Nestor Eduardo Nava Rodríguez *Editor*

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Prof. Nestor Eduardo Nava Rodríguez
Carlos III University
Av. Universidad 30
28911 Leganés, Madrid
Spain
e-mail: nnava@arquimea.com

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Preface

This book provides information of the stage of mechanical design for relevant applications in robotic fields. During recent years, some new technologies have been developed and put into widespread use. Humans have always been fascinated with the concept of artificial life and the construction of machines that look and behave like people. The robotics evolution demands even more development of successful systems with high-performance characteristics for practical and useful applications. For example, humanoid robot is a system elaborated for helping or replacing persons in dangerous or undesirable works. But, it is a complex machine in which an effective design represents a challenge for researchers and scientists. Therefore, mechanical designers have studied suitable methods and procedures in order to obtain feasible results for this kind of biped walking machines. In rehabilitation field, the inclusion of robots is growing up rapidly since the good operation results that have been performed for these automated machines. Mechanical prosthesis of hand, arms or legs have improved the quality of life for handicap people providing them autonomy and versatility. Beside industrial robots, mobile robots can be the most frequent robot devices found in the market; vacuum machines or wheeled and legged robot for inspection or security applications are examples of commercial products that can be bought in a shop or by online. Parallel manipulators have opened a place in simulators market since its high structural stiffness, high payload and high-accuracy positioning in reduced workspace. Airplane simulator, automobile simulators and video game platforms are some examples of practical applications of these kinds of manipulators. The principal drawbacks of parallel manipulator are their limited workspace and losing of stiffness in singular position. The international robotics community has been working for resolving these handicaps by designing novel mechanisms that allow improving the parallel robot operation. Similarly, several innovative solutions for mechanical design of robotic systems have been reported from research centres and universities around the world. The aim of this book is to illustrate originals and ambitious mechanical designs and techniques for developing new robot prototypes with successful operation skills. In particular, humanoid robots, robotics hands, mobile robots, parallel manipulators and human centred robots are our case of study because they represent mechatronic projects with future growing expectation. Since for a good control strategy a good mechanical design is required, a book chapter has been spent on description of suitable design methods thinking of control architecture. I would like to take this opportunity to thank the authors of this book very much for their efforts and the time that they have spent in order to share their accumulated information and understanding of robotic systems.

Madrid, November 2010 Nestor Eduardo Nava Rodríguez

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Humanoid Robots

Luis Maria Cabás Ormaechea

Abstract This chapter is based within the study of the humanoid robots world and focuses specifically on the mechatronic study of them. From a scientific standpoint, will be represented mechanically this anthropomorphic robots (from now, called humanoid robots) as a final link in the evolutionary chain in robotics area. Likewise, the design of humanoid robots is based on a wide range of mechatronic disciplines (such as material science, mechanics, and even biomechanics), and we will try to describe them in this chapter. Therefore, the aim of this chapter is to approach progressively the problem of the humanoid robot design, using physical and mechanics concepts, interacting through analogies with the human body. The chapter begins making a further description of the humanoid robots world, showing the evolutionary process that have undergone this type of robots in recent years. With this run-through of the main important points, we try to describe a general procedure to find a key criteria for successful process design of humanoid robots. This "robot-making" process to explain an analysis with initial theoretical calculations that result in the selection of the various mechanical components of a humanoid robot (actuators, motors until structural components). Then, the objetive of this chapter is to present the comprehensive analysis of mechanical design of a humanoid robot that allows to know and quantify the variables you will encounter along the design process of this type of machines.

