Modeling and Simulation of Humanoid Robot Spine Vertebra

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Abstract: In this paper, a parallel mechanism is proposed for the design of humanoid vertebra. This mechanism is inspired by a flight simulator system, and has been adapted and optimized to enable pitch and roll motion of a humanoid trunk at reduced energy cost. The system consists of a bottom platform and a top platform connected by two articulated arms and a vertical central rod. A 3D model of the system has been elaborated for simulation and design.

1 INTRODUCTION

Robots are expected to live among humans to assist them in their daily tasks. Current humanoid robots are not fully suitable for working in our daily environment. They can do a few limited tasks compared with what a human can do. Walking humanoids robots equipped with joints in the trunk are listed in table 1 in increasing order of spine DOF number starting from pelvis. All of them feature a yaw joint in the trunk. The yaw joint is particularly useful for taking larger strides. It can also be used to compensate for yaw moment between feet and ground. It allows the robot to increase the working volume of its upper body for manipulation. Existing humanoids that have a yaw joint in the trunk are Asimo presented by (Sakagami et al, 2002), KHR2, Hubo in (Kim, 2005), Johnnie analysed by (Loffler et al, 2005), and Lola (Lohmeier et al, 2006). An additional pitch joint in the trunk extends the skills of the robot. The pitch joint is helpful for the robot to sit down on a chair. Examples of robots that can sit down are the series of REEM-A/B presented in (Tellez, 2008). This robot is manufactured by Pal Technology Robotics. Humanoids with a pitch joint in the trunk can also stand up from lying position. The HRP2 robot demonstrated its capacity to lie on the ground and to stand up again using its pitch joint in the trunk (Kaneko, 2008). Roll joints can be added to enhance locomotion capacities. That is the case of the last generation of Wabian robots developed by Waseda University in Japan (Ogura et al, 2006). Wabian II features two additional roll joints – one in the middle of the pelvis and the other one at the end of the trunk kinematic chain – that were introduced to implement new locomotion skills. This robot is capable of stretching the knee during walk when the supporting leg comes below the hip. Pitch and roll joints also increase the working space of the upper body and they can be used to bend the trunk forward and /or sideways to grasp something or to resist some perturbation at shoulder level. The DOF in the trunk are therefore task-dependent. It is interesting for humanoids to have a vertebral column to deal with both movement and manipulation skills.

Table 1: Walking humanoid robots with DOF in the trunk.

DOF	type of DOF	Prototypes
1	yaw	KHR2, Hubo, Johnnie, Asimo
2	yaw +pitch	HRP-2-3-4, Reem A/B
4	roll + yaw + pitch + roll	Wabian II

The contribution of this paper consists of adapting an existing parallel mechanism of flight simulator, found in thses of (Emilie, 2004), to the design of a pitch-roll vertebra joint, taking into account the specifications of forward, backward and left/right sideways bending amplitudes given for a humanoid robot. The objective of the study is to optimize the different length ratios of the mechanism in order to have a reduced torque required for the bending motions.

Section II deals with the description of the parallel mechanism. Section III presents simulation and results. Section IV is devoted to conclusion and perspectives.

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2 DESCRIPTION OF MECHANISM

This work deals with the adaptation of an existing parallel mechanism to a prototype of vertebra that could be implemented on humanoid robots. The parallel mechanism consists of 2 platforms – one bottom platform CA_3B_3 and one top platform OA_1B_1, that are linked by a central vertical rod CO and two arms arranged at $90[deg]$ in the initial position (Fig. 1). The central rod CO is fixed and always remains vertical. It joins the top platform through a Universal joint whose drive is responsible for roll and pitch motion of the top platform. The arm $A_1A_2A_3$ is planar and is composed of two segments, two revolute joints at A_2 and A_3, and one Universal joint at A_1. This is the planar arm. Figure 2 shows the parallel mechanism.

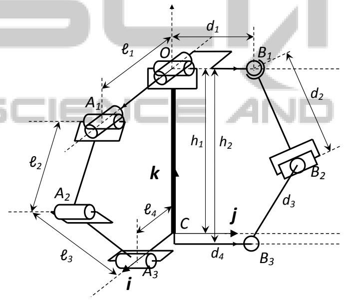

Figure 1: Perspective view of parallel mechanism in initial position. The central rod is fixed and rigid. It is attached to the top platform by a Universal joint at O. The mechanism is actuated by two revolute joints, each of them is located at the bottom of each arm. The two arms are arranged at 90 $[deg]$. The arm $A_1A_2A_3$ is planar and remains in the (xz) remains in this plane. It is composed of two revolute joints and one U-joint. The other arm $B_1B_2B_3$ is initially in the (yz) plane, and does not remain in this plane if the top platform rolls.

