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Research Article

Control Structure Design for Man-Function Humanoid Robot

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Abstract: This study presents a new humanoid robot control structure - Man-Function humanoid robot. The sensing devices worn on the human body, these devices will produce signals of joints' change when people move. Computer of the control system receiving the signals and processing them, then issue control signals to the servos of the robot at the same time, control the robot's behavior. For this reason, a control structure of human's behavior to determine the robot's behavior formed. The humanoid robot has 17 servos and two pressure sensors, the rotation of these servos' steering gears lead to the robot's behavior changes and 12 servos corresponding to the human body sensing devices, other 5 servos used for the stability control of the robot combined with the pressure sensors. Based on this control structure, some pilot tests of the sensing device or servo have been done, the closed-loop position control mode has been chosen and the Kalman filter smoothing optimization method been used, the initial static walking control of the robot been realized.

Keywords: Control structure, humanoid robot, kalman filter, man-function, static walking

INTRODUCTION

A humanoid robot or an anthropomorphic robot is a robot with its overall appearance, based on that of the human body, allowing interaction with made-for-human tools or environments. 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". Also a humanoid can do motions similar to humans. As we all known, ASIMO by Honda (2012) is the first humanoid robot to walk on its own, it can walk freely, complete some complex actions such as "8" shape walking, up and down stairs, bending, it can even dance with the music, running in a speed of six kilometers per hour and shaking with people, it seems like the plot of a science fiction movie become a reality. ASIMO is a symbol for advanced step in innovative mobility of humanoid robot. But we find that humanoid robot like ASIMO is limited to the behavior of the robot own control, just to imitate human behavior, but this need to simulate the complex function and lengthy implementation process. These robots can only do the programmed fixed action or the activities under certain circumstances now. Therefore, we want to use another way to design our robot which can simulate human's motion more easily and unconstrained.

In this study, we propose a new type of humanoid robot control structure. The main parts of our research are the people and the robot, people take part in the control of the humanoid robot as the main control reason and the computer as the controller linked the people and the robot together. Using the sensor devices which worn on the joints of the human body, the person's state of motion is transmitted to the servos of the corresponding joint of the robot by controller in a certain of control method, so, the robot in full accordance with the mode of action of the person's behaviors (Patrick and Uwe, 2004). This control method can achieve the unrestricted movement of the robot in different environments, because its brain is the human brain, the robot as another "own" of the people in imitation of their own activities. We call this kind of robot control structure for "Man-Function" control structure. Of course, for the reason that we can't built a robot as same as human body, in the Man-Function humanoid robot control research, to maintain the stability of robot in motion, ensure the consistency of the robot with human behavior, both are the foundation and difficulty of our research study.

MAN-FUNCTION HUMANOID ROBOT CONTROL STRUCTURE

The robot control structure we designed is mainly composed of three parts: people, controller and robot. People is the "original edition", people's motion decide

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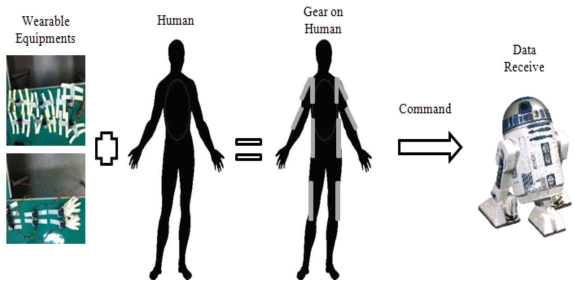


Fig. 1: The concept of man-function

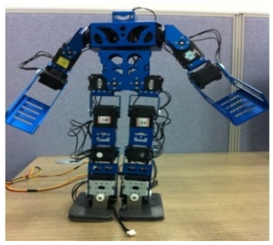


Fig. 2: Robot

Table 1: Servos design in robot

Servos	Position	Application
1, 2	Ankel (horizontal)	Keep balance
3, 4	Ankel (vertial)	Copy human motion
5, 6	Knee	Copy human motion
7, 8	Hip (vertial)	Copy human motion
9, 10	Hip (horizontal)	Keep balance
11	Waist	Keep balance
12, 13	Shoulder (horizontal)	Copy human motion
14, 15	Shoulder (vertical)	Copy human motion
16, 17	Elbow	Copy human motion

the robot's motion primarily. Robot looks like a little "copy" of the human in bodily form and structure, it copy the motion as same as the people. Between the people and the robot is the real time controller which used for realizing the communication and coordination of them, controller is the second "brain" of the robot here (Cai, 2009).

