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A Cost Oriented Humanoid Robot Motion Control System

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Abstract: This paper deals with implementation of a distributed controller for a humanoid robot. This teen sized humanoid robot Archie is currently under development. The main idea is to develop a cost oriented humanoid robot (COHR) to assist humans for their daily life.

After a short description of the existing hardware, the control is described. The control is realized by a PI controller for position and velocity of each joint of humanoid robot in specific time order. The main advantage of this method is to synchronize the motion of alljoints necessary for biped walking motion. The developed controller program was first tested by simulation and implemented on the robot. The results on the real robot show the efficiency of this method for the gait motion of the robot. Finally an outlook on further work is given.

*Keywords:*Humanoid robot, control architecture, distributed cascade control, motion controller.

1. INTRODUCTION

Since a humanoid robot is a non-holonomic system, the joints of the robot are facing different load properties regarding to the overall pose of the robot. Thus, the control of the robot should be designed in order to provide appropriate performance for a nonlinear, multivariable, instationary system.

In the currently available literature contributions describing the control in detail are very rare. Therefore in this paper a new cost oriented control architecture for a humanoid robot will be presented. First the mechanical and electrical structures including the necessary hardware components are shortly described. Furthermore the dataexchange between the on board PC and the motion controllers controlling each drive via a serial bus (USB) to the Control Area Network (CAN) bus converter is outlined.

2. MECHANICAL DESIGN

The main specifications of our cost oriented humanoid robot (COHR), called "Archie", are a height about 120cm, low weight - less than 35 kg, commercial servo and brushless motors. To reach this weight the structure is made of aluminium. The differences to existing humanoids are the design of the pelvis, the kinematics in the feet and the actuators equipped with two types of DC motors.

One of the main goals in designing was to have enough DOF to realize a wide range of human motions (e.g. walking, manipulating of objects with the arms bowing and other motions of the torso), yet to be lightweight so that the robot can move quickly and fluently.

This robot has an upper body with12 DOF in the arms, 2 DOF in the torso and 2 DOF in neck and head. The existinglower body has 14 DOF in legs and hips. Fig.1 shows the kinematic model of the lower body which is currently existing, including all joints (DOF) and dimensions.

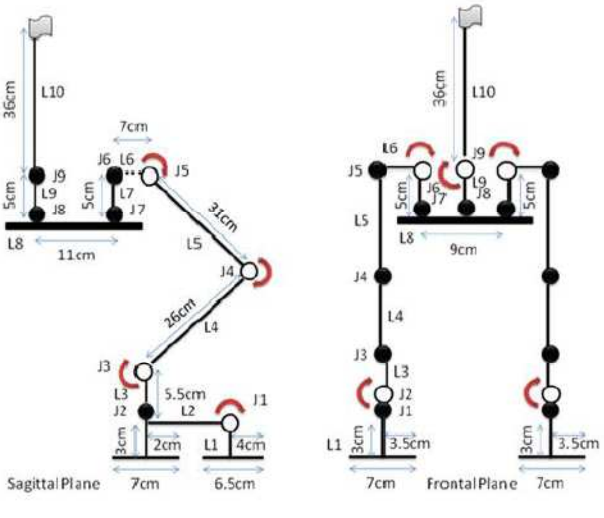


Fig.1. Sagittal (lateral) and frontal view of Archie

In order to create stable dynamic walking, three DOF in lateral, transversal and frontal direction for each hip and two DOF in lateral and frontal direction for each ankle are realized.

Further specifications and hardware architecture are given in Table 1.

3. ELECTRICAL DESIGN

The electronic, computer and distributed software architecture will be shortly described in this section.

Table 1.General Specifications

Total DOF	30 DOF
Actuator/Motor	Brushless- and brushed DC motors, harmonic drive
Communication Network	CAN bus
Control Unit	Motion controller
Operation Section	PC/Laptop
Operating System	Linux
Power (Battery)	2x14.4 V

There are two different types of motors used in for the joints; brushless and brushed DC-motors. Brushless DC-motors have advantages such as high efficiency and less noise. But the control isquite different compared with brushed DC-motors.

