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Human Motion Oriented Control Method for Humanoid Robot

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Abstract

The human can move flexibly in spite of the redundant degree of freedom. That is because the human previously acquires "knack" or "skill" such as timing in moving joints. Since the structure of a humanoid robot is similar to that of human, it is effective to use the "knack" or "skill" for a humanoid robot. The purpose of this research is to develop the control method to make the humanoid robot execute a human motion such as "knack" or "skill". As data for acquiring "knack" or "skill", we acquire angle patterns, myoelectricity patterns, time-varying images. The myoelectricity patterns is converted to a torque patterns. We analyze data of human motion in view of relations between movement of a joint angle and a direction of torque. In this research, we analyze a walking motion. We divide the walking motion into the part of control of COG by supporting legs and the part of the swing motion which human doesn't give torque. We control COG with Jacobian matrix and ZMP. In this research, we regard the motion given no torque when human swings a leg as "knack" or "skill". We apply this "knack" or "skill" to humanoid model in simulator OpenHRP and realize the motion of humanoid robot by using human's "knack" or "skill".

1. Introduction

Since the humanoid robot is a redundant system, if the humanoid robot can move flexibly, it is possible to realize complicated motions such as obstacle avoidance or coordinate work with human. But it is difficult to decide motion patterns.

In spite of the redundant degree of freedom, the human can move flexibly. That is because the human previously acquires "knack" or "skill". For example, the knack or skill is how to actuate the muscle when human touches grounds and how to make effective orbits when human reach the hand.

Since the structure of a humanoid robot is similar to that of human, it is effective to use the "knack" or "skill" for the motion of a humanoid robot.

The purpose of this research is to develop the control method to make the humanoid robot execute a human motion such as "knack" or "skill".

In order to acquire "knack" or "skill" of human motion, it is necessary to acquire human's motion data. In the past, people have acquired human's joint angle data, and generated a humanoid's motion patterns. Joints motion of human is caused by contracting some muscles. Therefore, by watching muscles, it is possible to acquire more information. As a example of more information, there is information about passive motion that human does not give torque to joints, and active motion that human gives torque to joints. We consider that these motions are useful in order to acquire "knack" or "skill". It is possible to acquire torque information by converting myoelectricity. So, we acquire myoelectricity patterns in addition to a joint angle.

In this research, in order to develop control method to make the humanoid robot execute a human motion such as "knack" or "skill", we perform below.

1)We develop the human motion acquiring system.

2)We derive "knack" or "skill" from human's motion.

3)We demonstrate effectiveness of the method by simulating 3D motion with humanoid model.

2. Human motion acquiring system

In this chapter, we construct the human motion acquiring system for humanoid robot control. With this system, It is possible to acquire joints angle patterns, joints torque patterns and time-varying motion images. The joints torque is presumed from myoelectricity that the signal is generated when the muscle contract. With these patterns, this system acquire the Ground reaction information about relation to the environment.

This system can acquire a data on each motion. Acquired data set is shown in Figure2.1. We can measure these data at the same time, analyze motion,

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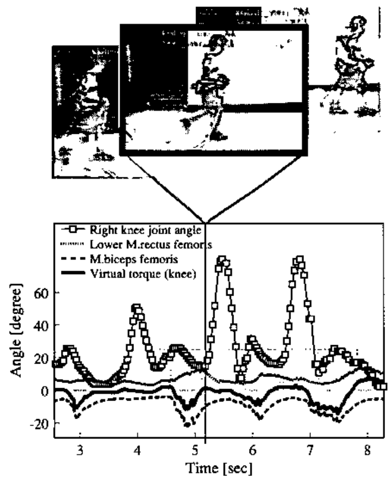


Figure2.1 Acquired data

and derive the control rules effectively.

2.1 Joints angle

In order to measure the joints angle data, the motion capture system is used. By using the motion capture system, it is possible to measure the joints angle data of the human whole body. It is necessary to use the whole body data for controlling the humanoid.

As a kind of the motion capture, there are optical, magnetic, and mechanical motion capture. With the optical one, the data is influenced by chairs and desks. With the magnetic one, the data is influenced by metal. Since it is necessary to acquire the data under ordinary living environment of human, not to measure with chairs, desks, and metal is adverse. So, we use the mechanical motion capture which is undisturbed by the environment.

The mechanical motion capture in this system has 44 potentiometers at each joint and one gyroscope at the hip.

