Antropomorphic Design and Operation of a New Low-Cost Humanoid Robot

Conference Paper · March 2006

DOI: 10.1109/BIOROB.2006.1639211 · Source: IEEE Xplore

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A Design and Simulation of a New Low-Cost Humanoid Robot

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***Abstract* – This paper reports a design and simulation of a new low-cost humanoid robot that has been named as CALUMA (CAssino Low-cost hUMAnoid robot). A 3D-CAD model of CALUMA has been developed in order to check the feasibility of the assembly, possible component interferences and kinematic behaviour. A dynamic simulation in ADAMS environment has been developed for CALUMA walking movements. Preliminary results of dynamic simulation have shown a falling down of CALUMA. Successful simulations of the robot walking movement have been obtained after carrying out some enhancements in the design of CALUMA.**

***Index Terms* – Humanoid robot, Low-Cost, Mechanical Design, Dynamic Simulation.**

I. INTRODUCTION

The development of humanoid robots with human characteristics is one of the most fascinating activities in the robotic fields. The goal of this research line is not only to replace humans in dangerous works, it is also developing something similar to the human being. Humanoid robots are human-like and are able to mimic humans, [1]. Thus, they are complex systems that make their design and construction a challenge for researchers in several fields of science and engineering.

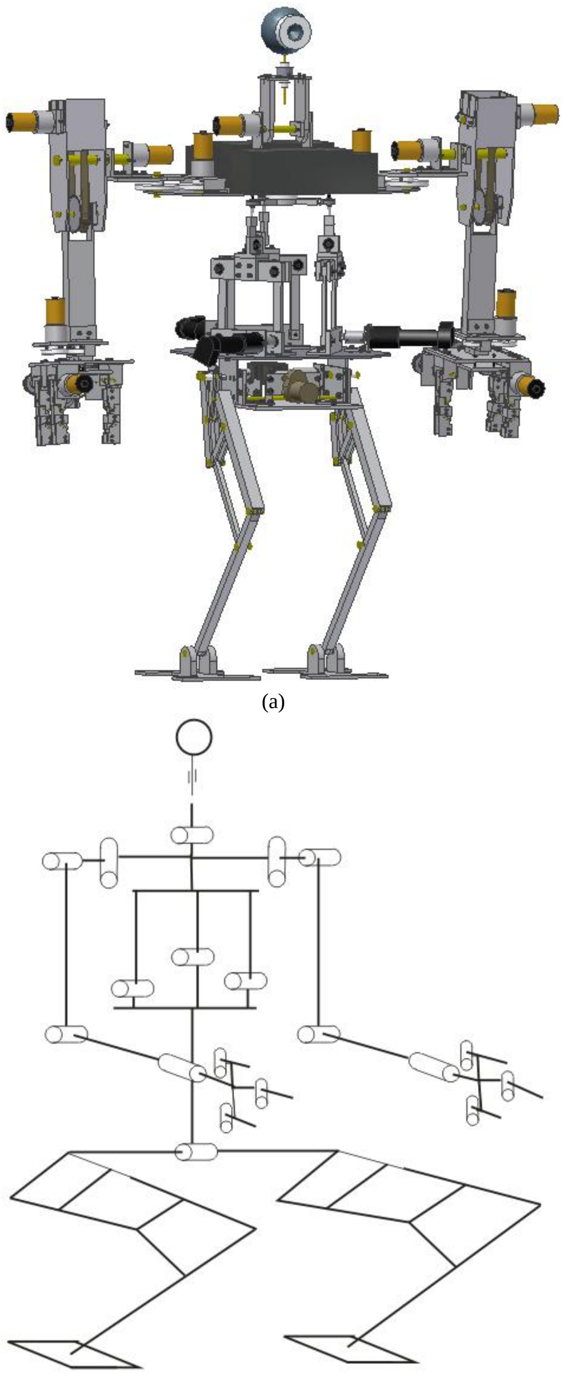
The Japanese have been leaders in the humanoid robot field since the beginning. Professor Ichiro Kato of Waseda University gave birth to humanoid robots in the word with the first full-scale anthropomorphic prototype named as WABOT-1, [2]. Several humanoid robots have been developed at Waseda University in the latest years, as for example robot WABIAN-RV, [3]. Similarly, in Japan others humanoid prototypes have been also built such as robot ASIMO of Honda Motor, [4], robot SDR-3X of Sony, [5], partners robots of Toyota, [6], ballroom dance robot of Nomura Unison Co. and Tohoku University, [7], and HPR-2 of AIST, [8]. But even outside Japan there are many researchers working on humanoid robots. Some interesting non-Japanese prototypes of humanoid robot are DB robot, [9], ROBONAUT, DART and EVA, [10], COCO, COG and KISMET, [11], and SARCOS, [12], developed in USA. The humanoid robot JOHNNIE and ERMES, [13, 14], ARMAR, [15], and robot H10, [16], have been developed in German research centers and universities. The humanoid robots CENTRAUR and KHR-1, [17, 18], have been developed in Korea in the latest years. Other significant humanoid projects are reported in [19].