In addition the brushless DC-motors are more expensive especially for high mechanical torque. Therefore we used brushed DC-motors for some joints that need less torque such as in the torso.

Figure 2illustrates the implemented distributed controller architecturefor the upper and lower body.

Each motor is equipped with an encoder, power source and motion controller. Each joint has its own controllerfor position and velocity realised by a digital servo motor drive(Elmo, 2010)

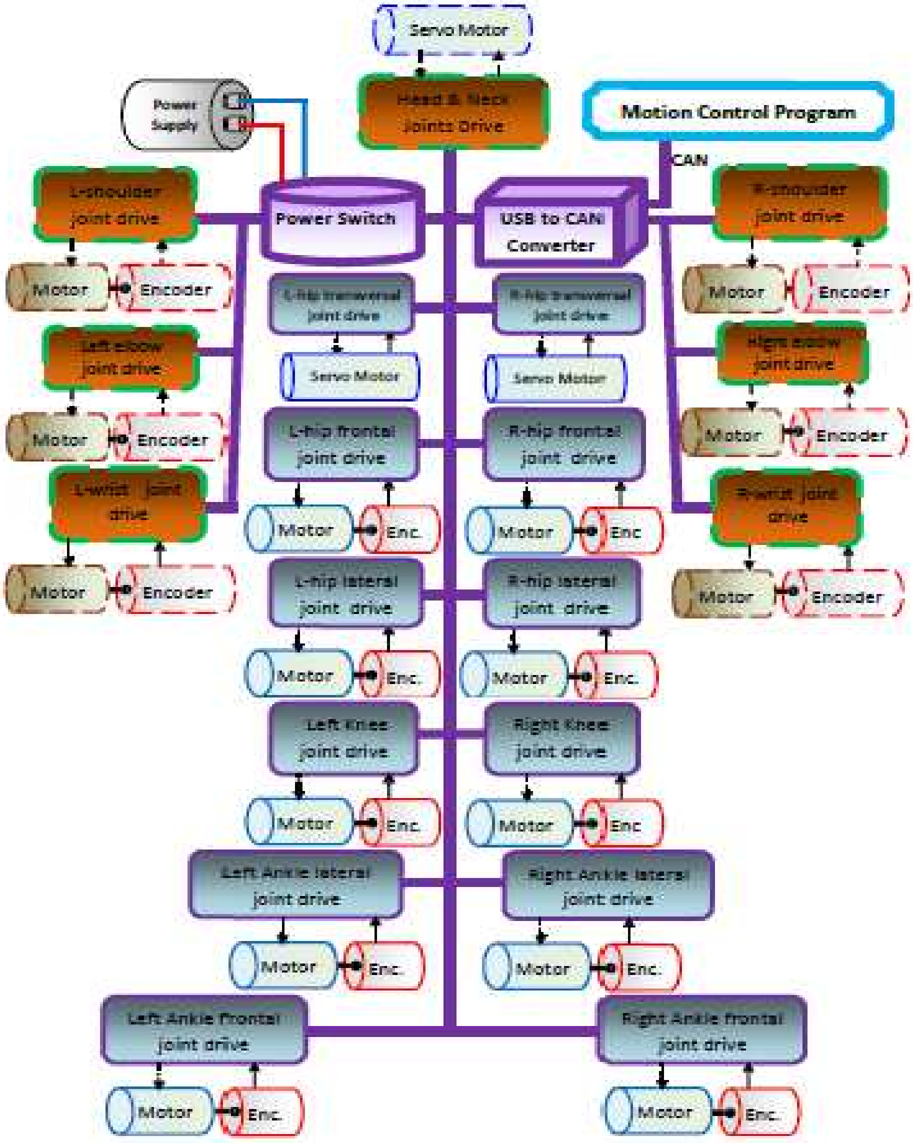


Fig. 2 Full Body of Archie

4. CONTROL ARCHITECTURE

The drive controllers are realized by miniature digital servo drives for the DC brushed and brushless motors of joints. The high level supervisory motion controller send the necessary commands for a stable walking toeach joint drive. (Dezfouli, 2012).

