Modelling and Simulation of Human-like Movements for Humanoid Robots

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Abstract: The humanoid robots are bio-inspired models of human body. The mechanical structure of humanoid robots consists of several joints and segments. Numerous degrees of freedom are caused the redundancy problem. There is an unanswered question concerning with strategies which central nervous system implements to predict the human posture and gesture during different movements. A 7 degree of freedom model is used for modelling humanoid robot and an optimization-based method is planned to simulation of human motion. The joints angles and torques are subjected as optimization variables. The joints range of motion and limits of actuator torques are used as optimization constraints. The weight lifting is the motion which is subjected to simulation. Finally the results presented for two velocity lifting. The result shows the body posture varies naturally and the weight maintain at the end position at final time correctly.

1 INTRODUCTION

Digital human modelling is used in an extensive field of researches such as robotics, biomechatronics, ergonomics etc (Blajer et al., 2007; Xiang et al., 2010), because it can implement for calculating the parameters that are not possible to measure like: torques and internal forces of joints and stress exerted to joint's soft tissues. An important usage of modelling of human body is dynamic analysis of humanoid robots (Arisumi et al., 2007).

For understanding how the human-like movements planned for a humanoid robot, it is so important to know how the redundancy problem solved by central nervous system. In order to know how the body postures varies during different movements to construct motion animation of human body, a model of whole human body dynamics applied to movement simulation process. Simulation and analysis of human movements commonly used for athletics in order to improve performance of the motion and so prevent injuries in cause of incorrect movements (Demircan et al., 2009).

Biomechatronical model with large number of degree of freedom needed to done the human motion simulation more exactly and accurately. The multiplicity of joint space variables (DOFs) causes model manoeuvrable but creates redundancy problem. We face with the redundancy problem when the number of DOFs is more than needed to perform a task. Both kinematic and dynamic redundancy is problems with wide range of solutions in some areas of researches as robotics biomechanics. The robot manipulators with redundant degrees of freedom are able to done different tasks skilfully (Wang et al., 2010; Park et al., 2001). Human body models usually contained large number of DOFs. For applying these models to motion simulation, optimization-based approaches are good methods to overcome with the redundancy problem. Some of these techniques are applied to robotic manipulator models with redundant DOFs (Schafer et al., 2003; Oh et al., 1997; Wang et al., 2010). Optimization-based solutions are suitable ways to solve problem with large number of variables, because this method uses a few amount of data as inputs to result a large number of variables as output set (Guran et al., 2012). The input contains two set of constraints impose to motion simulation process: 1. Constraints obtained from motion dynamics and 2. Variety limitation of optimized variables would be optimized. The second type used as inequality constraints and the first one contain some algebraic and differential equations.

CNS arranges the task with the balanced movements. Walking, sitting, running and lifting are

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good examples of tasks related to daily living activities performed completely balanced involuntarily. CNS uses an unknown algorithm to manage tasks unconsciously. Optimization-based simulation methods have performance analogous with CNS function caused balanced movements. These approaches used objective function description subjected to minimizing which is duality of CNS algorithm manner. On the other hand to simulate a movement as like as shape that biological system does, it assumed that optimization approach minimized the objective function considered that CNS try to minimize it too.

Ankle torque amplitude considered as criteria of stability and the optimization algorithm tries to minimize summation of ankle torque squares during lifting time. A seven DOF biomechatronical model of whole human body represented in part 2 obtained from kinematical modeling based on D-H method (Denavit and Hartenberg, 1995; Siciliano and Khatib, 2008; Khatib et al., 2009). Based on Lagrangian method, the equations of motion are formulated in inverse dynamics form. In section 3 simulation process is described and in sections 4 and 5 presents the simulation results and the conclusion respectively.

2 MODELLING OF HUMAN BODY

A planar model with 7DOF in sagittal plane implemented in represents coordination system of human body (Figure 1). All the limbs as shank, thigh, lumbar, thoracic and cervical spine, arm and forearm subjected to modelling and considered as rigid bars with mass points at center of mass of each link which named: $\mathrm{l}_1, \mathrm{l}_2, \mathrm{l}_3, \mathrm{l}_4, \mathrm{l}_5, \mathrm{l}_6, \mathrm{l}_7$ respectively. For human major joints as ankle, knee, hip, shoulder and elbow had considered joint angles in modelling to figurate human body posture and represented by the names: q_1, q_2, q_3, q_6, q_7 respectively. The box assumed jointed to human body at the wrist with a horizontal orientation. Biomechatronical models of human body with coordination systems illustrated by fig. 2. Human body dynamics commonly model as a kinematics chain like robot manipulators, so the method which is used to modeling the dynamics of motion of human body, is like ones used for robotic manipulators.