2.2 Myoelectricity

Myoelectricity is low voltage signals which is measured on skin surface when the muscle contracts. The voltage of this signal is distributed from some hundred μV to some dozen mV. The frequency domain of this signal is less than 500 Hz because the human body has the characteristic of low pass filter. Since this signal is low voltage, it is amplified immediately after measuring. Then this signal pass through high pass filter to remove the offset and the influence of body motions and low pass filter to remove high frequency noise. The frequency of cut off is 500Hz(low pass filter) based on the characteristic of myoelectricity and 33Hz(high pass filter) based on experiment. [1][2].

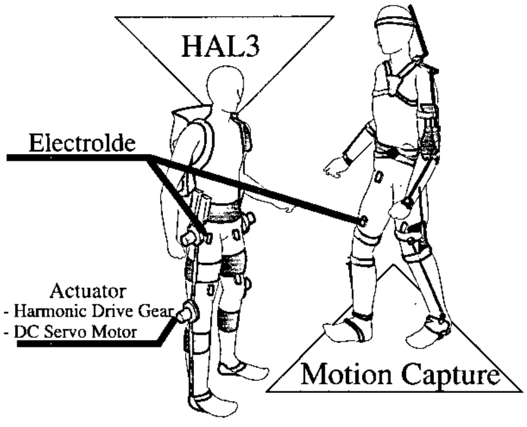
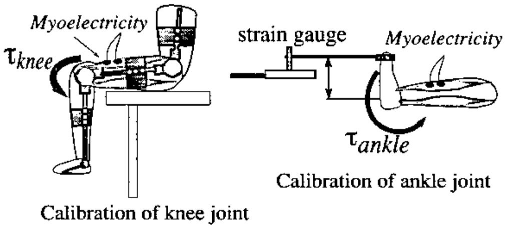


Figure2.2 Schema of a motion capture and HAL-3 system



Calibration of ankle joint

Calibration of knee joint

Figure2.3 The methods of calibration

The measured points for myoelectricity is at least 2 points on each degree of freedom because one degree of freedom on each joint is actuated by a group of muscles for extension and flexion. The myoelectricity is influenced by various muscles under the electrode on skin surface. Then, measured signal may be influenced by the muscle which is not related to the joint motion. Thus it is necessary to calibrate the signal of myoelectricity for homologise a joints torque and myoelectricity.

For calibrating hip and knee joints, we use the exoskeletal power assistive system(HAL-3) which is developed in our laboratory. HAL-3 has actuators at hip and knee joints and electrodes for measuring myoelectricity and can assist powers based on human's intention. HAL-3 and motion capture system is shown in Figure2.2. In a procedure of calibration, a subject wears HAL-3 and homologises a torque of actuators and myoelectricity from human's muscle like Figure2.3[3]. For calibrating ankle joints, we use a strain gauge like in right side of Figure2.3. Secondly, a subject changes into a motion capture with electrodes and we measures motions.

Figure2.4 is a example of measured data about hip joint.

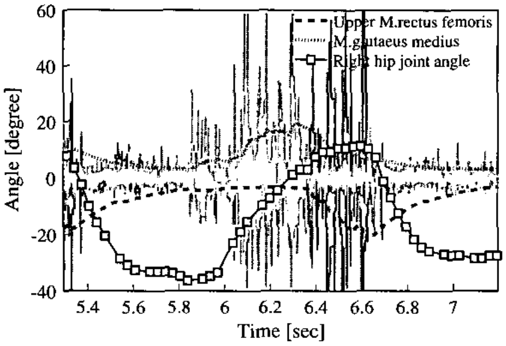


Figure2.4 Myoelectricity data of hip joint

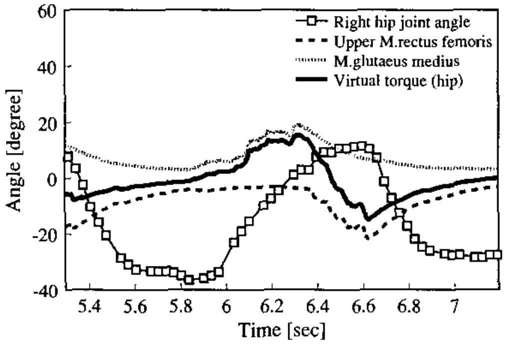


Figure2.5 Virtual torque of hip joint

Measured muscle is upper of M.rectus femoris and M.glutaeus medius. M.rectus femoris works on the flexion of hip joint and M.biceps femoris works on the extesion of hip joint. From this data, we can read a correspondence between the movement of angle and the myoelectricity.[1][2]

Since this signals are vibratile and don't have information about the direction, this myoelectricity data is calculated by below method.

