# LARMbot: A New Humanoid Robot with Parallel Mechanisms

**Daniele Cafolla, Mingfeng Wang, Giuseppe Carbone and Marco Ceccarelli**

**Abstract** LARMbot humanoid robot is presented with its peculiar design as based on mechanisms with parallel architecture. The mechanical design is described as motivated by biomimetic inspiration to human anatomy and functionality. The mechanical structure of the main parts are discussed with performance characterization. A prototype is presented with a built solution with low-cost solution and user-oriented operation by using commercial components and 3D printing manufacturing.

**Keywords** Humanoid robots · Torso designs · Biped locomotors · Parallel mechanisms

## 1 Introduction

Humanoid robots, which are designed as directly inspired by human capabilities, are considered to be partners and servants for human beings during daily life (Kemp et al. 2008). Research on humanoid robots has made rapid progress and several humanoid robots have been developed with mobility and operability for performing typical daily tasks in human environments, like ASIMO of Honda (Hirose and Ogawa 2007), WABIAN of Waseda University (Ogura et al. 2006), HRP of AIST/KAWADA (Kaneko et al. 2009), LOLA of Technical University Munich (Buschmann et al. 2012), and HUBO of KAIST (Zucker et al. 2015).

D. Cafolla · M. Wang · G. Carbone · M. Ceccarelli (✉)
Laboratory of Robotics and Mechatronics DICEM, University of Cassino and South Latium, Cassino, Italy
e-mail: ceccarelli@unicas.it

D. Cafolla
e-mail: cafolla@unicas.it

M. Wang
e-mail: wang@unicas.it

G. Carbone
e-mail: carbone@unicas.it



V. Parenti-Castelli and W. Schiehlen (eds.), *ROMANSY 21 - Robot Design, Dynamics and Control*, CISM International Centre for Mechanical Sciences 569,
DOI 10.1007/978-3-319-33714-2_31

Serial mechanisms in humanoids possess large workspace and dexterous maneuverability, which can guarantee the capability of imitating human-like movements. However, they are susceptible to bending at high load and vibration at high speed leading to lack of precision and poor dynamic performance (Sébastien and Bonev 2007). These drawbacks become an issue for the design of a humanoid robot since it requires more sophisticated sensor fusion schemes, model-based control algorithms and powerful driven systems. On the other hand, parallel mechanisms are well known for having better performance in terms of dynamic behaviour, accuracy, payload capability, stiffness so that they have been widely studied both in industry and academia (Ceccarelli 2004; Merlet 2006). Nevertheless, parallel mechanisms also have some drawbacks such as small workspace, complex direct kinematic, and singularity problems, which require a proper selection of mechanisms and optimized mechanical design (Carbone et al. 2009).

Human body is an extremely complex system with several muscles and tendons in each body part that act in parallel to each other to give mobility to the corresponding skeleton (Saladin 2008). With such a biomimetic inspiration a humanoid robot can be designed and operated with a kinematic structure made of several parallel mechanisms as suggested in (Ceccarelli and Carbone 2009). Sellaouti and Ouezhou (2005) have built a prototype called ROBIAN as based on hip and ankle designs with parallel mechanisms. Saltaren et al. (2007) have proposed orientation parallel mechanisms for the neck and shoulder of humanoid robots. Liang and Ceccarelli (2012) have designed a novel waist-trunk system by using parallel mechanisms. At Laboratory of Robotics and Mechatronics (LARM) in Cassino, a new biomimetic inspired humanoid robot, LARMbot, is under development as based on a biologically inspired parallel structures.

In this paper, a new humanoid conceptual design is described as motivated by an inspiration from design and function of human anatomy. The kinematic structure of a humanoid can be composed by several parallel mechanisms with different design solutions as depending of the body parts they will mimic in functionality and volume. The humanoid prototype LARMbot has been designed assembling CAUTO (CAssino hUmanoid TORSO), in (Cafolla and Ceccarelli 2015) with the Cassino biped locomotor (Wang and Ceccarelli 2015). The main characteristics of the humanoid are outlined with features for low-cost manufacturing and operation.