People: In traditional humanoid robot control, people just control the robot by control rods and buttons, or by voice and touch, all the motions of the robot just under the simple orders. But in our control structure, people as a part of the control system, on its shoulders, elbows, hip joints, knee joints and ankle joints to set up 12 motion sensors in order to obtain the information of the movement changes of the human as shown in Fig. 1. Each sensor made by the Dynamixel AX-12A actuator which is used for the servo of the robot too, using this modified gear we can get the information of curvature change and the rotational velocity of each moving part of the human and control the robot easily (Green *et al*., 2011).

Robot: The considered robot, shown in Fig. 2, is a small humanoid robot kit made by servos and rigid rods. The robot has 17 Degrees of Freedom (DOFs): 5 in each leg, 3 in each arm and 1 in the waist. These DOFs are present by the servos of Dynamixel AX-12A actuator. This robot is 25 cm tall and has a total weight of about 900g. Each servos and sensors has its FLASH-ROM and RAM, they can communication with the controller by digital packets. In the feet of the robot, there are 2 pressure sensors which combined with 5 servos (one in waist, 2 in hip joints and 2 in ankles) to remain stable of the robot. Other 12 servos in robot's shoulder, elbow, hip joints, knee joints and ankle joints are one to one correspondence with the sensors which are worn on human body. 12 joint sensors produce control signal as encoders, 12 joint servos drive robot to move as decoders. The position and application of all servos list in Table 1 (Ismoilovich and Min, 2011; Pedro *et al*., 2007).

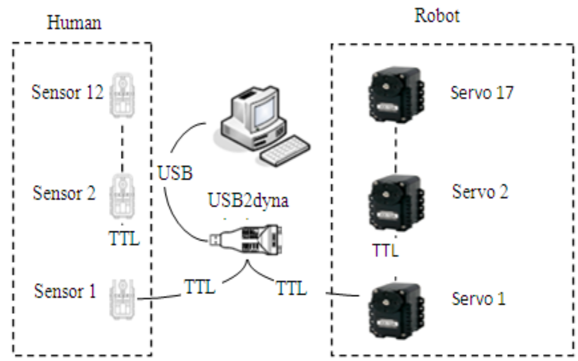


Fig. 3: Man-function robot control structure

Controller: The controller is the core of the control system. As shown in Fig. 3, the human-side is 12 sensors as the human joints, the robot-side is 17 servos as the robot joints, between them is the computer as the controller and three parts is connected by USB2dynamixel device. All sensors and servos made by AX-12A actuators, these actuators connected with USB2dynamixel device using TTL cable in daisy chain style and controlled by the computer. In our controller, we choosing half-duplex communication mode to receive and send the data between computer and outside node.

When people moving, the sensors produce initial signals and these signals received by the computer, after processing to the sensor signals, the computer send the control signal to the servos of the robot, then the robot moving like the people. In the same time, the feedback information of the robot is send back to the computer by the same cable. Based on the feedback information, computer calculates the center of gravity of the robot which is can be used as the basis of keeping balance of the robot (Masao, 2007).

SYSTEM IDENTIFICATION AND CONTROL

The wearable devices on human body and the servos in the robot both are the Dynamixel AX-12A actuator (Robotics, Co. Ltd), this kind of actuator is light weight, small size, low cost and direct editing of the digital signals. There are two type of operation mode for the steering gear of the actuator, one is wheel mode and the other is joint mode. The wheel mode can be used to wheel-type operation robots since motors of the robots spin infinitely. The joint mode can be used to multi-joints robot since the robots can be controlled with specific angles. For the reason of most of the servos' motion of the robot is seems like people's joint, we choose the joint mode for the actuator operation mode. Joint mode has the limited rotate range from 0 degree to 300 degree and has two directions of clockwise and counterclockwise, as shown in Fig. 4. Now let us test the actuator in joint mode and choose the best control style.