1)Value of myoelectricity is converted to absolute value. and homologize value of myolelectricity to movements of angles. Value of myoelectricity is smoothed. (Figure2.4)

2)We calculate differences between the myoelectricity value of muscle for extension and that of muscle for flexion. We call these calculated value virtual torque. and use this value as a guidepost of the joint torque.(Figure2.5)

3.Derivation of control method with human motion data

In this chapter, we derive the control rules by analyzing human motion patterns. In this research, we analyze relations between the movement of an angle and the direction of virtual torque.

1)If the movement of an angle is the same as the direction of a virtual torque, human moves joints actively.

2)If the movement of joints angle is not the same as the direction of a virtual torque, human moves joints actively though the joints doesn't move as human like. This happens when human moves joints against the inertia force or external force.

3)If the myoelectricity value of muscles for extension and flexion is zero, the joints motion is passive. The joint is moving by the inertia force or the external force.

In this research, we derive control rules of a walk motion with these relations.

3.1 The control rules of walking motion

Since the walking motion is often divided into the phase supporting by both legs, the phase supporting by one leg, and the phase swinging one leg. It is possible to divide walking motion into these phase with ground reaction. We derive control rules about the each phase of a each joint in walking.

The data about a hip joint is shown in Figure3.1. The hip joint rotates toward the direction of flexion by muscle for flexion in the previous period of swing phase. In the latter period of swing phase, the virtual torque is nearly zero. This means that human swings leg in the previous period and move joint passively by the force for swinging in the latter period. In right leg support phase, hip joints rotates toward the direction of extension by muscle of extension. This means that human moves body forward with right leg.

The data about a knee joint is shown in Figure3.2. In swing phase, the value of myoelectricity is nearly zero though the angle moves. This means that the joint of knee moves passively. In both legs support phase and

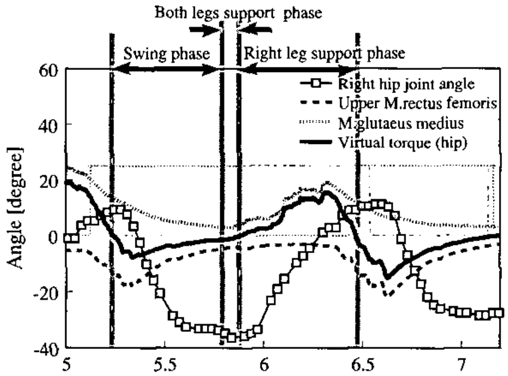


Figure3.1 hip joint data

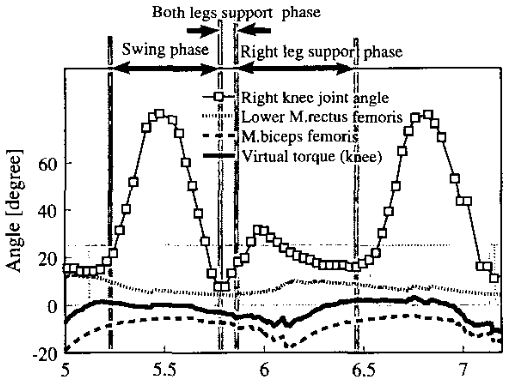


***Figure3.2** knee joint data*

previous period of right leg support phase, the knee joint rotates flexion though the virtual torque actuates toward extension. In latter period of right leg support phase, the muscle of extension and flexion actuates. This means that human controls center of gravity(COG) against gravity in right leg support phase.

By these analysis, we derive the control rules of humanoid robot. In swing phase, the hip and knee joints move passively after the leg is swung by hip joint. In support phase, humanoid robot control position of COG in the direction of back and forth and ups and down. We regarded the passive motion in swing phase as "knack" or "skill".

4. Control mechanism of COG

In previous chapter, we derived the control rules of humanoid robot. In this chapter, we derive the part of controlling COG. We control COG of humanoid robot with Jacobian matrix and ZMP.

4.1 Control of COG with Jacobian matrix

Jacobian matrix is often used in manipulator control. Jacobian matrix maps movement of end of arm to angles of each joints. With method of virtual work, the torque of each joints is calculated as follows.(1)

$$\tau = J^T F \tag{1}$$

We apply this equation to the leg joints of humanoid robot. The joints on sagittal plane is τ_1 , τ_2 and τ_3 shown in Figure4.1. The number of degree of freedom in these joints is more than that in end of arm. Therefore, it is impossible to decide unique angle patterns of joints. So we avoid this redundancy by setting torque of τ_3 to the torque for standing the end link vertically. The joints on lateral plane is τ_4 and τ_5 . We set torque of τ_5 to the torque for standing the end link vertically and control COG by using . τ_4 .

