Proceedings of the 18th World Congress
The International Federation of Automatic Control
Milano (Italy) August 28 - September 2, 2011

Cost Oriented Humanoid Robots

P.Kopacek

Vienna University of Technology, Intelligent Handling and Robotics- IHRT,
Favoritenstrasse 9/E325A6; A-1040 Wien
(Tel:++43 1 58801 31800, e-mail: kopacek@ihrt.tuwien.ac.at)

Abstract: Currently there are three categories of humanoid robots available: Professional humanoid robots developed by large companies with a huge amount of research resources. They are expensive and not available on the market. Research humanoid robots: The robots in this category are usually prototypes developed by scientists to implement and test new ideas. Humanoid "Toy" robots: There are a lot of humanoid toy robots, mostly developed by small or medium sized companies, available on the market. Usually they have extremely limited capabilities in hard- as well as in software. Because of these facts in this paper a new fourth category – cost oriented humanoid robots (COHR) are introduced. These robots will be able to support humans in everyday life e.g on the working place, in the household, in leisure and entertainment, and should be available on the market for a reasonable price.

Keywords: Humanoid robots, Cost oriented robots, Mechanical Design, Control concepts.

1. INTRODUCTION

A humanoid robot is a robot with its overall appearance based on that of the human body. Perception, processing and action are embodied in a recognizably anthropomorphic form in order to emulate some subset of the physical, cognitive and social dimensions of the human body and experience. Humanoid Robotics is not an attempt to recreate humans. In general humanoid robots have a torso with a head, two arms and two legs, although some forms of humanoid robots may model only part of the body, for example, from the waist up. Some humanoid robots may also have a 'face', with 'eyes' and 'mouth'. The definition of a humanoid is as simple as "having human characteristics."

It is an old dream to have a personal human-like robot able to help in everyday life. The main features of such a humanoid robot are bipedal walking , arms with gripping devices for manipulating, speech analysis and synthesis, facial expressions and gestures for communication.

Walking machines or mechanisms are well known since some decades. Usually they have 4 to 6 legs (multiped) and nowadays 2 legs (biped) – walking on two legs is from the view point of control engineering a very complex (nonlinear) stability problem. Biped walking machines equipped with external sensors are the basis for "humanoid" robots.

Biped walking robots are much more flexible than robots with other movement possibilities. The main advantage of legged robots is the ability to move in a rough terrain without restrictions like wheeled and chained robots. Legged robots could work in environments which were until now reserved only for humans. Especially fixed and moved obstacles can be surmounted by legged robots. In addition to walking such robot could realize other movements like climbing, jumping…

There are two methods of walking: Static and dynamic. "Static walking" means the robot keeps its centre of gravity within the zone of stability - when the robot is standing on one foot, its centre of gravity falls within the sole of that foot, and when it is standing on two feet it falls within a multi-sided shape created by those two feet - causing it to walk relatively slowly. In "dynamic walking", on the other hand, the centre of gravity is not limited to the zone of stability - in fact it often moves outside of it as the robot walks. Basis is mostly the "Zero Moment point – ZMP" method introduced in 1972 (Baltes, 2004). People moves usually by "dynamic walking".

Fig. 1 shows schematic the main parts of a humanoid robot. A human has 234 degrees of freedom (DOF`s). Each of them have to be realised by a joint consisting of a drive a gear, sensors and a controller. Therefore to built a humanoid robot with all the moving possibilities of a human, 234 joints would be necessary. The current available humanoid robots have between 18 and approximately 80 DOFs because the complexity of the design and the control increases with each DOF.

These joints are connected to the power supply and by a bus system with the central computer both situated in the torso. For communication an HMI is necessary.

2. CATEGORIES OF HUMANOID ROBOTS

The humanoid robots available today can be assigned to three categories:

Professional humanoid robots developed by large companies with a huge amount of research resources, both in turns of people and money. The idea is to develop robots that assist humans in tasks of their everyday life, serve for