## 2 Parallel Architectures in Human Anatomy

Human anatomy can be modeled with skeleton structures that are actuated by muscles acting in parallel as parallel manipulators. This conceptual design is summarized in Fig. 1 with a biomimetic inspiration for different design solutions as depending of the body parts they will mimic in functionality and volume.

Bones provide structural strength to the human frames. They provide support to the organs of the body, to transfer internal and external loads, and thus to perform

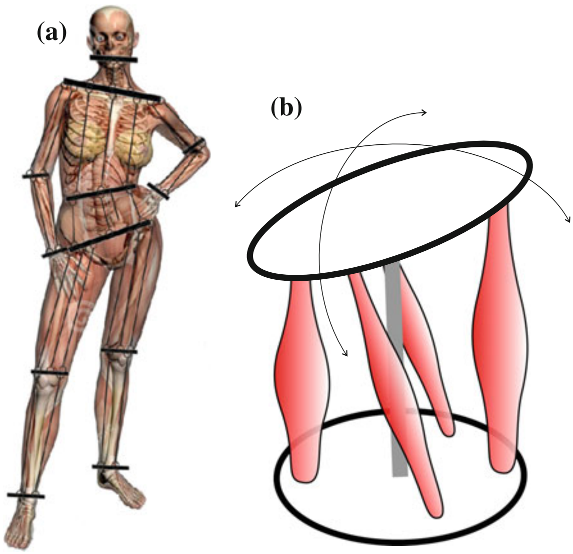


**Fig. 1** Models of human anatomy: **a** parallel mechanism for main parts, **b** scheme of muscle actuated parallel mechanism

useful tasks. It is important that the structural strength of a humanoid robot at least matches that of the human frame. The bones of the body are connected together at joints which permit various d.o.f.s (degree of freedom) of many movements of the human body. A considerable simplification can probably be made without significantly affecting its functionality. An example of this simplification concerns the shoulder joint. As the arm is raised, the initial range of movement is facilitated by the rotation of the ball and socket shoulder joint, but the later stages involve movement of the shoulder blade. In a robot, this movement could be performed by simply extending the range of movement of the shoulder joint and keeping the shoulder itself fixed with respect to the spine by using a parallel structure as shown in Fig. 1a. Figure 1b shows a conceptual scheme of the interaction of the two platforms of a parallel mechanism and its d.o.f.s.

In the human body muscles are the actuators that convert chemical energy into mechanical work. They are a form of linear actuators, and are joined to a bone at each end with tendons. They can only operate in tension, and the tensile force is created by muscle contraction. This means that they operate in opposing pairs to give even two-way motion, and this makes the control problem easier.

## 3 The LARMbot

The LARMbot design has been developed by looking at a humanoid structure that is composed by systems for manipulation, locomotion, and payload capability with human-like characteristics. Manipulation system is designed with traditional anthropomorphic structure of 3 d.o.f.s carrying an artificial hand of five cable-driven articulated fingers. Future developments are under consideration to design the arm with parallel mechanism for larger payload capability. Locomotion system is designed referring to the scheme of Fig. 1b to develop a biped locomotor whose legs have the structure of a 3 d.o.f.s parallel mechanism whose end-effector is the foot plate. Torso system is designed by combining the serial structure of a spine with a cable-driven parallel mechanism as muscle-like actuation system.

The conceptual design have been elaborated on the basis of kinematic design whose solution has given the CAD mechanical structure in Fig. 2. In particular, Fig. 2a shows the CAUTO (CAssino hUmanoid TOrso) design (Cafolla and Ceccarelli 2015) that is implemented as torso module in the full LARMbot humanoid in Fig. 2c. Figure 2b shows the Cassino biped locomotor that is designed with a leg structure for translatory motion of the foot. The waist plate contains gearing system to perform turning motion while walking. The Cassino biped locomotor is connected to CAUTO module through the waist plate giving the LARMbot full structure in Fig. 2c.

Most of the components are designed to use commercial parts, such as the vertebra-like joints, and the muscle-like leg actuators, while the frames are designed for low-cost 3D printing manufacturing, such as the vertebrae discs, the shoulders frame, the waist, and foot plates. The design feature can be summarized in with a light structure of 2.8 kg, compact size of (972.19 × 414.60 × 294.60) mm, payload capability of 0.86 kg that is limited by the current arm structure (as 3 kg if considering CAUTO and Biped locomotor only), fairly easy controlled actuation via commercial motors under Arduino control algorithms.