The above-mentioned humanoid robots have usually a complex control, high cost and require high level skills to be operated. Therefore, research activities have been carried out in order to elaborate new designs of humanoid robots for reducing the cost and adapting them to non-expert operators, as illustrated for example in [20, 21]. Developing new humanoid robots that can be built with commercial components and easy-operation systems could be another feasible solution for this problem as proposed in [22, 23].

The design and simulation of a new low-cost humanoid robot that has been named as CALUMA (CAssino Low-cost hUMAnoid robot) are illustrated in this paper. A 3D-CAD model and a kinematic simulation of CALUMA have been developed in order to check the feasibility of the assembly and to avoid mechanical interferences. Then, a dynamic walking simulation in ADAMS environment has been developed. Preliminary simulations have shown a falling down of CALUMA. Successful simulation of the robot walking movement have been obtained after implementing some changes on the robot structure.

II. A DESIGN OF A NEW LOW-COST HUMANOID ROBOT

Figure 1 shows the first design architecture for CALUMA (CAssino Low-cost hUMAnoid robot). In particular, Fig. 1(a) shows a 3D-CAD model that has been developed in Autodesk Inventor environment, [24], and Fig. 1(b) shows a kinematic scheme of the robot structure. CALUMA is composed by prototypes that have been designed and built at LARM in Cassino in the recent past, as illustrated in [25]. The maximum dimensions of the CALUMA model of Fig. 2 are 962 mm height, 839 mm width and 413 mm depth. The legs module is a biped leg prototype that requires only one actuator for the two legs. This prototype uses a Chebychev Pantograph mechanism in order to transmit the movement to the foots, as illustrated in [26]. The trunk module is a parallel prototype named CAPAMAN-2bis with 3 DOFs. The legs of this parallel manipulator have a chain structure that permits a better movement capacity than previous CAPAMAN prototype, as illustrated in [27]. The head module is a telescopic manipulator with 2 DOFs: one for pitch and one for up and down movement, as illustrated in [28]. The head module uses a commercial Web-Cam for the visual interface between the robot and the environment. The arm module is a prototype with 4 DOFs: one for the shoulder pitch movement, one for the shoulder jaw movement, one for the elbow pitch movement and one for wrist roll movement. This prototype uses a belt mechanism in order to actuate the elbow joint that gives to the prototype a more compact design in comparison with the original prototype that uses a tangent screw, as illustrated in [29].



(a)

(b)

Fig. 1. First design architecture for CALUMA robot: (a) a 3D-CAD model in AutoDesk Inventor environment; (b) a kinematic scheme with active joints.

The hand module is a hand prototype with three 1 DOF anthropomorphic fingers and only one actuator for all the fingers. This prototype is a simplified version of a three DOFs anthropomorphic robotic hand developed at LARM in Cassino, [30], by using a belt mechanism in order to reduce the number of actuators.