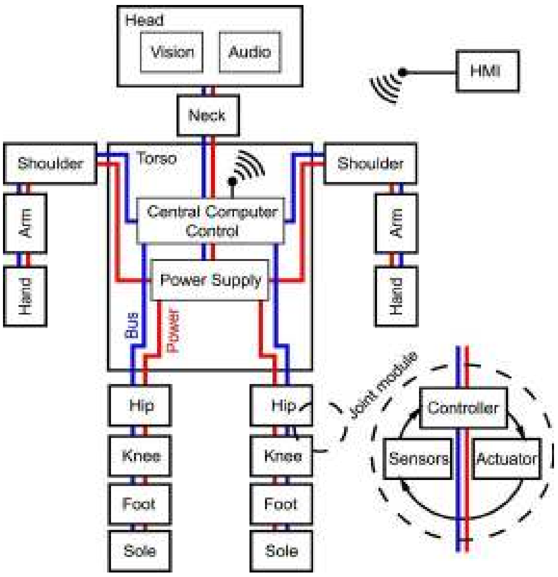

Fig. 1. Parts of a humanoid robot (Kopacek 2008)

entertainment, leisure and hobby and can be "personal robots". They are usually very expensive and are only partially available on the market.

Classical examples are: the Honda robots (P1, P2, P3, ASIMO) – with the idea to assist humans in everyday working, the SONY robots (SDRX – 3,4,5,6 and QRIO) – with the background to serve mostly for entertainment, leisure and hobby or in the future as personal robots.

Since 1986 the Japanese Company Honda has developed humanoid robots, P2, P3 and ASIMO (Advanced Step in Innovation Mobility). The basic idea is to integrate the intelligence and moving capability to robot for trivial works. Over the years the robot gets smaller (P3-160cm, ASIMO-120cm) and lighter (from 130kg of P3 to 43 kg of ASIMO). ASIMO can move with a speed of up to 6 km/h. This robot has 26 DOFs. This kind of robot can easily be used in home as wheel driven robots, because their capability move in an uneven surface, like stairs.

QRIO (Fig.2.) was SONY's next step after the Robodog-familiy "AIBO". Qrio is a biped humanoid robot that is able to walk on uneven and sloppy surfaces, run, jump, perceive depth through its two CCD cameras, be able to create a 3D map of its surroundings, recognize people from their faces and voices, learn, connect to the internet via a wireless home network, download and read information in which you are interested about, sing, dance and survive a fall unscathed and get back up by itself again.

In order for QRIO to walk and dance so skilfully, an actuator was needed with the ability to produce varying levels of torque at varying speeds and respond with quickness and agility. The robot moves with "dynamic walking".

Fig.2. QRIO

If pushed by someone, QRIO will take a step in the direction it was pushed to keep from falling over. When it determines that its actions will not prevent a fall, it instinctively sticks out its arms and assumes an impact position. After a fall, it turns itself face up, and recovers from a variety of positions. It is equipped with a camera and the ability to analyze the images it sees. It detects faces and identifies who they are. Moreover QRIO can determine who is speaking by analyzing the sounds it hears with its built-in microphones.
Most of the other robots in this category have similar features.

Research humanoid robots: The robots in this category are usually prototypes developed by scientists to implement and test new ideas. These types of robots are very popular – approximate 1000 research labs work in the related areas. Theoretical scientists from mechanical engineering implement walking mechanisms, control scientists implement new control strategies, computer scientists implement new ideas in AI and computer vision, social scientists implement human machine interfaces (HMI) for efficient communication between humans and robots. Usually they have a very poor mechanics and a "closed" software.

Humanoid "Toy" robots: There are a lot of humanoid toy robots, mostly developed by small or medium sized companies, available on the market. Usually they have extremely limited capabilities in hard- as well as in software.

An example for a reasonable cheap research robot is the humanoid robot of Robonova (Fig.3.). It is a fully customizable and programmable aluminium robot. 16 digital servos and joints give complete control of torque, speed and position. The basic programming software is simple – no advanced knowledge of programming is necessary. It can walk, run, flips, cartwheels and dance. The robot is available as a kit – assembly time approximately 8 hours - or as pre-assembled, ready to walk robot. In addition to the typical robot talent for walking until it senses a wall using ultrasound, Robonova can be instructed to do cartwheels, take a bow and even do one-handed push-ups.

Fig.3. Robonova

The simplest way for programming is with the "catch and play" function. With RoboScript or RoboBasic the robot is moved to any position and by mouse click that position is "captured". The software then links these "captured" positions and once activated, smoothly transitions the robot's movements through these programmed positions.