The decentralized control system is shown in Fig.3. The walking pattern planner calculates the food placements and trajectories for the left and the right foot and the torso based on feedback about the position and velocity of the torso from sensors. Then the joints angle trajectories are calculated byinverse kinematics transforming the walking trajectories from Cartesian to joint space (Bajrami, 2013).

Therefore, the outputs of the inverse kinematics are the desired joint angles $\theta d1$ to $\theta d6$ for both legs. The reference trajectories for the independent joint controller are obtained by multiplying the desired joint angle θdi by the corresponding gear ratio kri. The reference trajectories are actually the rotation angles of the motors θmdi.

An independent joint controller is used for each joint (Fig4). The controller uses the classical cascaded feedback loop of position and velocity to produce the appropriate control voltage vci according to the desired motor angle θmdi. Although, the acceleration feedback loop also can be used to improve the controller performance, direct measurement of acceleration is not possible at the moment and indirect measurement of acceleration is not used. Position feedback is obtained in each joint via an incremental encoder. The velocity feedback is carried out by a speed estimator algorithm provided in the Elmocontroller.

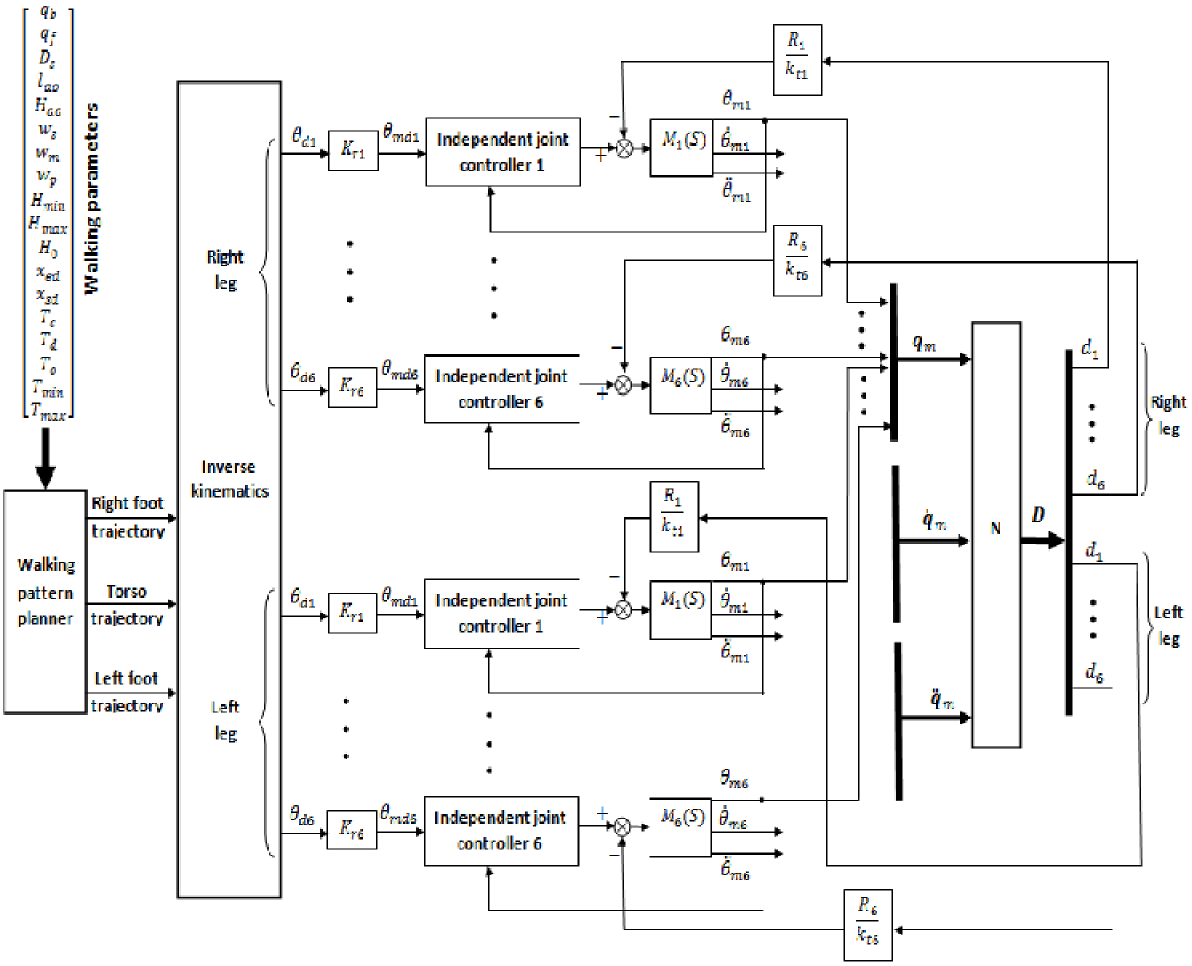


Fig. 3 Overall Control System (Daniali, 2013

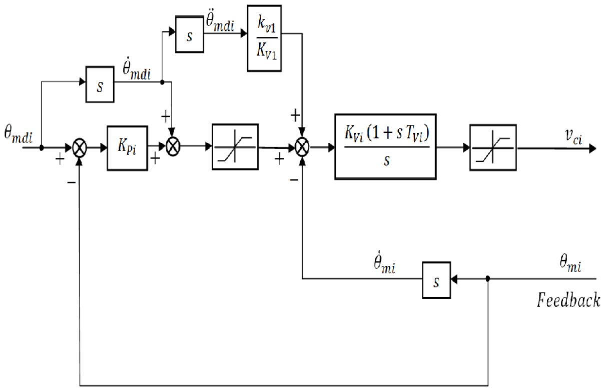


Fig. 4 Joint control

The control algorithm is based on thewell known distributed cascade control architecture. The cascade controller is derived from standard motor drive controller and contains three different loops: position, velocity and torque.

In the first inner loop (torque control) the drive controls the motor torque. For this only the position feedback is used. Position and speed are observed continuously to avoid high and low speed level.

The second inner loop gets the velocity feedback estimated based on position command. In addition the speed controller provides the torque command. The desired velocity to speed controller is a sum of two signals; velocity reference command and feed forward derivative of position command. The speed controllers are realised by simple digital time discretePI algorithms.. Both controller parameters are tuned by the gain scheduler.

The position control loop compromises a proportional gain, cascaded over the speed controller. This controller is fed with position reference command and feedback from encoder of the ELMOS.