The 3D-CAD model of Fig. 1 has been used in order to carry out a movement simulation of CALUMA. Figure 2 shows a sequence of a walking kinematic simulation of the robot. Possible component interferences and the assembly feasibility have been checked during this simulation. By using the kinematic simulation of Fig. 2, the synchronization of the robot components has been checked in order to obtain a successful walking movement. It is worthy to note that a movement synchronization of arms, legs and trunk is necessary for obtaining a human like movement.

The first design architecture of CALUMA robot has a total of sixteen active DOFs, as shown in Fig. 1.

Table I illustrates the mobility ranges of the active joints of CALUMA that have been measured during the animation of Fig. 2. The mobility ranges of the active joints show a high movement capability of the robot even if with a reduced number of DOFs.

TABLE I
MOBILITY RANGES OF THE CALUMA ACTUATORS

Joint	Joint Actuator Mobility
Leg	0 deg to 360 deg
Trunk	-40 deg to 40 deg
Shoulder (Jaw)	-90 deg to 90 deg
Shoulder (Pitch)	0 deg to 360 deg
Neck	0 deg to 90 deg
Head	-90 mm to 90 mm
Finger	0 deg to 54 deg
Elbow	-90 deg to 90 deg
Wrist	0 deg to 360 deg

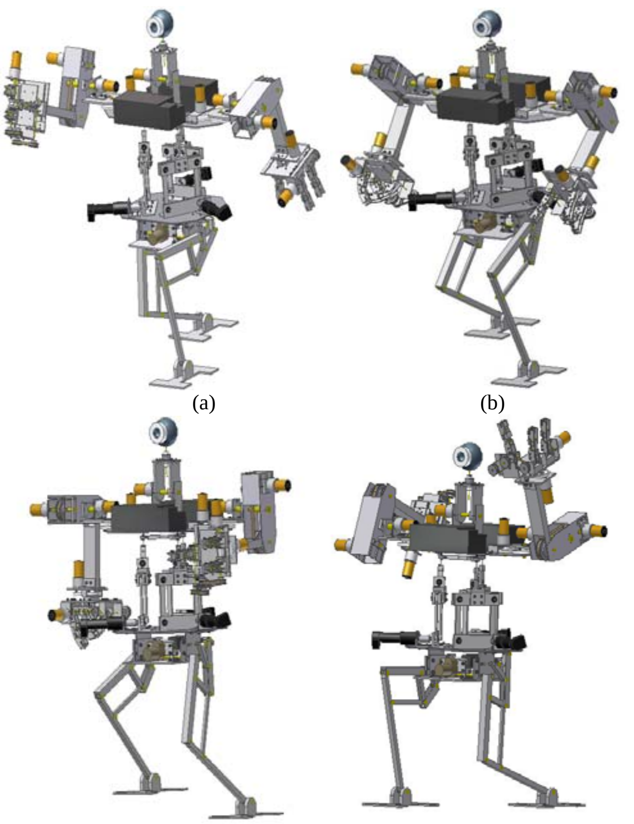
III. A DYNAMIC SIMULATION OF THE NEW LOW-COST HUMANOID ROBOT.

An ADAMS model of CALUMA robot has been developed in order to study the operation, task performances and feasible of the design. The MSC.ADAMS® software is considered the world's most widely used mechanical system simulation software, as outlined in [31]. Figure 3 shows the model of CALUMA robot that has been implemented in ADAMS environment to simulate the CALUMA performance. The CALUMA model in ADAMS environment takes into account several aspects such as, for example, external forces, gravity, contact constraints, friction and dynamic properties. The ADAMS model of CALUMA has been elaborated by introducing each component with its specific characteristics: material, mass, density, shape and mechanical characteristics. Table II reports the dynamic characteristics of the robot components for the proposed ADAMS model.