Figure 2: Parallel mechanism.

The arm $B_1B_2B_3$ also includes two segments, one revolute joint at B_3, one Universal joint at B_2 and one ball joint at the attachment locus B_1 with the top platform. This arm is 3D. The bottom platform is linked to coordinate frame R_0, centered at C with axes i, j and k.

The top platform rotates about O and is linked to coordinate frame R', frame centered at O whose axes are i', j' and k' (Fig. 3).

The top platform can be pitched about fixed axis j by angle θ_{10}, and rolled about axis i' by angle θ_{21}.

The two active joints are the revolute joints at A_3 and B_3. The associated rotation angles are denoted by α and β.

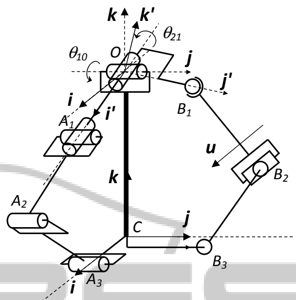

Figure 3: Perspective view of parallel mechanism after pitch and roll rotations.

3 SIMULATION AND RESULTS

3.1 Setup

Two configurations of mechanism are under study here. Figure 4 shows both configurations. The first configuration is rotated $90[deg]$ and the second one is rotated $135[deg]$ with respect to the configuration of the mechanism depicted on figure 3. This section aims to compare both configurations and shows that the second one is better than the first one in matter of torque consumption.

In the first configuration, the height between the top platform and the bottom platform in the parallel mechanism is set to $0.1[m]$. The length d_1 must be less than half the width of the trunk, which is $0.24[m]$. The length ℓ_1 must be less than half the depth of the trunk, which is $0.16[m]$. These values result from a space constraint because the vertebrae will be placed in the lumbar part of the humanoid trunk. A sphere with a mass M is placed above at the center of the mechanism to simulate the upper part of a humanoid robot. The two arms are perpendicular and they do not have the same dimensions. The mass M is set to $15[kg]$. The distance of the sphere center to the top platform is set to $0.1[m]$.Table 2 presents the lengths of the first configuration.

In the second configuration d_1 and l_1 are the same as in the first configuration. A sphere with a mass M is placed above the mechanism to simulate the upper part of a humanoid robot. M is not placed at the center

Table 2: Parameters of the first configuration.

Parameter	length $[m]$
d_1	0.07
d_2	0.09
d_3	0.0316
d_4	0.04
l_1	0.11
l_2	0.09
l_3	0.06082
l_4	0.05

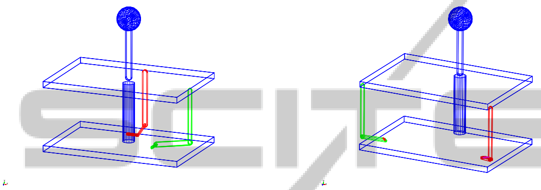

Figure 4: The first and second configuration of parallel mechanism.

of the prototype like in the first configuration, but at a distance of $0.030[m]$ to the front of the trunk. This enables to put the projection of the center of mass more inside the center of the support polygon delimited by the robot's footprints . Both arms are symmetric and perpendicular. Table 3 presents the lengths of the second configuration.

Table 3: Parameters of the second configuration.

Parameter	length $[m]$
$d_1 = l_1$	0.17
$d_2 = l_2$	0.09
$d_3 = l_3$	0.0443
$d_4 = l_4$	0.16

Both configurations are compared in matter of torque magnitude delivered by the two active joints for two kinds of motions to be executed by the top platform.

The first motion is obtained by giving the angular inputs for the pitch/roll joint of the top platform, namely θ_{10} and θ_{21}. This motion is named *pitch inclination*. The platform is bent $10[deg]$ forward, then $10[deg]$ backward. The angles for the joint motors, namely α and β are calculated thanks to the inverse geometric model.