5. POSITION FEEDBACK CALCULATION

In the toe joint existsan incremental positioningsystem based on a reference(zero) point.Therefore the motor is moved to afixed position at start. Then, the position will be determined using incremental encoders mounted on the motor. A permanent magnet and aHall sensor based on a absolute encoder gives always the correct position of the joint.However, the absolute encoder is mounted on the motor output.

The most common approach to determining the absolute position of the motor is to use end-switches. However, this requires the robot to move into possibly unstable positions at initialization, which is unsuitable for large and expensive teen sized humanoid robots.

Our method uses a contact-free solution. A chip that contains four Hall sensors, a flash analogue to digital converter (ADC), an embedded micro- controller and a permanent magnet is mounted opposite a magnet. The permanent magnet is attached on the output of the motor or equivalently on the input of the gearbox.

Each of the four Hall sensors has a different angle to the permanent magnet. Allowing to measure the absolute angle between the chip and the permanent magnet. This implements a contact-free absolute encoder that provides pulses like an incremental encoder as well as an absolute position of the permanent magnet.

However, this solution only allows us to determine the absolute position of the motor shaft (input to the gear box). With a gear ratio of 1:160, there are 160 possible positions for the output shaft (output to the gear box) for each position measured on the input shaft.

To determine the absolute position of the output shaft, a Hall chip is mounted on the output of the harmonic gear box and a permanent magnet is connected to the output of the motor(input of the gear box).Since the output shaft rotates with the gear box, the relative angle between the position indicated by the Hall switch and the position feedback from the Hall sensor will vary, thus allowing us to determine the absolute position of the output shaft.

To determine the absolute position of the output shaft, the motor is slowly moved until the Hall switch is triggered. Because of the high gear ratio, a full rotation of the motor shaft corresponds to less than 2 degrees rotation on the output shaft. This puts the motor into a fixed position. Then the absolute position recorded by the Hall sensors is measured, which allows us to determine the absolute position of the output shaft according tothe following formula for a complete revolution.

$$\text{Sensor Angle} = 360 + (360/r) \tag{1}$$

where r is the gear ratio.