TABLE II
DYNAMIC CHARACTERISTICS OF THE CALUMA SUB-SYSTEMS

Sub-system	Weight (N)	Ixx (Kg-m^2)	Iyy (Kg-m^2)	Izz (Kg-m^2)
Leg	9.74	3.39E-3	2.99E-3	5.38E-4
Trunk	161.98	0.18	0.11	9.55E-2
Head	7.1	0.57E-3	0.50E-3	3.78E-4
Arm	22.0	7.31E-3	6.46E-3	1.78E-3
Hand	7.24	2.82E-3	2.42E-3	6.90E-4
Total	247.04	0.21	0.13	0.10

CALUMA has eighty seven joints: sixteen actives and seventy one passives. Figure 3 shows the nomenclature for the CALUMA joints. In particular, the nomenclature of joints indicates the position of the joint and number. In some cases the nomenclature indicates also the number of the link. For example, left joint 23;3 is the left joint 23 on finger number 3. CALUMA has eighty three revolute joints, three spherical joints and one prismatic joint that is the linear actuation of the telescopic head. A good dynamic walking for the robot requires a high friction between ground and feet. For the ADAMS simulation, static and dynamic coefficients of friction between the CALUMA feet and floor have been taken into account as the average friction values for a contact between rubber and concrete. In particular, the coefficients have been chosen as equal to 0.7 for the static condition and 0.5 for the dynamic condition, [32].



(a) (b) (c) (d)

Fig. 2. A movement sequence for the low-cost humanoid robot of Fig. 1 from a kinematic simulation in AutoDesk Inventor environment: (a) one leg in contact with the floor; (b) left leg moves upward; (c) left leg moves forward; (d) two legs in contact with the floor.

The ADAMS model of CALUMA of Fig. 3 has been used in order to carry out a simulation of the walking performance. The movement constraints have been chosen for a human-like motion of CALUMA, as reported in [33]. Preliminary simulation have shown a falling down of CALUMA, as shows in Fig. 4. The unsuccessful simulation has been used in order to study the movement behavior for the CALUMA model of Fig. 1.

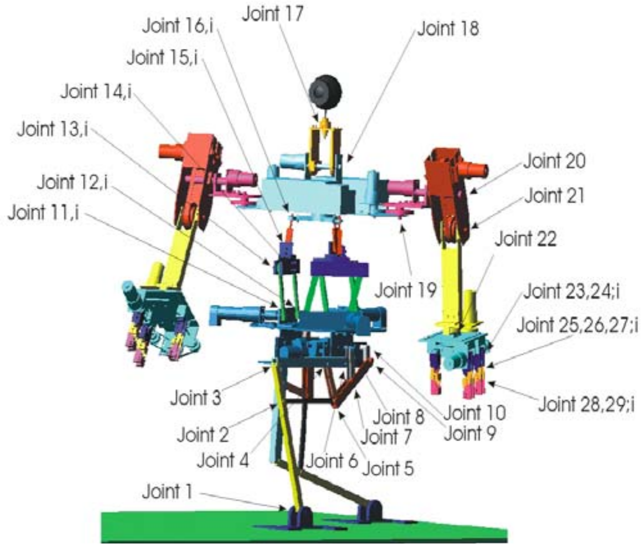
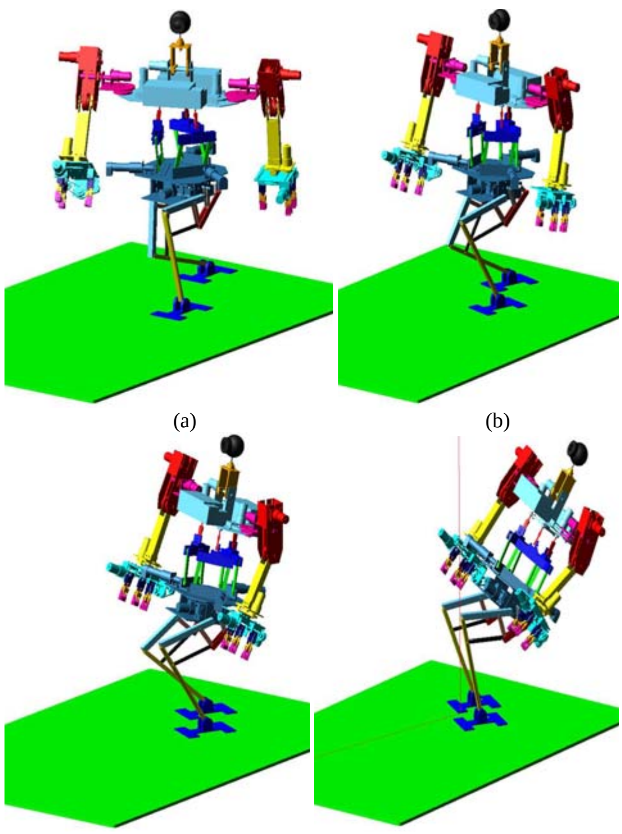