Because of the limited market and the high price of professional humanoid robots, the availability of research humanoid robots, and the limited capabilities of humanoid toy robots, in this contribution a new fourth category – ***Cost Oriented Humanoid Robots (COHR),*** will be introduced. These robots will be able to support humans in everyday life e.g on the working place, in the household, in leisure and entertainment, and should be available on the market for a reasonable price. These goals could be reached by standardisation of the hard- and software platform, using the latest technologies, applying modern control concepts, ...

3. STATE OF THE ART

A COHR can be conceived by using industrial components with a robust simple mechanical design, easy operation through flexible programming. The use of such kind of components may decrease the complexity of design. Therefore, low-cost components are a very good expedient for reducing the cost and time of designing humanoid robots. Nevertheless, such a low-cost design will yield to a humanoid robot with limited capability both in mechanical versatility and programming flexibility. But in general, it can be thought that a low-cost humanoid robot can have still interesting performances for mobility, manipulation, and autonomous operation that are useful in many applications. Some examples are:

In (Nava Rodriguez, 2007) a low-cost easy-operation humanoid robot CALUMA is described. In this humanoid robot each subsystem must be operated as a part of a whole structure, rather then as a individual prototype. The proposed subsystems for CALUMA structure have presented operation problems as consequence of their application as a part of a humanoid platform.

Fig.4. Design architecture for the CALUMA robot - 3D-CAD model (Nava Rodriguez, 2007).

The Robo Erectus (Zhou, 2004) aims to develop a low-cost humanoid platform so that educators and students are able to build humanoid robots quickly and cheaply, and to control the robots easily. Currently works are ongoing to further develop this platform for educational robots, service robots and entertainment robots.

By using the fuzzy reinforcement learning approach, Robo Erectus is able to start walking from an initial gait generated from perception-based information on human walking and learn to fine-tune its walking and kicking behavior using reinforcement learning. Humans do not just learn a task by trial and error, rather they observe how other people perform a similar task and then repeat them by perceptions. How to utilize perception-based information to assist imitation learning will be a new challenge in this field.

Since a humanoid robot tips over easily, it is important to consider stability during controlling the robot and learning new behaviors. Many methods have been proposed for synthesizing walking patterns based on the concept of the zero moment point (ZMP). Since the humanoid gait consists of a large number of unknown parameters, this allows us to formulate constraint equations to determine the unknown parameters of the gait to achieve dynamic locomotion. Due to the large number of unknown parameters for the above optimization problem and some requirements of human-like dynamic walking, we need to specify some constraints, e.g. ZMP constraints for dynamically stable locomotion, internal forces constraints, for smooth transition, geometric constraints for walking on an uneven floor, etc.

Other robots of this category are described in Baltes (2004), Davies (2008),……..

4. COST ORIENTED DESIGN

The cost oriented humanoid robots presented before are more or less ("advanced") toy robots. Therefore in the following first ideas for the development of a real robot able to support humans in everyday life as well as for industrial applications will be presented based on our experiences from mobile robots realised in the past (Kopacek, 2006, 2008, 2009; Silberbauer, 2008)

Therefore a robot to fulfil these tasks have to have the following features:

1. Height: 120 cm
2. Weight: less than 40kg
3. Operation time: minimum 2hrs
4. Walking speed: minimum 1m/s
5. Degrees of freedom: minimum 24
6. "On board" intelligence
7. Hands with three fingers (one fixed, two with three DOFs)
8. Capable to cooperate with other robots to form a humanoid Multi Agent System (MAS) or a "Robot Swarm".
9. User friendly Human Machine Interface - HMI.

4.1 Mechanical construction

First of all the construction should be reasonable lightweight for power saving and increasing the operation time of the robot. Existing robots with extremely lightweight constructions are not able to handle the necessary payloads for the tasks mentioned before.
Cost orientation can be reached by

- Using commercially available components for a reasonable price
- Using standardized modules available on the market or developed

For design there are, according to our experiences, some new constructive ideas necessary. Some of these will be presented in the following using our "Teen sized" humanoid robot "Archie".

4.1.1 Standardised joints

For our humanoid robot Archie we developed a joint module which can be used as a standard for all joints on the robot. One design goal was to copy as close as possible the physical appearance of a human. This requires a high volume to power ratio; high torque in a small volume. This can only be reached with harmonic drives (Fig.5.). Therefore the joints of Archie are realised by brushless motors coupled with a harmonic drive, which gives the robot very high performance and efficiency.