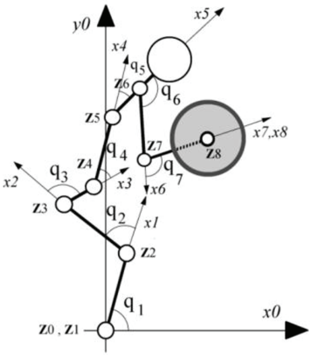

Figure 1: 7DOF model of human body with Denavit-Hartenberg coordination systems which is attached to each link.

The inverse dynamics form of equations of motion of a kinematical chain is presented as bellow

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + V(q) = \Gamma \tag{1}$$

In (1) $D(q)$ is 7×7 matrix related to mass and inertial properties of the model (Xiang et al., 2009) and Γ is 7×1 generalized joints torque vector. $C(q,\dot{q})$ is a term related to centrifugal and coriolis forces and $V(q)$ is gravitational forces vector, this term calculates as (2) and (3).

$$C(q,\dot{q}) = \dot{D}(q) - \frac{1}{2}\dot{q}^T\left(\frac{\partial D(q)}{\partial q}\right) \tag{2}$$

$$V(q) = \left(\frac{\partial V}{\partial q}\right)^T \tag{3}$$

Generalized joint torque represented in (1) divided in two parts: 1. torques resulted in muscle forces and 2. torques due to the box load exerted on wrist. These kinds obtain as (4):

$$\Gamma = \tau_{muscle} - \tau_{weight} \quad ; \quad \tau_{weight} = J^T(\ m_{weight} g^T) \tag{4}$$

In (4) J^T is transpose of Jacobean matrix which project box load to joints m_{box} is box mass and g^T is transpose of gravity force vector.

3 OPTIMIZATION-BASED SIMULATION

In this paper lifting movement simulation considered as optimization problem which CNS do either. In this problem an objective function subjected to be optimized with some constraints which limit the motions boundary to a feasible range to construct motion naturally. In other words it's being assumed that CNS try to minimize a particular function value to perform each task, and musculoskeletal system impose some constraints to the motion too.

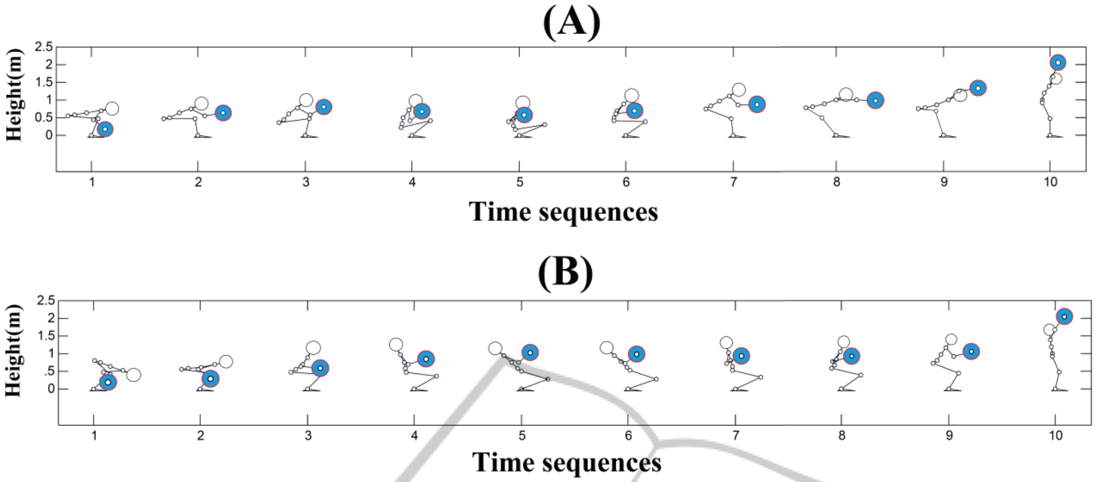

Figure 2: Body postures of humanoid robot, during lifting task for two lifting time: A) 3 second and B) 2.5 second. The horizontal axis is time in term of second, by scaling 0.3 second for (A) and 0.25 second for (B).

Predictive dynamics is a novel approach used to motion simulation (Xiang et al., 2010; Xiang et al., 2009). It implements inverse dynamics as a major constraint to modeling the dynamics of the motion in the simulation process. The joints torques and angles selected as the optimization variables, so by using this method we can obtain joint angles and torques as output according to task parameters used as inputs (Guran et al., 2012). Simulation elements are described in bellow sections.