When humanoid robot supports body by one leg, we apply this control method to supporting leg. When humanoid robot supports body by both legs, we apply this method to both legs.

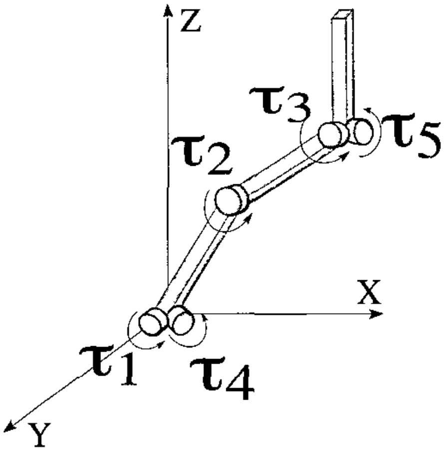


***Figure4.1** 3D link model emulated humanoid*

4.2 Control of COG with ZMP

It is possible to control COG by using Jacobian matrix only when the ZMP is located within a polygon constructed by supporting sole. ZMP is a contact point between the floor and the vector of resultant force which is formed by the gravity and inertia force. If ZMP is not located within the polygon, it is impossible to prevent a humanoid robot from falling down because the humanoid robot can't negate the moment of falling down by floor reaction force. So if ZMP move outside of the polygon, we control ZMP of humanoid robot by changing feet.

5. Sequential control method of walking

Until previous chapter, we derived control rules. In this chapter, we combine control rules of COG with "knack" or "skill" from human motion data. We describe the control method of each phase below.

5.1 Both legs support phase

In this phase, the position of COG is controlled by both legs. We calculate torque of foot and knee joints by using (1). The reference of COG on z axis is always kept a static value. The reference of COG on x axis is set to the sole of a forward leg. The reference of COG on y axis is set between the ankle joint of both legs. When ZMP is located within the sole of forward leg, the phase change to one leg support phase.

5.2 One leg support phase

In this phase, the position of COG is controlled by supporting leg. We calculate torque of knee and foot joints of supporting leg by using (1). The reference of

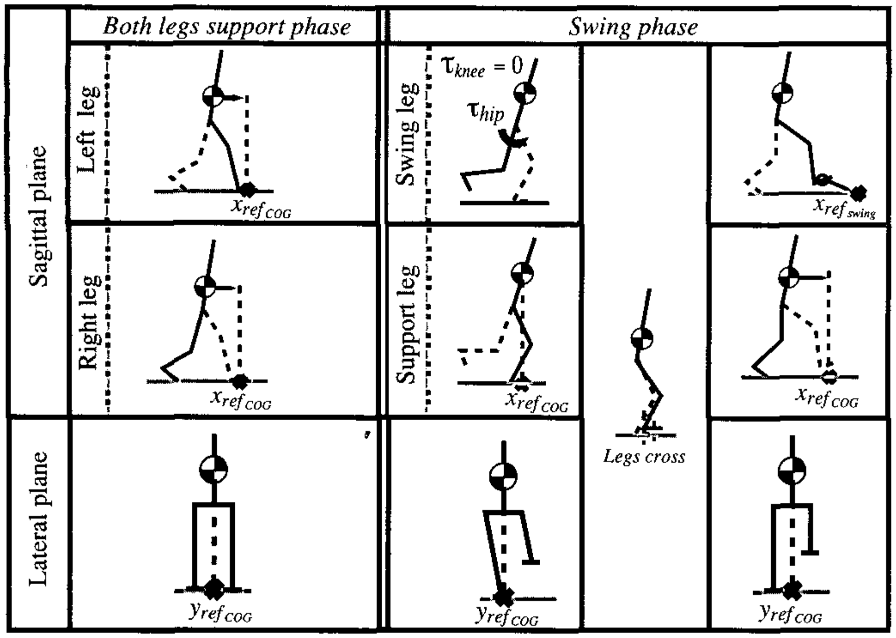


***Figure5.1** Phases in sagittal & lateral plane*

COG on z axis is always kept a static value. The reference of COG on x axis is set to the sole of supporting leg until the supporting leg and the swing leg crosses. After this cross, the reference of x axis is the position of sole of swing leg.