Each of these joints (modules) realise only one DOF. Because of the modular design they can be combined to joints with two (e.g. shoulder) or three (e.g. hip) DOF's.

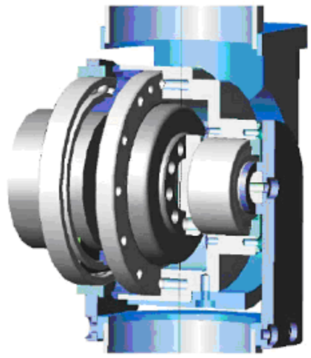

Fig.5. Standard joint module

4.1.2 Hip design (Mastny, 2010)

For the hips moving the upper body, tooth belt drives were used. The main disadvantage is the backlash resulting from the elongation of the belts because of the high tension and the backlash of the tooth wheels. A suitable solution of the problem is the usage of tighteners. The tightener balances a too small distance between the two pulleys and guarantee a constant tension of the tooth belt (Fig.6). Here the tighteners just get pulled against the tooth belt and then are fixed with screws. Slip between the belt and the tightener was avoided by using a rubber with a good grip. It is obvious that now in the case of a change of the rotation the bow in the tooth belt would not cause a clearance since the whole belt is under tension.

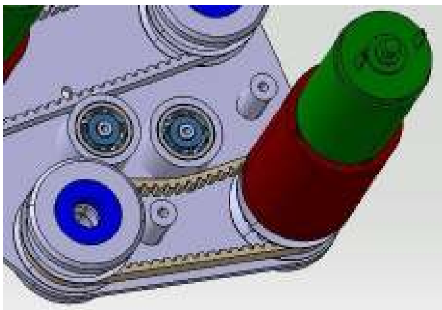

Fig. 6. Hip with tighter

4.1.3 Legs (Mastny, 2010)

For the legs (Fig.7.) the standard joints – 9 for each - are used mounted on aluminium profiles. To minimise the torsion additional cross ties on the thigh and the shank, similar to a framework construction are attached. The additional weight is a minimum and the additional parts are easy to integrate.

4.1.4 Torso

Because of the limited space for the electronics in the upper body it`s included in the torso. The circuit board with the controller and the peripheral devices will be mounted directly in the front of the upper body (Fig. 8). This yields to more space for the

Fig. 7. Leg

motion controllers which can be arranged freely in the space for the motor of the head. An additional advantage is that the centre of mass is now nearer to the hip.

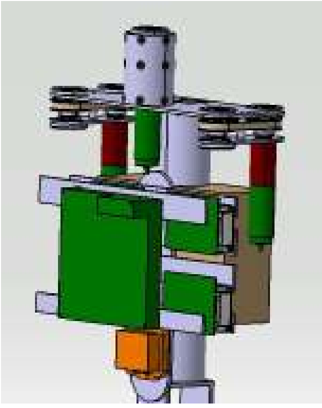

Fig. 8. Torso

4.1.5 Arms

To fulfil the described tasks the robot has to have two arms with the necessary DOF`s. As mentioned above the layout should be the same than the legs. As the arms are shorter and get less loaded the torsion should be less a problem than at the legs. Additionally a minor deformation of the arms would not have major effects as the arms are not important for a smooth movement of the robot. Additional to the rotation two drives are combined to the shoulder and thus provide the same amount of DOFs as the human shoulder. The forearm is again connected with a drive which provides the one DOF of the elbow. The rotation of the forearm a human being is capable will be realized with an additional joint in the hand.

4.1.6 Head

The head needs a proper mounting system for two cameras, the eyes of the robot. The pictures of the cameras will be computed by a stereo vision system that makes the robot able to move through unknown surrounding. A human being is partially able to move the eyes independent to each other. This possibility will not be realized since the stereo vision systems needs one direction recorded from two different viewing points. Thus a simultaneous movement of the cameras is fundamental.

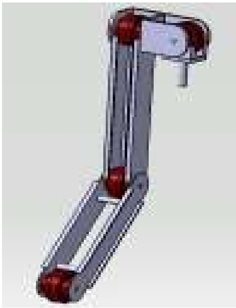

Fig. 9. Arm design

One possible solution is shown in Fig.10. For the pitching movement of the head a standard joint is used to keep the costs low. A tooth belt driven by a servo can turn the cameras left and right which enhances the view of the robot.