Description of the measured signals from the actuators: A set of output signals can be retrieved from the AX-12A actuators. These signals provide information regarding the actual servos angular position, angular velocity, lord, temperature and voltage. The theory behind control systems and how to control actuators and other devices is the foundation of all modern mechanical systems. Using control system mathematics and theory, we can design systems that do nearly anything we want, to the granularity that you desire, in the amount of time that you desire. Control system theory can be broadly broken up into two major categories: open loop control and closed loop control.

Open Loop Control (OLC): Open loop control is by far the simpler of the two types of control theory. In open loop control, there is some sort of input signal, which then passes through amplifiers to produce the proper output and is then passed out of the system. For our control structure in Fig. 5, when people move the actuator (sensor) on people's joint will produce angular velocity, the controller get the data of speed in a sample of timing and put it into the actuator in the robot, by a delay time the robot move.

Open loop controls have no feedback and require the input to return to zero before the output will return to zero. We do the experiment of one actuator's open loop speed control, as shown in Fig. 6. We can find that servo's input speed (angular velocity) is a constant (300), the value of amplifier is 1. Although the output speed which relative to the input speed has a certain delay that is can be tolerated but, in the change of the speed direction, the value of load has a relatively sharp break.

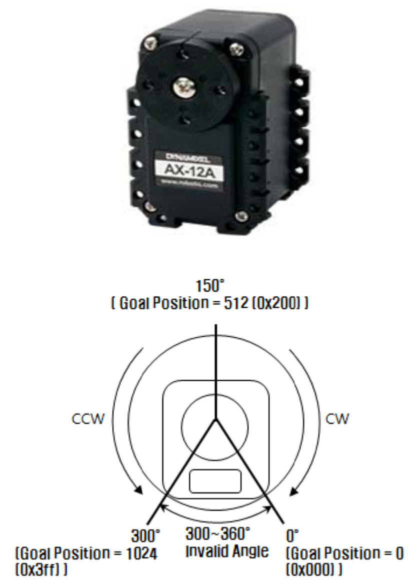


Fig. 4: Dynamixel AX-12A actuator and its joint rotating mode

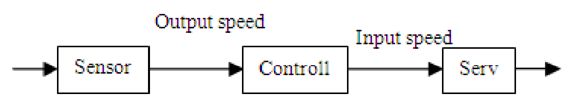


Fig. 5: Open loop control structure

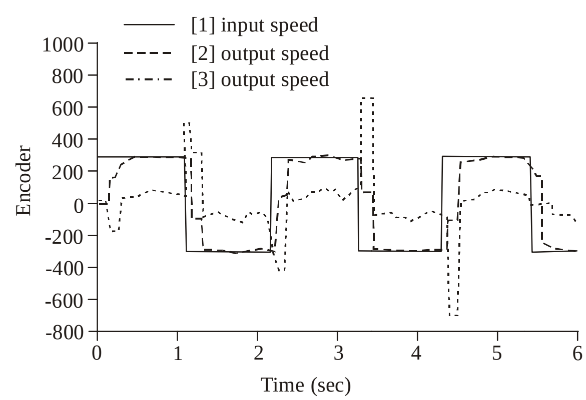


Fig. 6: Servo following a reference speed (OLC)

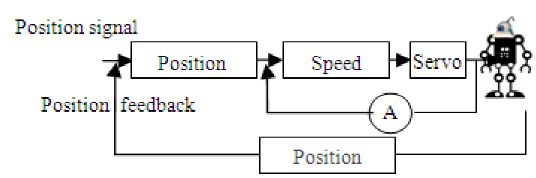


Fig. 7: Close loop control structure

Closed Loop Control (CLC): In closed loop control, the system is adjusted by itself. Data does not flow one way; it may pass back from a specific amplifier (such as