1 Introduction

The robotics proposes an attractive point of view of the technology with respect to science. From a purely technological point of view, there are many applications through the use of robots: military and security tasks, health sector, domestic

L. M. Cabás Ormaechea (✉)
Robotics Lab, Carlos III University, Av. Universidad 30,
28911 Leganés, Madrid, Spain
e-mail: Luis.Cabas.External@military.airbus.com

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services, means of access and exploration of remote or dangerous places, in the industry (cottage, car, heavy, iron and steel) to increase the productivity and the efficiency. Therefore it is expected to generate a wide variety of applications for the robots that will give a technological added to this type of machines, as in any evolutionary technology process. In a scientifical point of view, understand and explain the human intelligence behaviour and then, through this knowledge, try to create intelligent machines still follows one of the greatest scientific challenges and a highly topical subject even, is in this field where could best produce these challenges. On the other hand, one of the best theories related to human intelligence maintain, that the human intelligence can only be understood when it is associated with a physical body (embody) that allows it to interact with the world. So, if we have this kind of gorgeous mechanical machines, it will allow us to advance in modern control theories, so that the robot can not only walk even can run and help in many tasks (dynamically controlled). Finally, the robotics allows research in the design of new sensors and electronic equipment that meets needs in energy savings (to operate in real time) and low cost required for the development of humanoid robots.

2 Robots Coexisting with Human Beings

All of these desires and projects listed above will influence our daily lives. It is estimated that humanoid robots will change it in a large-measure our lives in the future. It is expected from this kind of robots, it will assist people to perform functions in virtually all types of activities. In fact, they are developing robots that assist in housework (cleaning, grass cutting, etc.), security, and entertainment, educational and even robots that assist elderly people or with disabilities. In I + D researches, there are more than a hundred projects related to humanoid robots in the world. The strange thing is that we can draw a parallel of the current state of humanoid robot with personal computers. Just before the discovery of computers (and their high growth rate through the last 30 years), nobody thought that this invention would become in personal computers. Fifteen years ago no one could see the usefulness of phones that they could fit in their pockets. Specifically, humanoid robots offer great technological challenges that once it achieved, it will be most fascinating. Starting with the basic tasks until they have the ability to use the tools that man has been used throughout history and without it has to be adapted to special environments. This may seem easy, but it is very important because it demonstrates the versatility of the humanoid robot in an environment that has been created by opening a wide range of applications (as many work environments).

3 Humanoid Robots: Definition and Classification

Like flying, one of the most sought challenges was to create a man very like him, able to communicate in their own environments and, at some point, be autonomous in its decisions: a robot. In the twenty-first century, the industrial citizen has seen the need to learn in recent years, the meaning of new terms marked by a high technological content. Irrespective of technological advances and the implications of these developments, science-fiction element of our culture will always be a mirror of our concerns, desires, and fears and hope forces for the future. Generally, robots novels and films show a little resemblance the robots that have been manufactured or designed in reality, however, because of their stellar participation in most, if not all, those futuristic movies have allowed us that the term and the machine be more familiar, making easier integrates it into our daily lives before they see the reality. After sometime was enough those we have seen as a real robot, either on a television or print news, and we put aside the myth and we accept the robot as a machine more than our environment, that sort of animated mechanical arm with speed and precision welded vehicle body or insert electronic chips on plates. From there, the rest remained within the limits of our imagination. Robotics as a tool of science fiction (or vice versa), takes its inspiration from reality, from a lack of something or necessity in daily life and exploits it to unimagined future. This revolution not only regarding on definition of robot, but also in its practical applications makes that possibilities for creating will be multiplied.

4 Advantages and Disadvantages

Taking into account the design of this kind of machines, the human had to look into the nature due to its present big part of inspiration for the designers. However the designer concluded that copying exactly the nature is not reliable and it is becoming useless and complex. So scientists of the University of California, Berkley, have focused in one common characteristic in all of the animals that without it, the robot will be useless: locomotion. After numerous studies, one of the most significant discoveries was that, regardless of the number of legs and how to perform the movement, each animal performs the same force to press the soil regardless of the leg in question. Therefore, the principle of motion is the same in all legs. However, bipedal animals have something we do not have as a centipede: greater stability, with respect to the first and greater maneuverability with respect to the second. The advantage of legged locomotion is that each makes the functions as a buffer spring and they all work as a team, led synchronously by the brain in order to do the activity that the animal wants. But paradoxically, if you look at most of the robots that exist today, one can see that they have a common characteristic which is the lack of speed and smoothness of movement. The walk of the robots is very elegant and is a problem that researchers have spent decades trying to solve. However, we will see a more detailed overview of benefits and differences of the walk that the robots actually have:

1. Mobility: Legged robots exhibit greater mobility than those who use wheels because they use intrinsically omnidirectional mobility steering. This means they can change direction on the main axis of the body by moving only their support (legs). Furthermore, they can also rotate about the axis of their body without lifting their legs supported by just their joints, that means that its body can rotate, tilt and change position.
2. Active suspension: Intrinsically, a robot with legs has a suspension for adaptation by varying the height of his body with the position of their legs into uneven ground. In this way the movement can be softer than a wheeled robot because the latter will always be parallel to the ground by adopting similar positions to the relief of the land.
3. Natural ground or Land discontinuous: The wheeled robots require continuous surface in order to move efficiently. At first the robots with legs do not require a continuous ground and may travel along sandy, muddy, steep and smooth land.
4. Landslide: A wheel can slide on a surface because of adhesion, the legs of a robot usually deposit the weight of the robot directly on the ground and the chances of slipping are lower.
5. Average speed: A robot with leg can overcome small obstacles maintaining a constant speed of its body with rectilinear uniform motion if its necessary or if the programmer so wishes.
6. Overcoming obstacles: The robots with leg can overcome obstacles which have low height compared to the size of the robot. On the other hand, a wheeled robot could be stuck if the size of the obstacle is greater than the radius of the wheel.

The tendency in recent years has tried to incorporate robots into daily life within the home or workplace, to do this, it is very important also the design, since they must be able to adapt to different environments which not requiring clear and structured extensive handling, overcome obstacles in height and also makes them look most familiar, always eyeing the Uncanny Valley. Of course, robots with legs are not the general solution of robotic locomotion. They present a series of problems and disadvantages that have kept them out of the use in industrial and service sectors. However, humanoid robots are more complex than those that use wheels with regard to electronics, Control and scroll speed (provided that the surface is flat, of course). But the main disadvantages that we can find are the following:

1. Mechanics: A system for locomotion with legs is much harder to get than those with wheels. The wheel is an extremely simple mechanism. With a single actuator, we can provide motion to the robot, however, one single leg required several kinematic links and joints. One leg needs at least three actuators to allow full movement.

2. Electronics: Each robot joint is associated it with a controller and must be controlled individually. This means that it requires many sensors as joints. A robot with wheels is always in contact with the ground, thus simplifying the electronics.
3. Control: A humanoid must coordinate the positions of all joints to make any move even with very strict guidelines to prevent fall (ZMP Control) and it is certainly more complex than a similar robot with wheels.
4. A wheeled locomotion mechanism on land surface is much faster than a similar mechanism which use legs.

5 Design Methodology

The design process consist of transform information based on conditions, needs and requirements related to the description of a structure, in order to satisfy this structure. Thus, we could say that the person, who designs, is a processor of information. Not only he starts with necessity to get something, but also with knowledge that the designer have acquired, this in order to get this imagined solution become true confirming all the characteristics for those who have been created. Today we speak of design as a science and it recognizes the interaction of a large set of features within its definition, problem solving, decision making, development, learning, knowledge, optimization, organization, satisfaction of needs; all of them are necessary but not sufficient by themselves. In this chapter, in the main topic of this article, we are going to describe the mechatronic design methodology of the natural size of humanoid robot, through a methodology for the design of it, made through the knowledge gained during the design and manufacture of prototypes RH and RH-0-1.

Definition of the Priority Tasks

It is pretended that this developed robot has to look like human beings so that their presence have to be friendly. That means, in general, the prototype. The RH-0 will have a bipedal locomotion in order to move and will have a hinged clip on the ends of their arms to manipulate small objects and a head equipped with sensors, through which the robot could be orient and move in their environment work. Moreover, as one of the tasks of the robot is the attention to disabled people, it has been designed with specific measures for a person sitting in a wheelchair can interact with the humanoid robot (which is a specific constraint objective that we are looking for) but really the applications that can be allocated to a robot of this kind today are many and various, including the following:

1. Human Assistance, for which it must be able to live with people and work well in their environment. Examples of such applications: assistance to elderly or disabled persons, personal assistants in offices, hospitals, schools, hotels and all kinds of public services that can be imagined.
2. Performing physical labor, transportation of goods both individually and collectively with other robots or with humans when it comes to large pieces. In this regard, it is noted the importance of this kind of robots when it comes to transportation in buildings where it is necessary to go up and down stairs, walking through narrow corridors, etc.
3. Periodic maintenance, with this application is intended that the robot perform those maintenance tasks that results dangerous for integrity of the operator, as e.g., electric transport airlines, and inspection of bridges in the reactor core nuclear, etc.
4. Surveillance and rescue work, security and surveillance applications for buildings and people, as well as applications in rescue work in developing natural stress, collapse of buildings, etc.
5. Entertainment and education, the robot must be capable of fulfilling leisure activities such as sports, play. In the case of education, the applications are intended to be guides in museums, explain lessons to students.

With these applications, it is understood that the environments where the robot performs its functions should be unstructured and need to do so in a broad spectrum of possibilities, from an industry to a house, past shops and hospitals, therefore, the robot should be able to walk both flat or sloping surfaces as well as save point, from up and down stairs, up a hill or mountain. Despite the functional diversity that may lead to having this kind of machines, to believe in a multitude of different solutions (in fact, hardly a human being performs the same activity in the same way twice) can be counterproductive to the goal of project, largely because of our imagination. However, we must never cease to be realistic when you assign sizing or assign a PT. This concept of flexibility should be considered as another fundamental requirement to be considered early in the design of the humanoid.

Finally, the basic design of this first prototype, the RH-0, and what we think that will be the "Priority Takes" are the following:

1. Assist human.
2. Walk straight.
3. Walking in circles.
4. Up/down stairs.
5. Incorporate the functionality of human arms when walking.
6. Carry objects weighing up to 750 gr.
7. Gesturing with his arms (pointing, waving).

Conceptual Design

These types of mechanical devices have two major subsystems, divided on kinematic chains defined as lower body and upper body. The lower string is formed by the legs and its primary function is to provide the entire robot locomotion through the environment of action and the upper chain is formed by the arms, hands and head. The union of these two parts form the hip. Like humans beings, the upper is made up by the arms, which can be interpreted well as two robotic manipulators that give you the versatility to help achieve the objective. Furthermore, we find here the torso and back that would be the trunk of the robot whose function due to the lacking mobility, is host of onboard electronics. This part is also responsible for helping maintain the balance of the whole mechanism to shift the center of gravity to the proper position, thanks to the large amount of mass that we have hosted here.

Mechanical Synthesis

Anthropomorphism is a set of beliefs or doctrines which attribute to the divine figure, or qualities of man. One of the most important features of humanoid robots is the spirit in which they are designed. From this point of view it will be taken into account the following basic features:

1. Head: It is very important that all humanoid robots have to need a head in order to present it to the environment. The robot will be devoted primarily to the interaction with the human population. Hence the importance of them look as human as possible, reflected mainly in the face and increased the capacity of gesture that allows the interaction of emotions, in turn, social inclusion. Thus, the face of the robot must be able to reflect the basic emotions (sadness, anger, fear, surprise, happiness and disgust). Besides presenting the face, must possess vision, not for personal use but for their interaction with the user, and for other sensing systems that allow it to be positioned and be oriented in the environment of interaction. For this reason, it is necessary to provide the head of a mechanism in order to be oriented. For this, we should put a DoF whose lines of action coincide at one point and in this way facilitating the kinematics of the same. The head should contain all the necessary mechanisms for all mentioned gestures and are able to work in a future. The use of eyelids, lips and mobile devices that give movement to the brow of the robot will be an aim in the development of humanoid robot. In the future, are also placed here the elements for the humanoid robot to interact through gestures with the human population.
2. Arms: Ideally, we should build an architecture arm 5, 6 and 7 DoF. In most cases, the arms have 5 or 6 DoF, have less than human arms, which is a kinematic chain of 7 DoF. If we assume that the degrees of freedom necessary to position and orient a body in space is 6 DoF human arms would then be

redundant. The advantage provided by 7 DoF is not only the hand is located and oriented, but also the same arm. It is also preferred that the motors are coupled directly to the joints (Direct Drive). This helps to eliminate weight, but mostly mechanical backlash grows over use of broadcasts. This provides the facility to orient and position the arm without changing the hand position, power necessary to avoid obstacles, even find positions that involve less energy expenditure during movement. This should be taken into account to develop the best mechanical system and that will be addressed in this research.