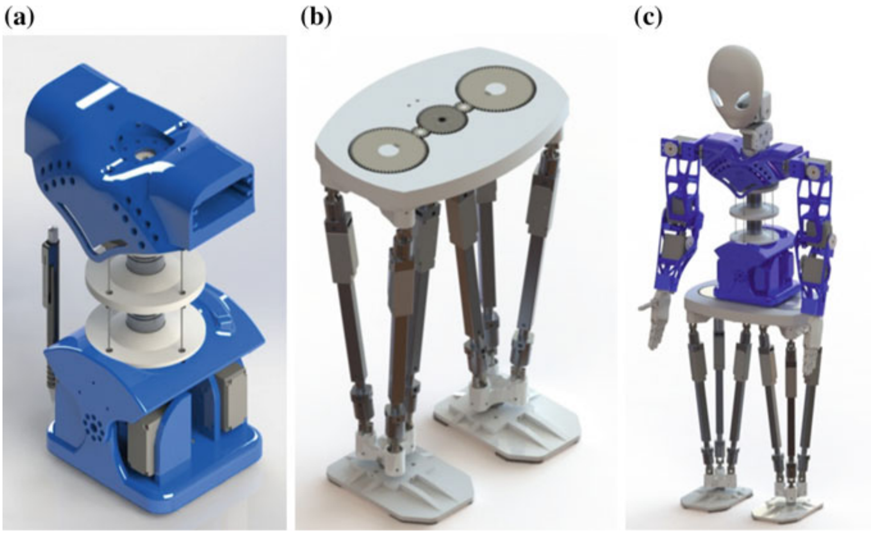


**Fig. 2** A CAD design of the humanoid LARMbot at LARM in Cassino: **a** torso, **b** biped locomotor, **c** full assembly

## 4 Prototype and Testing

A prototype of LARMbot humanoid has been built as in Fig. 3 following the CAD design solutions in Fig. 2 by using commercial components and 3D printed manufacturing parts. Several tests have been worked out to validate the design features and to characterize the operation performance. Main test results are reported in Figs. 4, 5, 6 and 7.

Figure 4a shows a scheme for the experimental tests with the humanoid torso CAUTO. The torso is powered by a Li-Po battery of 11.1 V–2.2 Ah and is operated through Bluetooth the Arduino boards and its software. An Inertia Measurement Unit (IMU) is placed on the center of the neck along the spine axis to sense significant angles of motion and linear accelerations around the reference axes, Fig. 4b. A current sensor is used to monitor the power consumption. A control box contains 4 Arduino Nano, 4 HC-05 Bluetooth modules and 1 ACS714 current sensor and it is arranged at the bottom of the torso, Fig. 4b.

Tests results are reported in Fig. 5 for lifting a load of 0.86 kg with a motion of 20.40 s. The humanoid torso starts in a standstill position with the load on the arms, Fig. 5a, and then the load is lifted simultaneously by the two arms. In Fig. 4c the lifting test is measured as a smooth motion in angles with few acceleration peaks (less than 3 $m/s^2$) for a limited power consumption (max 26 W).