The sensed angle is the sum of two terms: the first term corresponds to one full revolution of the rotor and the second term corresponds to the movement of the output of the gearbox.

6. MOTION AND DRIVE CONTROLLER

The policy to execute a full line ensures that commands are executed in a guaranteed sequence and enables the user to regulate the speed of program execution. The drive controller

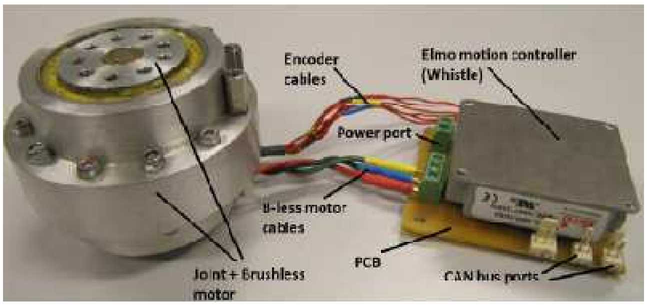


Fig. 5. Motion controller driver

Fig. 5 (motion controller) uses a set ofcommands to manage the flow of the motion controllerprogram which is implemented in a PCB (printed circuit board) (Dezfouli, 2011).

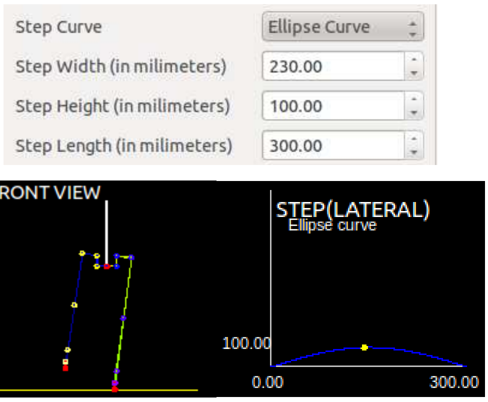
The commands enable drivers to perform much more complicated functions than just running a set of commands sequentially.

For synchronizing multiple joints motion aPVT (position velocity time) table is used. In a PVT motion desired position and speed that are calculated from inverse kinematics are fed to position and velocity control loop at selected time interval.

Between these specified times, the motion controller interpolates to obtain smooth motion. The position and speed specifications are absolute, while the time specification is relative.

7. IMPLEMENTATION AND RESULTS

In this section the implementation of the controller is described. There are different options for planning the trajectory of the swinging leg for gait imitation. The elliptical path is considered as a desired trajectory for toe motion. Based on the inverse kinematic model of the robot and this reference trajectory the angle of each joint is calculated.



Step Curve: Ellipse Curve
Step Width (in milimeters): 230.00
Step Height (in milimeters): 100.00
Step Length (in milimeters): 300.00

Fig. 6. Desired toe trajectories and parameters

The desired elliptical path is generated according to step height and length of robot. The selected values for these parameters in the motion controller program are shown in Fig. 6.

The PVT parameters are provided by reference command generator using this desired toe trajectory. Then these parameters are inputs to each drive controller.

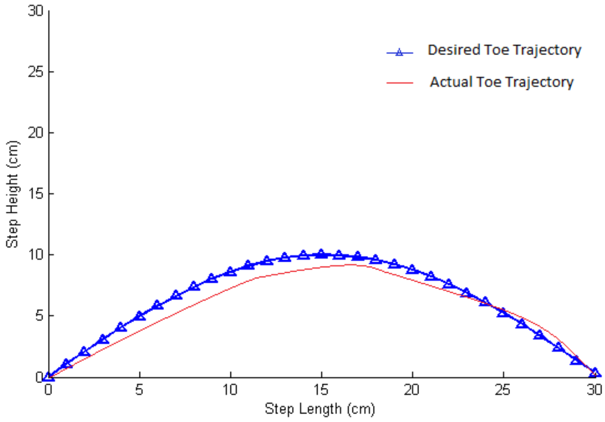


Fig. 7. Desired vs. actual toe trajectory

For the performance of the motion controller, the actual trajectory of the toe is needed. Therefore in each sample time point the position of the toe is calculated using the angle measured by the encoder and forward kinematics of the robot. The performance of the proposed motion controller for tracking the desired trajectory of the toe is illustrated in Fig. 7 (Byagowi, 2010).