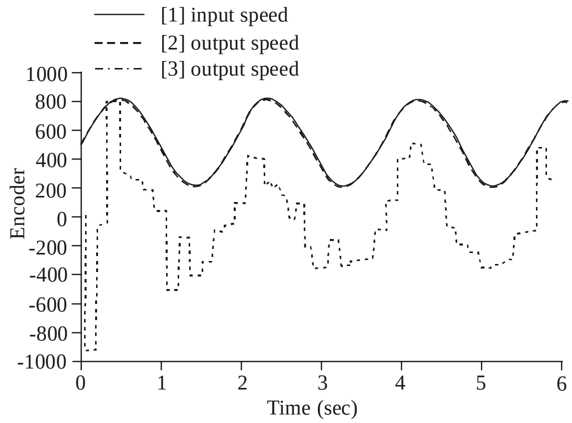


Fig. 8: Servo following a reference speed (CLC)

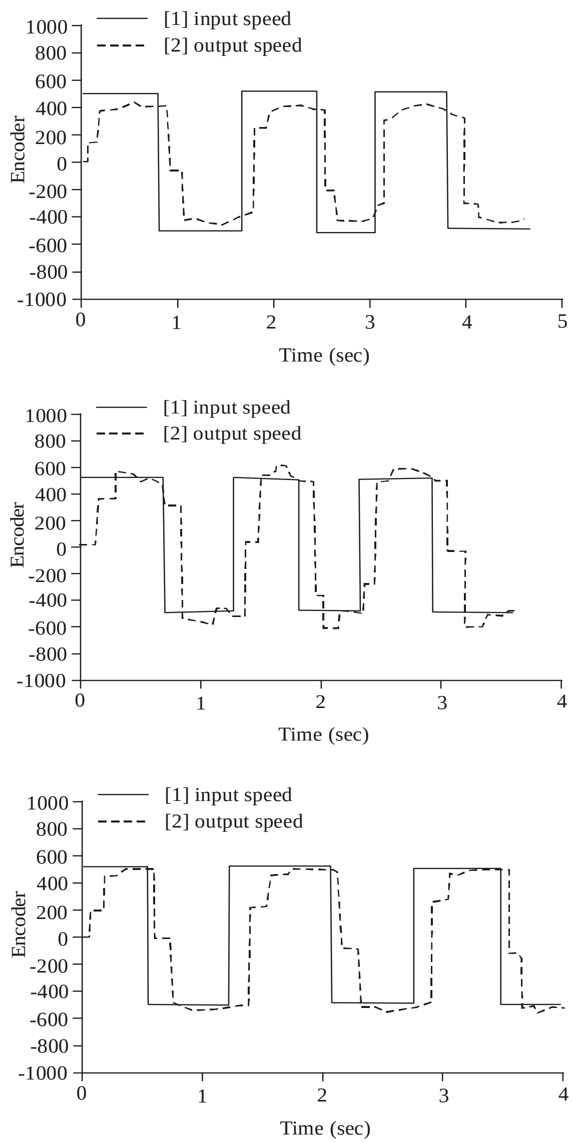


Fig. 9: Effects of the supplied voltage (9v-upper, 10.5v-middle, 12v-under) to the servos in the outputs velocity response

position feedback in Fig. 7) to the start of the control system, telling it to adjust itself accordingly. For the reason of our servos have the feedback of position information, we can get the data of servos' position in every timing sample. Based on these data we can let the servo follow the desired time varying curve reference position which we get from the sensor by changing its actual speed or load charge through time.

In Fig. 8 the servo tries to follow the desired time varying sinusoidal reference position by changing its load charge through time and the value of output position is very close to the input position as we can see. Compared with open loop control method, closed loop control method need more complex design of system architecture and programming, but it can realize a stable and controllable status in our Man-Function robot control structure.

Voltage supply: Another parameter with relevance to the behavior of the system is the voltage supplied to the servos. The effective voltage range of AX-12A actuator is 9-12V, but we want robot's motion follow the people's motion in a quit similar degree, or we can't realize the accurate control of the robot by people. Because open loop control method have a big error between of input and output signal, here we do the voltage experiment of open loop speed control. Our experiments show that the output velocity error is proportional to the voltage supplied to the servo. In fact, good output velocity estimation is achieved only if the power is charged around 10.5 V, as can be seen from Fig. 9.