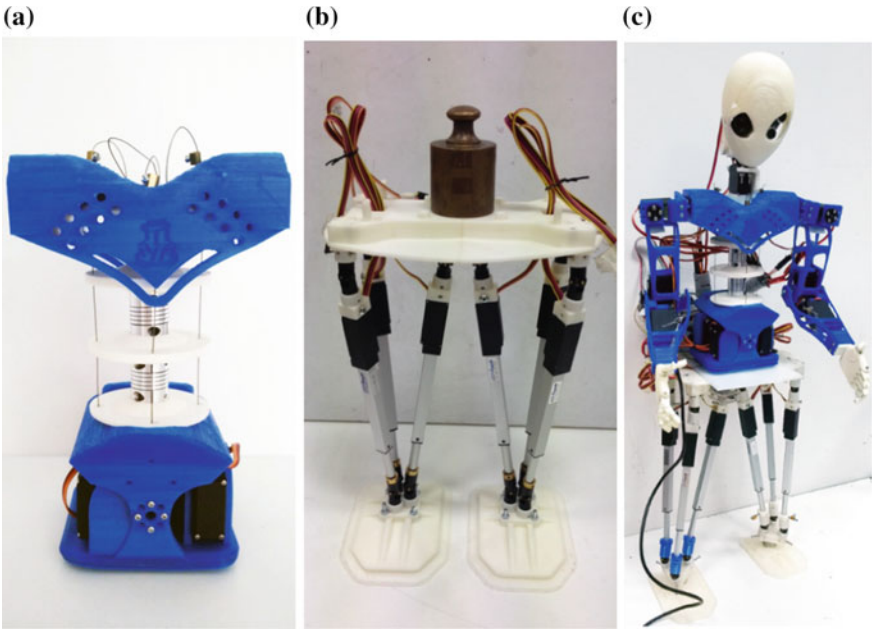


**Fig. 3** A prototype of the LARMbot in Casino: **a** torso, **b** biped locomotor, **c** assembly

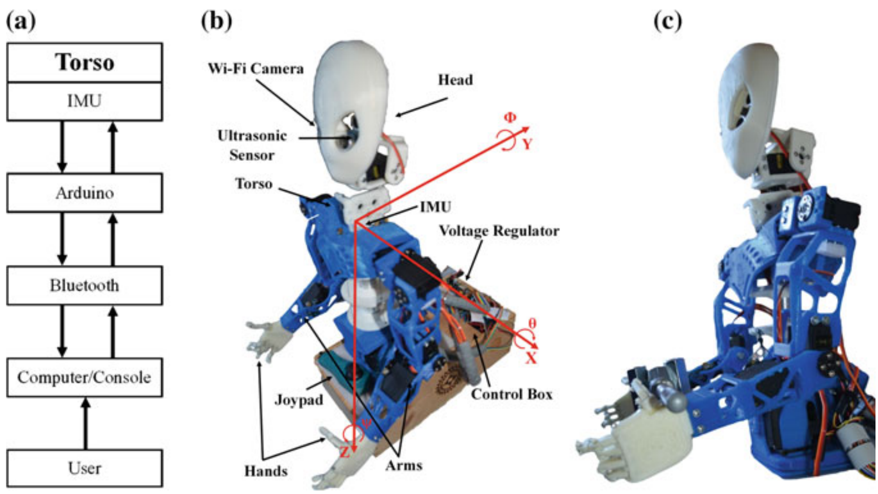


**Fig. 4** An experiment layout for testing of CAUTO as LARMbot torso: **a** a scheme of the operation control, **b** the laboratory setup, **c** lifting a load

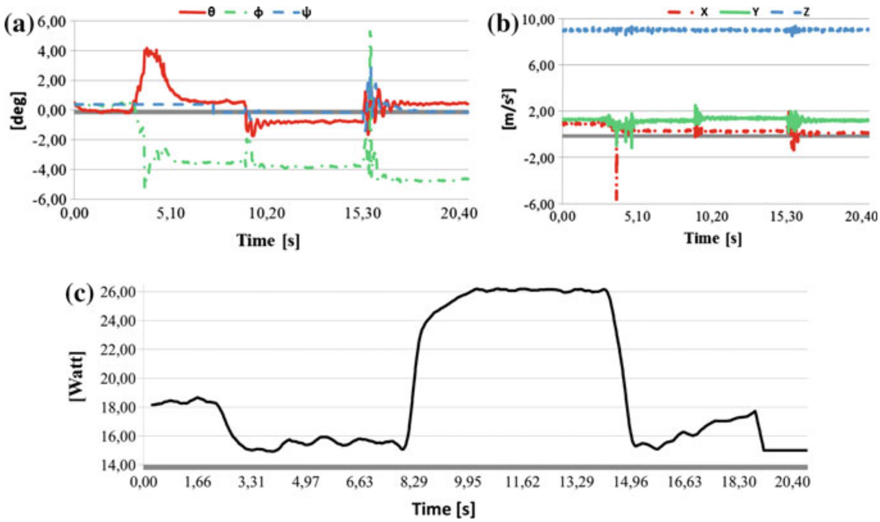


**Fig. 5** Results of the experimental test in Fig. 4c: **a** spine angular displacement, **b** spine acceleration, **c** power consumption

A prototype of the Cassino biped locomotor is built, as shown in Fig. 3b, whose a dynamic simulation is reported in (Wang and Ceccarelli 2015). Figure 6 shows two snapshots during an experimental test and results are shown in Fig. 7.