3. Legs: This component of the robot, is the one that will give the necessary support to the entire structure, which involves loading the weight of all engines, machinery, batteries, electronics and various materials involved. On them will swing around the chest and arms balance by looking for correct positioning of the center of gravity. Their engines must respond quickly and in coordination with the whole structure, and also absorb all the momentum that causes the movement.

Study of the Worst Case Analysis (WCA)

Following the analysis of the most unfavorable positions, forget the pair and their subsequent engine, also have been used several hypotheses as demonstrated in his case. From a more practical standpoint, we calculated the most unfavorable positions whether they be more achievable or not. This led, of course, both to very large results as well as those positions impossible to achieve for the humanoid. But the main objective of these states was a first approach to values and also managed, better adapted to the software currently used. Then, based on the theory of ZMP they are opted to take more realistic positions considering ZMP validity and comply with the requirements for each PT.

In conclusion of this stage, we can say

1. In the sagittal plane, we obtained very convincing pairs based on technically feasible positions. Pseudo-state was considered a real for each case.
2. As a prerequisite, you should always consider the ZMP is located within the eligible area.
3. The joints obtained were considerably lower than those estimated in previous analysis because the engine and the structure are subjected at more relaxed position.

Preliminary Design of the Robot

Within these considerations, we point out:

1. Building materials: The materials used in building the robot should be lightweight and highly resistant. Of course the design of mechanical components

should help in this task. On the other hand, one of the major problems in the development of humanoid robots is the energy efficiency because it has not yet developed enough batteries and small electric motors and high capacity, so the optimization mechanical structure is of prime importance.

2. Optimal mechanical design: The performance of the humanoid robot rests essentially on the mechanical design. The pieces should have less inertia possible without sacrificing strength and rigidity. The optimal mechanical design allows to develop lighter and stronger parts, increasing responsiveness. The assembly of mechanical system should produce a stable, solid and robust system. Without doubt, one of the main characteristics that define the robot is that it includes DoF. Talk of DoF is the same as talking about the number and type of movements that the robot can perform. On the other hand, watching the movements of the robot, it is possible to determinate the number of DoF that is presents.
3. Mechanical actuators: We must use effective actuators and strong. However, we are not leaving aside the possibility of investigating other types of actuators, including hydraulic or pneumatic. It is important to develop mechanisms for small actuators that can be housed in very small spaces in the arm and hand. The joints may be powered by mechanical energy conversion devices of an electrical, hydraulic or pneumatic.
4. Balance: For many authors, to achieve a right balance is the most important consideration when designing a mechanical humanoid robot. The primary objective of all design in the biped locomotion is to ensure that when the robot walks it will achieve a dynamic equilibrium. Control methods are used to achieve dynamic balance, however the mechanical design must be chosen so that the robot can respond quickly to the required movements. One method to achieve this goal, is to distribute the dough through the robot in such way that any movement (sudden or not) must to be small. Thus, these movements can be made quickly without generating large moments that usually destabilize the robot. To achieve this, the CoM should be placed as low as possible, to stabilize the inertia of the robot but also fairly high, in order to move only small amounts of mass to correct unwanted behavior. The correct placement for the trunk CoM would be slightly lower, similar to humans. This provides stability and allows the trunk to be moved; changing from place to CoM for accelerations that counter exist unwanted accelerations.