THE OPTIMIZATION OF CONTROL ALGORITHM

Previous experimental tests of the actuator parameters prove that the closed loop position control method is fit for the Man-Function robot control structure. Based on the control structure, the controller first gets the changes from the body sensor when body form change and then adjusted the data as the servo control command input to the robot. Our control system has a more step than the traditional robot control that is the data acquisition from the body sensor. For the reason of irregular body movements and the sensor of the AX-12A actuator which we used, the position data we have obtained actually have some error and mutation relative to the real movement of human, so we chose the Kalman filter algorithm to deal with obtained from the human body. After the data are processed by the Kalman filter, the processed signal will become smooth and stable, using these processed data as control signal of the robot's movement.

Kalman filter is proposed by R.E. Kalman's famous study which describing a recursive solution to the

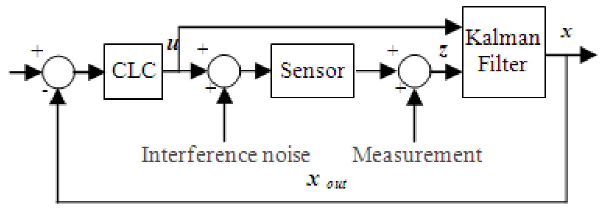


Fig. 10: The CLC structure based on kalman filter

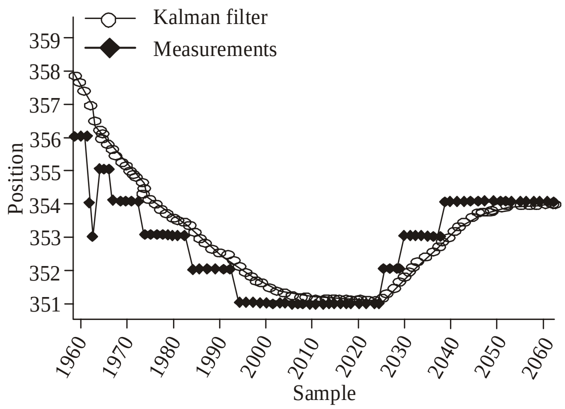


Fig. 11: The optimizing of control signal by kalman filter

discrete data linear filtering problem in 1960. Since that time, due in large part to advances in digital computing; the Kalman filter has been the subject of extensive research and application. Kalman filter is a tool that can estimate the variables of a wide range of processes. In mathematical terms we would say that a Kalman filter estimates the states of a linear system (Xin *et al*., 2007).

Combined with the close loop control method, we get the Fig. 10, when people's joint act as a variable of u, after the interference noise w and the measurement noise v, the output value of the sensor is z, but this measurement is not smooth as we can see in the Fig. 11. Via the Kalman filter we can get the estimate value x which is smooth than the measure value z by experiment test based on the program (in MATLAB) below. In Fig. 11, the star dot line is the measurement value of z, it is the real output of actuator; the circle dot line is the estimate value x after Kalman filter, it is smoothly than z. We use x as the control single of the robot servos, it must let the robot move stable and easily control (Choomuang and Afzulpurkar, 2005).

Function position = Simple Kalman (z) persistent A H Q R persistent x P persistent first Run if is empty (first Run)