Experimental results in terms of ground contact forces, power consumption and rotation angles are measured for performance evaluation and design characterization

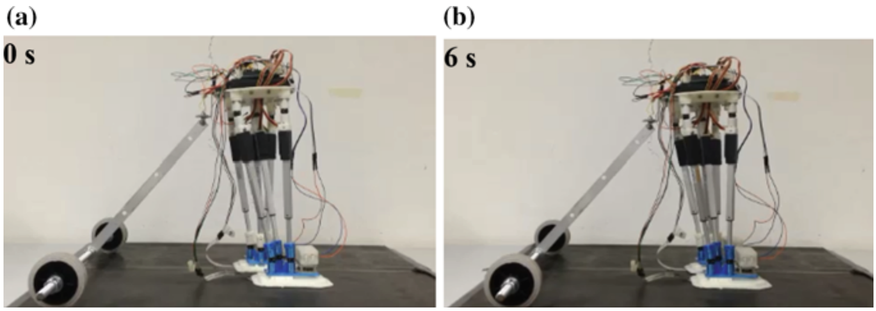


**Fig. 6** Two snapshots of an experimental test of LARMbot biped locomotor as rickshaw: **a** starting configuration; **b** during motion

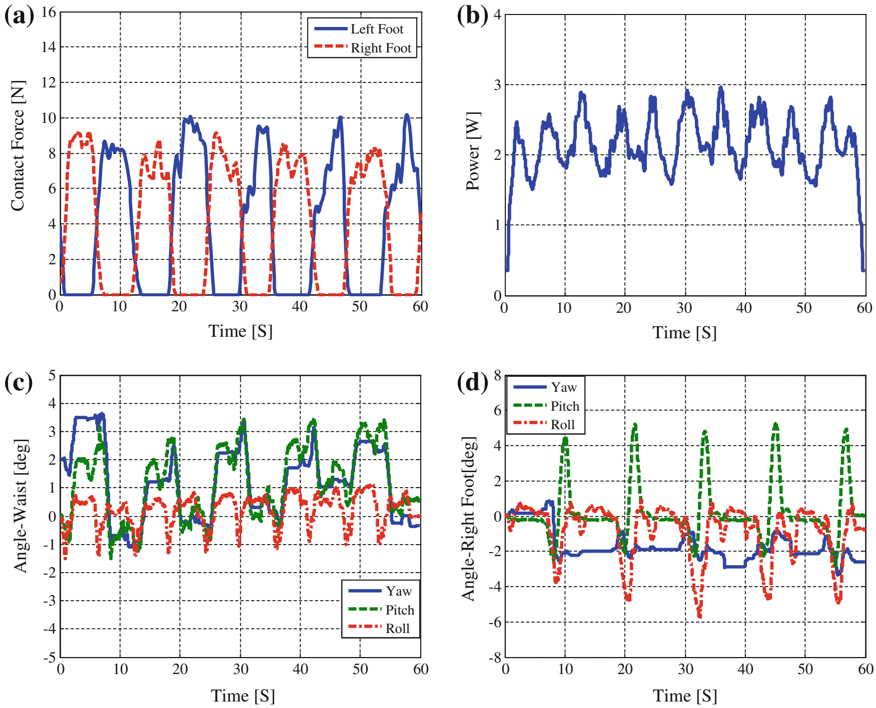


**Fig. 7** Measured results of the experimental test in Fig. 7: **a** ground contact forces; **b** power consumption; **c** angles of waist; **d** angles of right foot

of the built prototype of Cassino biped locomotor. In Fig. 7a, there are one or two minor jumps in each step (max 10.2 N), which are due to the corresponding foot landing impact on the ground and waist swinging. In Fig. 7b, the power consumption is measured with a maximum value of 2.9 and a peak value occurring when waist is in the middle during swinging from back to front. In Fig. 7c, d, the rotation angles are plotted in terms of yaw, pitch and roll with proper limited ranges. The largest rotation motions of right foot are in pitch and roll when in the swinging phase, while the largest rotation motions of waist are in yaw and pitch when waist swings from back to front.