Fig. 3. A model of CALUMA in ADAMS environment.



(a) (b) (c) (d)

Fig. 4. A sequence of the falling down movement of CALUMA: (a) one leg in contact with the floor; (b) left leg moves upward; (c) left leg moves forward; (d) falling down.

Some enhancement on the robot design have been implemented after studying the falling down movement sequence of CALUMA robot in Fig. 4. In particular, Fig. 5(a) shows a new design of CALUMA foot with a larger contact area and two bars installed on the ankle in order to increase the stabilization and improve the step traction. Moreover, additional bars have been installed on CALUMA trunk, as shown Fig. 5(b), in order to improve the CALUMA walking by following a criterion of semi-passive dynamic walking, as reported for example in [34]. Other biped robots have used similar solutions in order to obtain a successful walking performance, as reported for example in [34, 35].

Figure 6 shows the walking performance of CALUMA after carry out the above-mentioned changes. In particular, the arm movements of CALUMA have for the beginning position the same ranges of the human being, [33]. The parallel manipulator of CALUMA's trunk module and the two arms move conveniently in order to stabilize the robot during the walking movement. The walking sequence of Fig. 6 shows one step of CALUMA walking performance, that is given by a rotation of 180 deg. of the leg mechanism input crank.

Figures 7 shows some significative result plots of the CALUMA walking sequence in Fig 6. In particular, Fig. 7(a) shows the plots of force and velocity of the contact points between the left foot and the floor. Figure 7(b) to (e) shows the plots of force and velocity of representative robot joints.

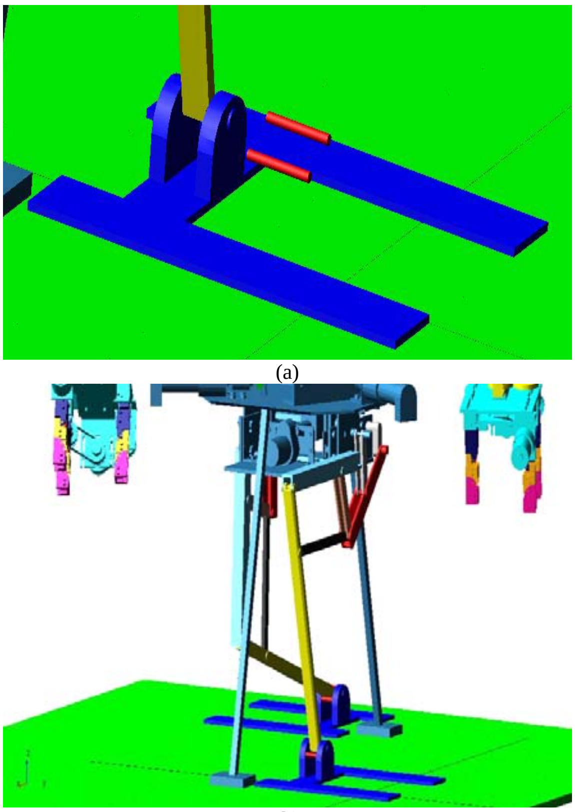


Fig. 5. Enhancement on the first CALUMA structure: (a) a new design for CALUMA's foot; (b) additional bars for improve the CALUMA walking movement.