Until this cross, the swung leg is swung by the torque of a hip joint. After the cross, the torque of hip and knee joints is zero. These control rule is derived from the analysis of human motion data. If ZMP move outside of the sole of supporting leg, the landing point of swing leg is calculated and the input torque is also calculated by (2) and (3).

$$\tau_{hip} = K_1\left(x_{ref} - x_{ankle}\right) - K_2\theta_{hip} \qquad (2)$$

$$\tau_{knee} = K_3\left(\sqrt{\left(x_{ref} - x_{ankle}\right)^2 + z_{ankle}^2}\right) - K_4\theta_{knee} \qquad (3)$$

x_{ref} :Reference of landing point

x_{ankle} :The position of ankle joint on x axis

z_{ankle} : The position of ankle joint on z axis

K_1 K_2 K_3 K_4 : Gain

θ_{knee} θ_{hip} :Angle of hip and knee joint

τ_{hip} τ_{knee} : Torque of hip and knee joint

Until cross of support leg and swing leg,, the reference of COG on y axis is set on the sole of supporting leg. After the cross, the reference is set between the ankle joint of both legs.

When the swing leg contact with the ground, this phase move to both legs support phase. These sequential control rules is shown in Figure5.1

6. Simulation

In this chapter, we realize the humanoid motion including human's "knack" or "skill". We use OpenHRP as the simulator. [4].

6.1 OpenHRP

OpenHRP is developed in "HRP"(Humanoid Robot Project) in Japan. This OpenHRP is a simulator for the object that has many degree of freedom and contacts continually with environment like a humanoid. We use this simulator as a platform as a common base and develop the control method of humanoids effectively.

We use HRP1S that developed in HRP as a simulator model. Since this simulator model has the mass and moments of inertia about each joint, it is possible to apply control methods to the actual model after demonstrating the effectiveness of the control method in OpenHRP.

6.2 Generated 3D motion

We simulate waking motion with the simulator model which is applied the control rules developed in chapter 5.

Figure6.1 is a sequential walking motion. Figure6.2 is the result of this simulation in model's knee joint. Figure6.3 is original human walking motion. The torque of human is virtual torque calculated with

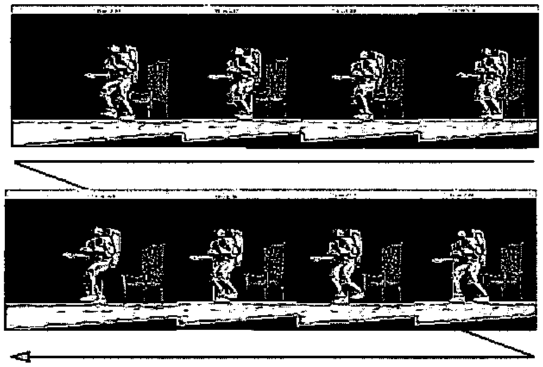


***Figure6.1** The result of simulation*

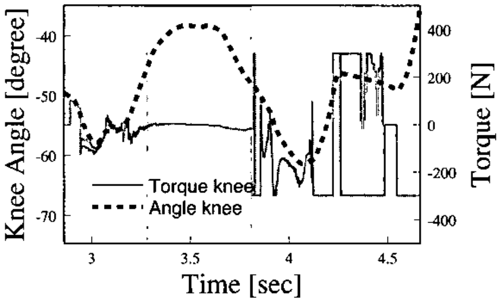


***Figure6.2** Humanoid motion*

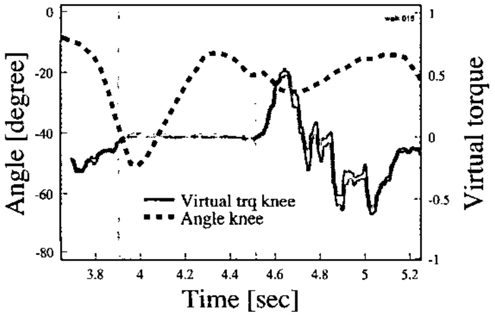


***Figure6.3** Human motion*

myoelectricity.

In the gray part of Figure6.3, the torque of humanoid robot is nearly zero though angle move as well as human motion in the gray part of Figure6.2. We realized the passive motion which is human's "knack" or "skill" in the knee joint.

7. Conclusion

In this research, we aim at developing the control method to make the humanoid robot execute a human motion such as "knack" or "skill" and

1)We developed human motion acquiring system.

2)We derived "knack" or "skill" from motion of swinging leg in walking.

3)We realized the motion of the humanoid robot by using "knack" or "skill".

It is possible to acquire necessary information for humanoid control like joints angle and torque patterns. And by analyzing acquiring patterns, we derived "knack" or "skill" that human move joints passively when human swing a leg in walking. We applied this "knack" or "skill" to the simulator for humanoid robots and realized the motion of the humanoid robot by using "knack" or "skill".

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