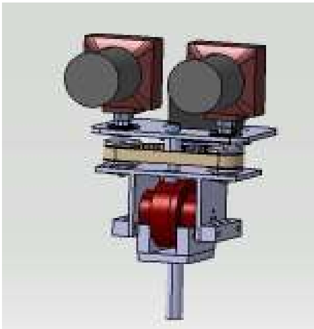

Fig.10. Head

4.2 Control

The suggested control system is based on a distributed architecture. In this structure, each joint is controlled individually by a motion controller which in turn communicates with the central controller via a data network. The central controller is responsible for the following tasks:

- Energy management
- Multitask management

- System failure detection
- Performing received commands
- Synchronizing the joint controllers
- Ensure the overall balance of the robot
- Calculating the location of the supporting polygon
- Preventing mechanical collision in manual movements
- Updating the desired positions resulted from calculation with the joints
- Splitting general commands into joint commands (for combinational movements)

A method able to minimize these unexpected effects is based on the relations between forces and moments which appear in different regions of the robot. The attempt to control the moment of robot joint with respect to a reference point is a solution hereto problem. The angular moment of human in time of walk, with respect to an outside reference point, from the actual studies, has a variation nice and a slow, and in stationary state actually 0. This was the reason for beginning the research and the implementation of a method where exactly this is attempted: the check of the angular moment of robot.

The control system is realised by a network of processing nodes (distributed system), each for one node, consisting of relative simple and cheap microcontrollers with the necessary interface elements. According to the currently available technologies the main CPU is for example a PGA module, one processor for image processing and audio control and one microcontroller for each structural component. To increase the processing power of the entire network additional nodes can be easily added to the network. Special nodes are reserved for vision processing, sound synthesis and speech recognition as well as for sensor processing.

5. CONCLUSIONS

Service-robots will become a real "partner" of humans in the nearest future. One dream of the scientists is the "personal" robot. In 5, 10 or 15 years everybody should have at least one of such a robot. Because the term personal robot is derived from personal computer the prices should be equal. Some new ideas in automation especially in robotics are realized very fast while others disappears (Kopacek 2008).

The cost oriented humanoid robots presented in chapter 2 are more or less ("advanced") toy robots. Therefore in this paper first ideas for the development of a real robot able to support humans in everyday life as well as for industrial applications are presented based on our experiences from mobile robots realised in the past.

To support humans in everyday life e.g working place, household, ... , these cost oriented robots (COHR) must have an appropriate size (minimum 1.2m) as well as much more functionality then the currently available toy robots. The software has to be "open" for easy adapting according to the special demands of the user. The price should be not more than the price of a currently available, expensive toy robot. Probably COHR are a first step to one of the oldest dreams of the humans – the Personal Robot.

REFERENCES

Baltes,J. and P. Lam (2004). Design of walking gaits for tao-pie-pie, a small humanoid robot. *Advanced Robotics*, 18(7):713–716, August 2004.

Davis, N.G. Tsagarakis and D. G. Caldwell (2008). The Initial Design and Manufacturing Process of a Low Cost Hand for the Robot iCub. *8th IEEE-RAS International Conference on Humanoid Robots* December 2008, Daejeon, Korea

Kopacek,P. (2006). Robotsoccer; Past, Present and Future". *Proceedings of ISR 2006, Munich,Germany 2006*; p.153, 2006.

Kopacek, P. (2008): Automation in Sports and Entertainment. In S.Nof: *"Handbook of Automation"*. Springer 2009; p. 1313 - 1331.

Kopacek,P. (2009). " Cost Oriented mobile mini Robot for Space Application"; in Proceedings of " Informatica"; La Habana, Cuba; February 2009.

Mastny, W. (2010): Improvement of the mechanical construction of advanced mobile robots for Landmine detection. *PhD. Thesis, Vienna University of Technology,* 2010.

Nava Rodriguez,N.E, G. Carbone, M. Ceccarelli (2007): Design Evolution of Low-Cost Humanoid Robot CALUMA. *12th IFToMM World Congress*, Besançon (France), June18-21, 2007.

Silberbauer, L. (2008). Development of an intelligent mobile robot for landmine detection. *PhD thesis, Vienna University of Technology*, 2008.

Zhou,C and P.K Yue (2004): Robo-Erectus: a low-cost autonomous humanoid soccer robot. *Advanced Robotics,* Vol. 18, No. 7, pp. 717–720 (2004).