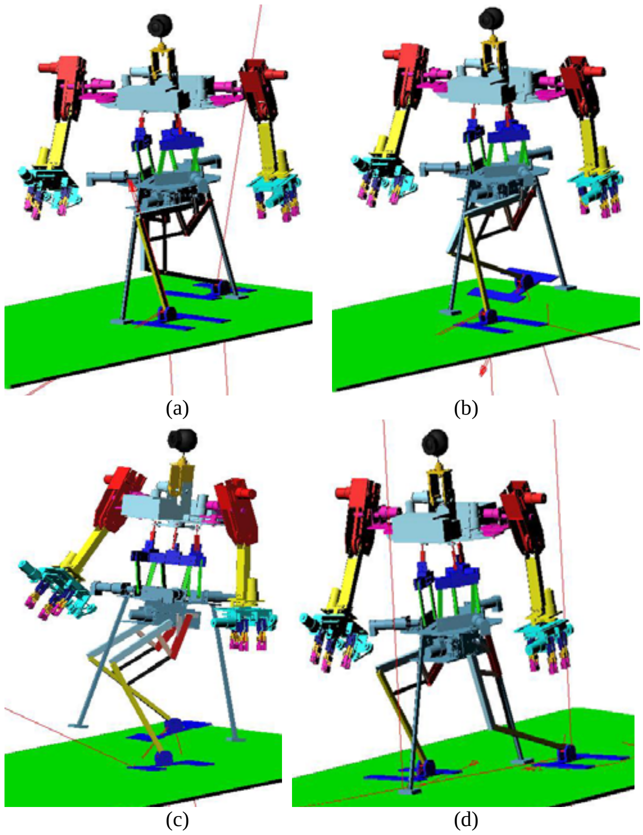
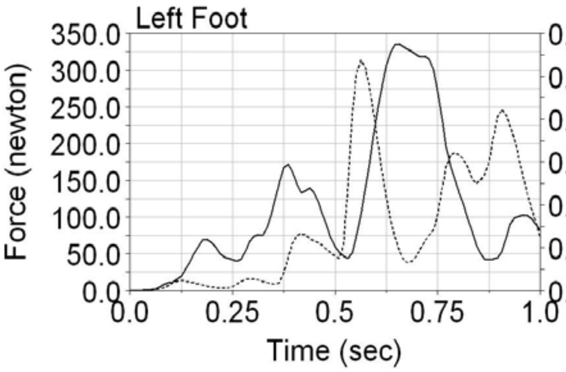
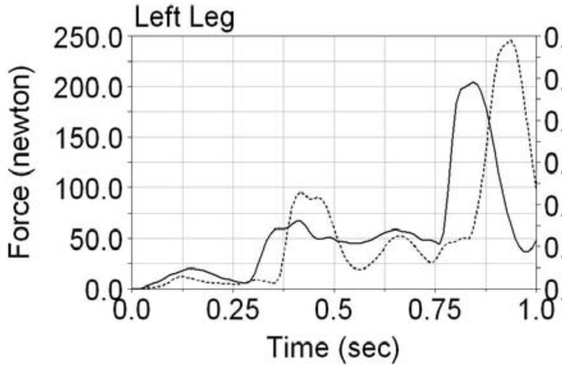


Fig. 6. A sequence of the walking performance of CALUMA in ADAMS environment: (a) one leg in contact with the floor; (b) left leg moves upward; (c) left leg moves forward; (d) two legs in contact with the floor.