In the second motion pitch and roll joint angles are combined to have a bent circular motion of the spherical mass. First, the mass is pitched by $10[deg]$. Then it executes a complete circular motion about the vertical. The trajectory for this circular motion uses spherical notation and precession angles (θ, ϕ) as inputs. These inputs are then converted into θ_{10} and θ_{21} to execute the motion.

Trajectory planning is designed with Matlab-SIMULINK, which is used to control the ADAMS model. To control the inclination of the spherical mass in Adams PID controllers were used for the motors.

The parameters (d_i, l_i) of the mechanism were optimized by testing several configurations (Souissi,2012) to check which one was best in matter of torque magnitude and space occupancy. Each arm was tested separately by fixing the other one. For the first configuration we concluded that the motor axes should be located at half-way between the center and the related external edge of the top platform. For the second configuration the motor axes should be located more externally. In addition the upper part of each arm must be longer than its lower part in both configurations. This enables to optimize the lever arm.

3.2 Torque Comparison between the First Configuration and Second Configuration

Figure 5 shows the trajectories of platform pitch and roll angles θ_{10} and θ_{21} and the related motor angles α and β in the case of pitch inclination motion. Figure 7 is related to the circular motion. The left-hand part of each figure is related to first configuration and the right-hand part to the second configuration.

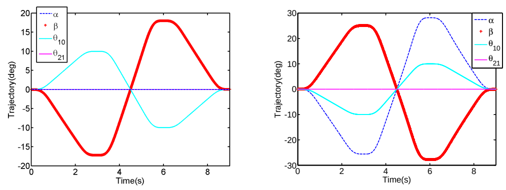

Figure 5: Angle trajectories θ_{10} and θ_{21} of platform and the related motor angles α and β for the pitch inclination motion. Left: First configuration. Right: second configuration.

Figure 6 shows the torques of each arm's motor joint in both configurations for the pitch inclination motion. Figure 8 shows the torques of each arm's motor joint in both configurations for the circular motion.

Regarding pitch motion and circular motion the second mechanism allows a torque reduction of more than 50% with respect to the first.

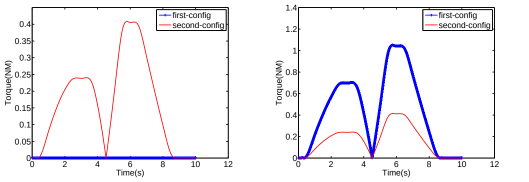

Figure 6: Active torques in the first and second configuration for the pitch inclination motion. Left: 2D arm. Right: 3D arm.

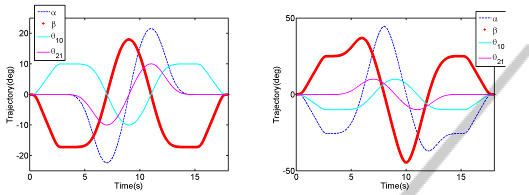

Figure 7: Angle trajectories θ_{10} and θ_{21} of platform and the related motor angles α and β for the circular motion. Left: first configuration. Right: second configuration.

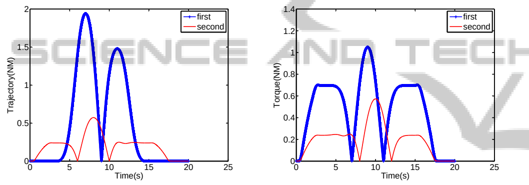

Figure 8: Active torques in the first and second configurations for the circular motion. Left: 2D arm. Right: 3D arm.

3.3 Mechanical Design of the Mechanism

The second mechanism was simulated with Solidworks. All joints come from the HPC company. For both active joints electric motors are used. Torque versus speed was plotted for both movements of the top platform. The variation of torque with speed allows to select the motors that best suit our needs. We use Maxon motors, because these actuators are lightweight and one of them meets our requirements: the *RE*25*G*. The caracteristics of the motors are given in table 4.

Table 4: Parameters of the motor.

Characteristic	Value
Supply voltage	12V
Rated current	1.2 A
No load speed	202 r / min
Load speed	156 r / min
Rated torque	0.49 Nm

4 CONCLUSIONS AND PERSPECTIVES

A new vertebra mechanism for a humanoid robot vertebral column has been proposed. It is based on a parallel architecture driven by two active arms equipped with one rotary actuator each. Inverse kinematic equations have been formulated. A 3D model has been elaborated with Adams and Solidworks and simulated for checking the operation feasibility and design sizes. Simulation results show that the proposed column system can reproduce some of the human spine mouvments.

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