3.1 Objective Function

By considering the lifting task as a simple inverted pendulum motion, represents represent a simple model to analysis the stability of motion. In other hand If lifting motion models as a inverted pendulum (Demircan et al., 2009) it can says that magnitude of torque of pendulum joint, has direct relation to amount of deviation from stability position ($\theta = 0^{\circ}$). Therefore we can use of a particular function which constructed in term of ankle torque as motion stability index. It proposes this function as integral of ankle torque squares in each time sequence (5).

$$F(q,\tau,t) = \int_{t=0}^{T} \tau_{ankle}{}^{2}\, dt \qquad (5)$$

3.2 Constraints

The constraints used in this research are: joints torques and angles limitations, initial and final position of box, elevating constraint, inverse dynamics, and body collision avoidance constraint which is used for prevent of collision box with body (Denavit, 1995).

$$\tau - \tau_{invd} = 0 \ ; \ \tau_{invd} = f(q,t) \qquad (6)$$

In equation (6) τ is joints torque vector should be predicted, and τ_{invd} is joints torque vector obtained from inverse dynamics. Body collision avoidance implemented in this simulation is a systematic method to check the penetration value of the box into the body in each iteration of optimization process. It is used to determine horizontal position of the box to collision avoidance adaptively.

The collision avoidance considered in optimization process as a constraint to prevent penetration of box with the body. It's inequality constraint and defined as a term of sufficient horizontal distance dx which wrist should move to prevent collision box with the body.

4 RESULTS

The optimization process designed for 10 evenly distributed time sequences. Inertial properties considered as data used previously (Guran et al., 2012). The optimization process ran for two lifting times 2sec, 2.5 sec and 3 sec.

An index presented to evaluate the motion stability during all the time sequences. Total moment arm (TMA) of all the links are calculated as (7) it's calculated from the moments respect to all of the links weight for each configuration related to time sequence. m_{all} is total weight of body and $x_i(t)$ is horizontal position of $i'th$ links at time t, and N is number of links. Optimized joint angles show that how the body posture varies during lifting task, it illustrated in figure 2.

$$TMA(t) = \frac{1}{m_{all}} \sum_{i=1}^{N} m_i x_i(t) \tag{7}$$

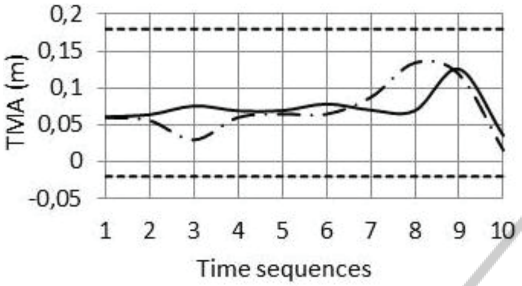

Figure 3: TMA values for two lifting times (2.5 sec for solid line and 3 sec for broken one) during lifting time. To prevent falling forward or backward, TMA values should be restricted between base of support (distance between heel and toe). These two boundaries are shown as dashed lines at TMA=-.02 (m) and TMA =0.18 (m).

5 CONCLUSIONS

Simulation process implements 7DOF biomechatronical model of human body to simulate weight lifting motion by using predictive dynamics approach. The constraints which applied to this process, limit motion space to a feasible region that human limbs move through it. Major constraint named inverse dynamic, implement the dynamics of the motion in simulation process and finally the optimized postures shaped by objective function minimization. Figure 2 Shows that posture variation does in a natural shape. The box motion is extremely uprising, and it situates at initial and final position exactly and also it hasn't collision to the body in all of the postures. The motion of weight started at its first position and ended at the final position correctly. The wrist is mounted at centre of mass of weight in sagittal plane. The results show that this position never collided with the body. The motion of the weight is uprising.

Figure 3 illustrate the TMA values during lifting time and its boundaries. According to this figure, Lifting movement performed completely balanced because TMA have values between upper and lower boundaries. In other words minimizing ankle torque summation can guarantee motion balancing.

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APPENDIX

The parameters of lifting task and lifter's body which subjected to simulation are presented in table1 and table 2 respectively.

Table 1: Parameters of lifter's body and related values.

	Length (m)	**COM (m)**	**Inertia (N.m^2)**	**Mass (kg)**
shank	0.48	0.24	1	8
hip	0.44	0.22	1.7	20.8
Lumbar spine	0.10	0.05	1.0	6
Thoracic spine	0.18	0.09	1.3	7.9
Cervical spine	0.21	0.105	1.4	11
arm	0.28	0.14	0.7	3.8
forearm	0.30	0.15	1.34	3.2

Table 2: Parameters of lifting task and related values.

Parameters	**Values**
Weight	40 kg
Initial horizontal position of COM of weight	0.20 m
Initial vertical position of COM of weight	0.18 m
Final horizontal position of COM of weight	0.1 m
Final vertical position of COM of weight	1.95 m
Lifting time	2.5 and 3 (sec)
Number of time sequences	10