It is worthy to note that in these plots the force is plotted as a continuos line and the velocity is plotted as dotted line. Figure 7(f) to (h) shows the plots of torque and angular velocity of representative robot actuators. It is worthy to note that in these figures the torque is plotted as a continuos line and the angular velocity is plotted as dotted line. The plot results of Fig. 7 show suitable values of force, velocity, torque and angular velocity. In fact, the maximum value of reaction force has been about 320 N for the contact point between the left foot and ground, as shown in Fig. 7(a). The maximum value of input torque has been about 58 Nm on the input shaft of the left leg, as shown in Fig. 7(f). The maximum value of velocity has been about 0.6 m/sec on a left leg joint, as shown in Fig 7(b). The maximum value of angular velocity has been about 150 deg/sec on the input shaft of the left leg, as shown in Fig. 7(f). Also the smooth shapes and ranges of variation for the result plots can be considered reasonable and feasible for the proposed model. It is worthy to note that the plot of force and velocity for the contact point between the left foot and floor shows an increase of force magnitude in a time range of about 0.5 to 0.8 sec. In fact, in this time range the robot moves upward and increases the action force on the ground for completing the step, as shown in Fig. 6. Also the plots of Figs. 7(b), 7(c), 7(d) and 7(e) show a similar increase of magnitude at about the above mentioned range and decrease of force before the end. It is worthy to note that the Chebychev mechanism of the legs require a higher torques at the beginning and end of a step, as shown in Fig. 7(f). The torque plot of a trunk actuator of Fig. 7(g) shows a specific torque evolution that is needed in order to obtain the humanoid robot equilibrium during the walking performance of Fig. 6. Similarly, the arm actuators require a specific torque evolution for obtaining the robot equilibrium, as shown in Fig. 7(h).



(a)



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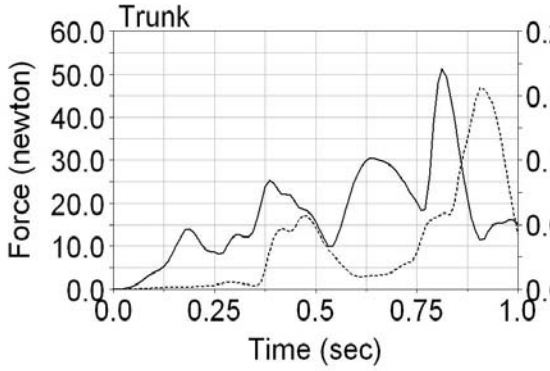

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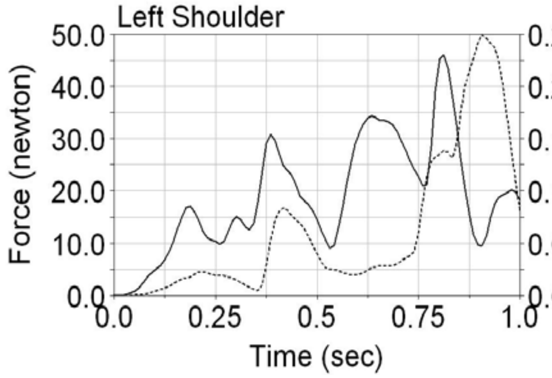

