an imitation process for conversion of human to humanoid motion is proposed. Virtual markers are introduced in the humanoid model for following the Real marker. This imitation process is adaptable for different type of motions. Then, based on comparison on several IK algorithms with different criterions and different motions, we conjecture that minimization of distance between joint configuration and ergonomic configuration weighted by an approximation of the inertia matrix is an appropriate tool to recover human like motion.

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