In addition to these considerations, we studied the range of motion of joints in the human being, to keep them as reference in the respective RH-0. So with these concepts we divide the study into two parts:

1. Structure and distribution of the DoF in the arms.
2. Structure and distribution of the DoF in the legs.

So for the arms we required movements that simply are imitating the human walking, extension of the frontal and lateral plane, transport and carry with lightweight things. Based on these concepts, we selected an arm with sagittal mobility and front in the shoulder, sagittal mobility in the elbow and transversal mobility in the wrist; additionally we will place a clamp to manipulate objects. As a summary, 4 DoF in the arm. For the trunk, we recommend one DoF in the transverse plane to enlarge the angle of arm movement around this axis. We prefer this DoF at the top of the column. The result of this study leads us to select the structure of 6 DoF, which guarantees enough mobility for a stable ride similar to human beings. In this type of structure selected, with certain variations, related to mobility in the hip, an area critical to a stable path and in turn keep the stability of the robot, as well as assume the primary role of supporting the upper weight of the robot (torso, arms, batteries, electronic components, etc.). We then have the conventional structure similar to a simple portico, whose bending strength is mainly concentrated in the center of it. This is used by Asimo and most humanoids, due that its good performance has been proved. On the other hand, the novel cantilever structure, that was introduced by the HRP-2, this type of structure allows to distribute the bending stresses in the hip due to higher weight in the robot body.

Calculation of the Mechanical Requirements

The purpose of the dynamics is to establish the relationship between the forces and moments acting on a body, and the movement in which it originates. This relationship in the case of a robot is given by the mentioned dynamic model, which mathematically relates:

1. The location of the robot due to the joint variables defined by its coordinates or for the locations of its end, and their derivatives: velocity and acceleration.
2. The forces and torques applied to the joints.
3. The dimensional parameters of the robot, such as length, mass and inertia of its elements.

To obtain these kind of mechanisms that have a high number of degrees of freedom, the difficulty increases significantly. This makes that this dynamic model could not be done always in a closed manner, i.e., expressed by a set of normal equations of differential type of 2nd order, whose integration allows knowing the movement when applying forces you have to do it for a particular movement. The dynamic model must be solved iteratively using a numerical procedure. The problem of obtaining the dynamic model of a robot is one of the most difficult aspects of robotics, which has been avoided in numerous occasions and that, however, it is essential to achieve the following purposes:

1. Robot motion simulation.
2. Design and evaluation of the mechanical arm.
3. Sizing of the actuators.
4. Design and evaluation of dynamic control of robot.

It is important to know that the full dynamic model of a robot should include not only the dynamics of its elements (bars or links), but also own their transmission systems, actuators and electronic control equipment. These kinds of elements incorporate into the dynamic model new inertia, friction, saturation of electronic equipment, etc. further increasing their complexity. There are two possible approaches to the balance of forces and torques involved on a robot, that result in the so called models:

1. Direct dynamic model: it expresses the temporal evolution of the robot joint coordinates in terms of forces and torques involved.
2. Inverse dynamic model: it expresses the forces and torques involved in terms of the evolution of joint coordinates and their derivatives.

The obtaining of the dynamic model of any mechanism is mainly based on the approach to equilibrium of forces and moments acting on it and respectively established on the second law of Newton and its equivalent for rotational movements, the law of Euler.

Center of Gravity (CoG) Trajectory

Previously justified the desired trajectory for the ZMP, during the progress of the robot along a full step. The kinematic simulations that have been done provides a trajectory considering that all the conditions were not fulfilled, however it was close enough to the desired goal. It shows the evolution of the position of the CoG (blue line) along with the both feet in red on the left, and on the right shows the simulation of robot movement during its time evolution. The main objective, as named above, of all these calculations and algorithms, is the determination of the motors to ensure optimum performance of the biped, at powerful point of view. The selection of these kinds of motors are taken into account the results obtained (with speed and zero acceleration) in quasi-static state. At this stage of the project, it is difficult to find the nature of the mechanical stresses to which they must subject the robot, so it is supposed to a quasi-static state (both their velocities as their accelerations were very low) even though logically the robot moves. Therefore, it is very important for the dynamic analysis of robot, the choice of an acceleration and proper motion velocities, because this selection will depend on torque efforts on its joints and even the possibility of the system to respond adequately with its motors. The way to compensate the quasi-static calculation of stresses generated in the robot to expect a good response and movement of the system, is adding a safety factor to the values obtained (taking into account the inertial factors too), so that all engines are oversized in order to respond to higher loads in an effective way. In addition to calculations, the process of obtaining these permits to establish a set of conclusions is to be taken into account in future designs. Note that carried out an exhaustive dynamic study, can make it difficult and very costly. The dynamic study presented above, has many simplifications and