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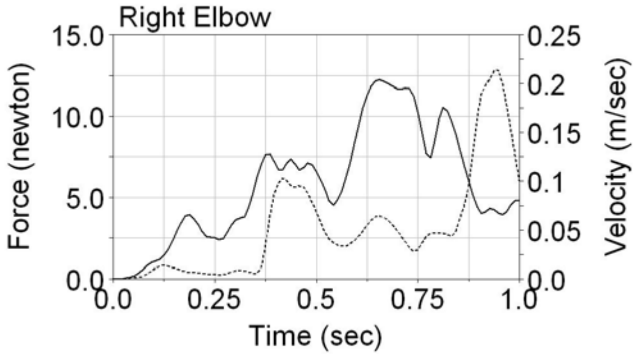
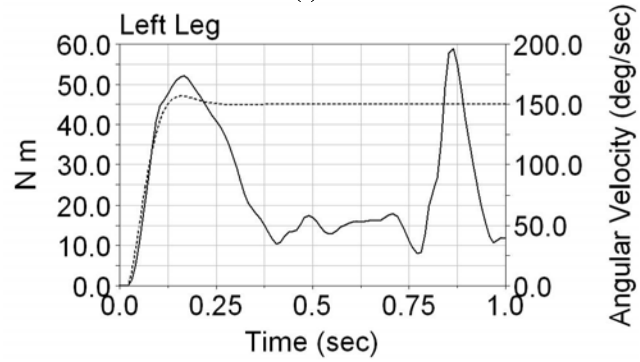
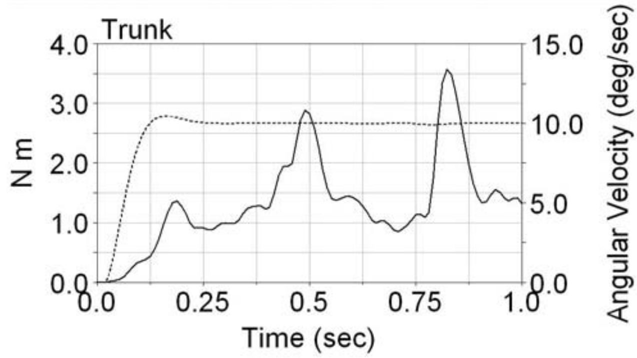


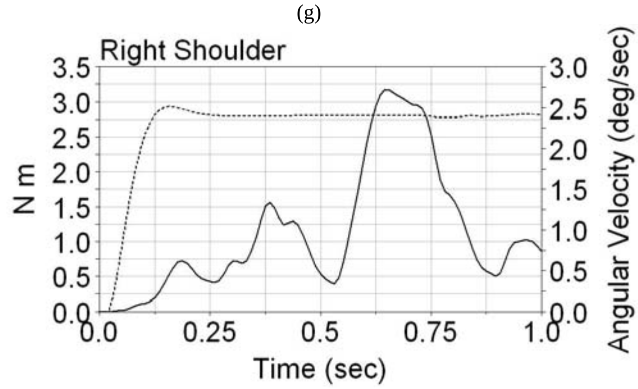
(e)



(f)



(g)



(h)

Fig. 7. Results of ADAMS simulation of the CALUMA walking performance of Fig. 6: (a) force as a continues line and velocity as dotted line of the contact point between the left foot and floor; (b) force as a continues line and velocity as dotted line of left joint 4 of leg; (c) force as a continues line and velocity as dotted line of joint (12;1) of trunk; (d) force as a continues line and velocity as dotted line of left joint 20 of shoulder; (e) force as a continues line and velocity as dotted line of right joint 21 of elbow; (f) torque as a continues line and angular velocity as dotted line of left leg actuator; (g) torque as a continues line and angular velocity as dotted line of a trunk actuator; (h) torque as a continues line and angular velocity as dotted line of right shoulder actuator.

The simulation results present suitable values for the robot actuation, as for example the above-mentioned maximum value of actuating torque and angular velocity can be achieved by means of commercial DC motors, as shown in the plots of Fig. 7. Similar results have been obtained on the other robot joints and actuators, as reported in [33].

By comparing the result magnitudes of the falling down with the walking simulation, almost all magnitudes show a more regular shape with feasible values. Moreover, the implementation of the changes of Fig. 5 for a semi-passive dynamic walking for CALUMA robot has been checked. Thus, as future work the proposed design can be built and tested at LARM in Cassino.

IV. CONCLUSIONS

A design of a new low-cost humanoid robot named as CALUMA (CAssino Low-cost hUMAnoid robot) has been illustrated. A 3D-CAD model of CALUMA has been developed for checking the feasibility of the assembly and avoiding mechanical interferences. The 3D-CAD model has been used for carrying out kinematic simulations of the robot walking performance that show a high movement capability for the robot even if with a reduced number of active DOFs. The reduction of active DOFs reduces both the costs and control complexity of the proposed humanoid robot. Dynamic simulations have been carried out for CALUMA walking movement in ADAMS environment. The simulation results validate the walking performance of the robot.

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