## 5 Conclusions

The LARMbot humanoid is presented with its peculiar design that is based on a biomimetic inspiration from human anatomy by using parallel mechanisms in torso and leg designs. The mechanical design has been developed in compact and light solution permitting the use of commercial components and 3D printing manufacturing of the parts. The LARMbot prototype has been experienced with basic motions confirming the design features for low-cost, powerful, compact design in human-like tasks. The proposed design structures permit a close-form formulation of kinematics and dynamics so that the control design has been achieved with straightforward algorithms for fairly easy operation programming.

## References

Buschmann, T., Schwienbacher, M., Favot, V., Ewald, A., & Ulbrich, H. (2012). The biped walking robot Lola. *Journal of the Robotics Society of Japan, 30*(4), 363–366.

Cafolla, D., & Ceccarelli M. (2015). Design and simulation of a cable-driven vertebra-based humanoid torso. *International Journal of Humanoid Robotics* (in print).

Carbone, G., Liang, C., & Ceccarelli, M. (2009). Using parallel architectures for humanoid robots. In *Proceeding of the Kolloquium Getriebetechnik*, Aachen, September 16–18 (pp. 177–188).

Ceccarelli, M. (2004). *Fundamentals of mechanics of robotic manipulation*. Dordrecht: Kluwer Academic Publishers.

Ceccarelli, M., & Carbone, G. (2009). A study of feasibility for a leg design with parallel mechanism architecture. In *Proceedings of 2009 IEEE/ASME Conference on Advanced Intelligent Mechatronics (AIM 2009)*, Singapore, July 14–17 (pp. 1447–1452).

Hirose, M., & Ogawa, K. (2007). Honda humanoid robots development. *Philosophical Transaction of the Royal Society, 365*(1850), 11–19.

Kaneko, K., Kanehiro, F. Morisawa, M., Miura, K., Nakaoka, S., and Kajita, S. (2009). Cybernetic Human HRP-4C. In *Proceeding of 9th IEEE/RAS International Conference on Humanoid Robots (Humanoids 2009)*, Paris, December 7–10 (pp. 7–14).

Kemp, C., Fitzpatrick, P., Hirukawa, H., Yokoi, K., Harada, K., & Matsumoto, Y. (2008). Humanoid robots. In B. Siciliano & O. Khatib (Eds.), *Springer handbook of robotics* (pp. 1307–1333). Berlin Heidelberg: Springer.

Liang, C., & Ceccarelli, M. (2012). Design and simulation of a waist–trunk system for a humanoid robot. *Mechanism and Machine Theory, 53*, 50–65.

Merlet, J. P. (2006). *Parallel robots* (2nd ed.). Dordrecht: Springer.

Ogura, Y., Aikawa, H., Shimomura, K., Morishima, A., Lim, H. O., & Takanishi, A. (2006). Development of a new humanoid robot WABIAN-2. In *Proceedings of 2006 IEEE International Robotics and Automation (ICRA 2006)*,Orlando, (pp. 76–81).

Saladin, K. S. (2008). *Human anatomy*. New York: McGraw Hill Higher Education.

Saltaren, R. J., Sabater, J. M., Yime, E., Azorin, J. M., Aracil, R., & Garcia, N. (2007). Performance evaluation of spherical parallel platforms for humanoid robots. *Robotica, 25*(03), 257–267.

Sébastien, B., & Bonev, I. (2007). Are parallel robots more accurate than serial robots? *CSME Transactions, 31*(4), 445–456.

Sellaouti, R., & Ouezdou, F. B. (2005). Design and control of a 3DOFs parallel actuated mechanism for biped application. *Mechanism and Machine Theory, 40*(12), 1367–1393.

Zucker, M., Joo, S., Grey, M. X., Rasmussen, C., Huang, E., Stilman, M., & Bobick, A. (2015). A general-purpose system for teleoperation of the DRC-HUBO humanoid robot. *Journal of Field Robotics, 32*(3), 336–351.

Wang, M. F., & Ceccarelli, M. (2015). Design and simulation of walking operation of a Cassino biped locomotor, new trend in mechanism and machine science. *Springer, 24*, 613–621.