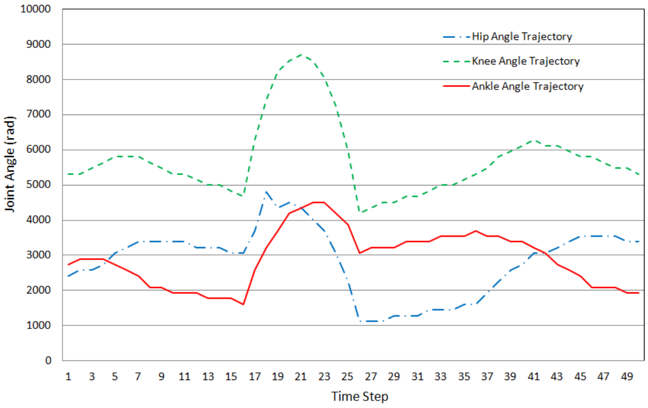


Fig. 8. Hip, knee and ankle angle trajectories

Fig. 8 shows the joint angles of hip, knee and ankle calculated in reference command generator. These values are used in each time step to synchronize the motion of toe for one gait step to track the desired position.

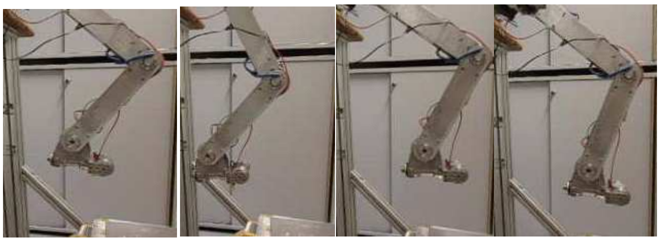


Fig. 9. Single step test of motion for Archie

The single step motion of Archie according to elliptical desired path is tested and presented in Fig. 9 (Byagowi, 2010).

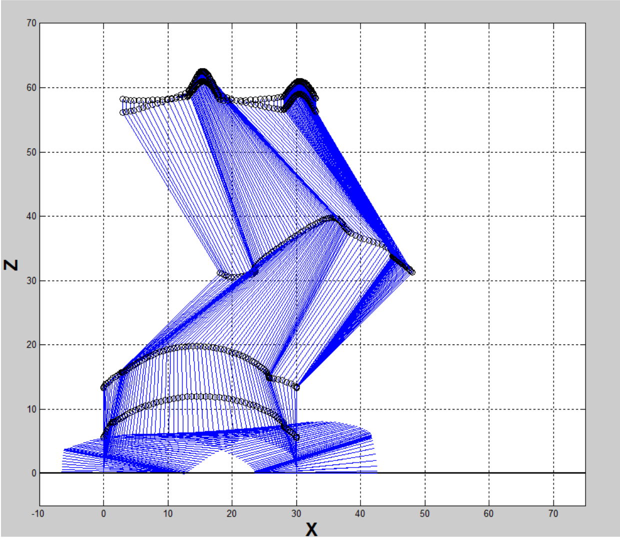


Fig.10. Robot walking cycle (Dezfouli et.al.;2012)

Fig. 10 shows the positions of the robot links and joints during one complete cycle of walking in X-Z plane for the right leg. The trajectories of the frontal ankle joint (foot top) and the torso are depicted in this figure which are the same trajectories planned according to the desired walking parameters. The trajectories for the lateral ankle joint, the knee joint and the hip joint are also included.

8. CONCLUSIONS AND OUTLOOK

The hard- and control software of a teen sizedhumanoid robot is described using brush-less and DC motors and absolute position encoders.

A distributed cascade controller is presented using closed-loop PI controllers to control the position and velocity of the robots multiple joints. The implementation and performance of this method is tested on an existing hardware and shows a good performance. Currently hard- and software improvements are ongoing

The outlook of this project aims to improve hardware in order to decrease the weight and software package as well as to improve the joint control by estimating a grey box model of the plant through the methods of system identification.

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