A = 1
H = 1
Q = 0.6
R = 4
x = 500
P = 6
First Run = 1

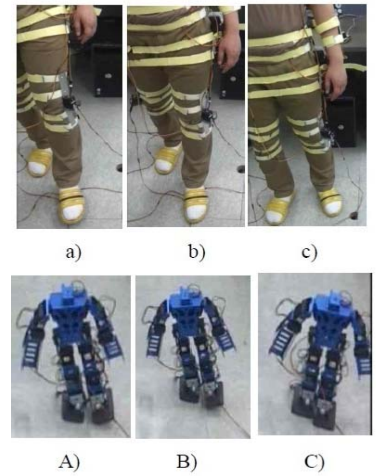
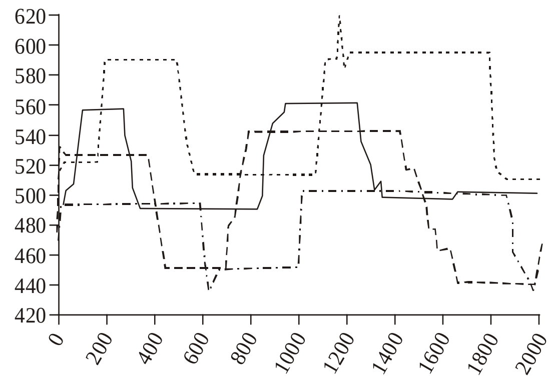
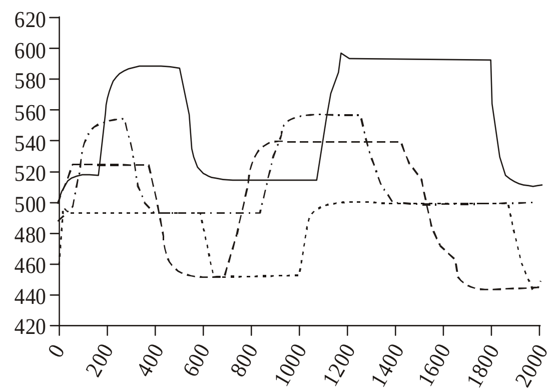


Fig. 12: Static walking of MS-robot



(a) Static walking without Kalman



(b) Static walking using Kalman

Fig. 13: The comparison of robot position feedback for using or not using kalman filter in static walking control experiment

End
xp = A*x; I %. a priori estimate
Pp = A*P*A' + Q; % Estimate error covariance
K = Pp*H'*inv (H*Pp*H' + R); II%. Compute the Kalman gain

x = xp + K*(z-H*xp); III%. Update estimate with measurement z

P = Pp - K*H*Pp'; IV%. Update the error covariance

Position = x

Experiment of static walking: Using brain, nervous system and muscle, human can control their own center of gravity in the walking process and maintain the body's stability. Although the frame structure of our robot is similar with human and its behavior is controlled by the people, but the robot does not have human advanced brain and self-control function to keep a good balance in motion, so we joined the COM (Center of mass) algorithm design in the control process. When people move, the changes of 12 joints' of people will be sent to the 12 joints' of the robot by the computer, the robot will move and the COM of robot will change. At the same time, the computer calculate the new COM and sent another 5 joint's control signal together the 12 joint's for keeping the stable of gravity center of the robot. For example, when one leg put up and go forward, the COM shadow on the ground will move to the supporting leg. Figure 12 showed the static walking by our control method (Fang, 2009; Cui *et al*., 2012).

Figure 13 is the comparison of using and not using the Kalman filter in static walking test of Man-Function robot. Lines are servos' feedback data of walking robot's thigh and knee we have controlled. Four lines present the left thigh, right thigh, left knee and right knee separately by different colors. The first picture is the normal control results without solution of control signal; the second picture is the feedback results after optimizing of control signal by Kalman filter. Obviously, we can find that the application of certain filtering algorithm will make the movement of each joint of the robot becomes flat and smooth and conducive to the stability of the robot during walking to maintain and accuracy improved. (Ning and Guo, 2004)

CONCLUSION

A new robot control structure-Man-Function humanoid robot was established in our study. This kind of structure realizes a true sense of the humanoid movements' simulation than traditional robot control structure. The control of Man-Function robot need as close as the action state of the human and it can keep the stable by itself in motion. To this end, we conducted the analysis of the control mode, the closed loop position control is selected and the Kalman filter algorithm to ensure a stable and efficient robot servo control. Through simple static walking test, it proved that we can realize the basic control of our Man-Function robot. Of course, this kind of control structures need more intelligent and sophisticated control algorithms to achieve the combination of human control and robotics control to let the robot forward a step better. This will be the next step in our research.

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