Humanoid Control Method Based on Human Knack for Human Care Service

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***Abstract*— The humanoid is expected to realize a human care in Japan where a problem of the shortage of care workers is occurring by aging. In order to determine the complicated motion like the human care for the humanoid, it is efficient to use the same motion of human. If the motion of the human is directly applied to the humanoid, it is difficult to achieve the requested motion because the humanoid takes unstable posture by the difference of dynamic parameters. Therefore, it is suitable method to determine the motion of the humanoid based on the human knack which is necessary for realizing the complicated motion such as the human care. The humanoid can not keep the stable posture by using only the human knack because the human knack is the technique to realize the motion of the human who has the difference of dynamic parameters. So a posture control system is required to control the humanoid. The purpose of this research is to develop the humanoid control method based on the human knack for human care. In order to acquire the knack easily, the joint's movement measured by motion capture system and the force estimated by Myoelectricity are divided into the unit of meaningful motion called "Phase", and the knack is derived from each Phase. Since the humanoid needs to touch people in the human care, the humanoid may fall down on and injure a person in need of nursing care. In order to keep the humanoid's posture stable, we developed the control system in consideration of the relationship among Zero Moment Point (ZMP), the support polygon, and the action force to the Center Of Gravity (COG). The motion of the humanoid is determined based on the human knack and the posture control system. To confirm the effectiveness of the proposed control method based on the human knack, we simulated the situation of the humanoid caring for the human rising from the chair. The humanoid model "HRP1S" and the human model which has human parameters and can not rise by itself were used in this simulation. As the result of the simulation, we realized the human care by the humanoid and and verified the effectiveness of the proposed method.**

***Keywords*— Humanoid, Human knack, Care, Myoelectricity, Phase Sequence**

I. Introduction

Development of Various applications of the humanoid are beginning [2]-[4]. A problem of the shortage of care workers is occurring by aging in Japan, so the realization of ah uman care by the humanoid is expected. The human care by the humanoid is to assist a motion which is a heavy burden for the care worker. However, the human care by the humanoid is not realized yet, because it is difficult to determine the motion of the humanoid which performs complicated motion of the human care.

It is efficient to use the motion of human to determine the motion of the humanoid. If the motion of the human is directly applied to the humanoid, it is difficult to achieve the requested motion, because the humanoid takes unstable posture by difference of dynamic parameters and falls down. Therefore, it is suitable to determine the motion of the humanoid based on the human knack. The knack on the human care is considered the method to exchange the force between a person in need of nursing care (is expressed as the person receiving care) and the care worker appropriately, and to reduce the care worker's load.

The humanoid must not wound people during the human care. The humanoid can not keep the stable posture by using only the human knack, because the human knack the technique is the technique to realize the motion of the human who has the difference of dynamic parameters. The humanoid needs to touch the person receiving care during in human care. If the humanoid takes unstable posture to fall down during the human care, the humanoid may injure the person receiving care. In order to prevent the falling down, the control system which maintains a stable posture is required for the humanoid.

The purpose of this research is to develop the humanoid control method based on the human knack for human care, and in order to realize the purpose, the follows are performed.

1: Development of the method of acquiring the knack from the motion of human care by human.
2: Development of the method of the motion of the human care by the humanoid using the knack.
3: Development of the control system to stabilize posture of the humanoid during the human care.

The subject for the human care in this research is the person who can act by receiving the care, but can not act by himself. By combining these techniques, we perform the simulation of the humanoid caring for the human rising from chair and consider the effectiveness of this technique.

II. Acquisition the human knack

A. Acquisition of the human motion

The information about movement and the force on the joint of the human are acquired to obtain the knack from the motion of the human care.

The movement of the joint in the human care are captured by using the motion capture system "GYPSY Ver 2.5".

A force sensor using strain gauge is usually used to measure the force. The force sensor is not fit to measure complicated motion by the whole body due to the character of the structure, although it can measure a exact magnitude of the force. Hence, we adopt Myoelectricity as the recipe to measure the complicated motion of whole body easily.

Myoelectricity is a signal which has close association with muscular force[5], and can be measured in many points simultaneously by easy equipment. In this research, Myoelectricity is used to estimate the muscular force.

B. Myoelectricity

The muscle consists of organizations called a muscle fiber. The muscular tension is generated by two or more muscle fibers contracting simultaneously. A feeble electric signal occurs in the muscle fiber when the muscle fiber contracted. The electric signal of the muscle fiber measured on the skin surface is the signal called Myoelectricity. Measured Myoelectricity is the electric signal whose potential difference is from dozens [μV] to several [mV], and frequency is not over 500 [Hz]. The frequency component of the measured Myoelectricity does not include high frequency, because the organization of body functions as a lowpass filter.

The system for measuring Myoelectricity consists of electrodes for measuring the electric signal, filters for removing noise, amplifiers for amplifying and a computer for recording and processing. These measurement systems is easy to miniaturize and can measure many points simultaneously.

There is a strong correlation between the muscular force and the rectified, normalized and smoothed value of Myoelectricity. The relationship among the muscular force, the raw Myoelectricity and the processed Myoelectricity is shown in Fig. 1. Myoelectricity and the muscular force in Fig. 1 were measured on biceps brachii. Myoelectricity and the muscular force have normalized respectively by the value of the maximum voluntary isometric contraction, and Myoelectricity is rectified to compare easily with other signals. The muscular force and the processed Myoelectricity have a peak around for 6.8 seconds and 8.5 seconds respectively, and a strong correlation between pattern of the muscular force and pattern which processed Myoelectricityare recognized by Fig.1.

In this research, the value rectified, normalized and smoothed Myoelectricity was used as the estimated value of muscular force. This estimated value was defined as virtual muscular force.

C. Acquirement of the human knack in the care by the human

The information about motion of the person receiving care is also required to obtain the knack in the human care, although the information of the care worker's motion is important, because the motion of person receiving care decides the motion of the care worker, and the knack is the technique to exchange force between the care worker and the person receiving care properly, So, the required data to find the knack are the motion of the care worker and the person receiving care.

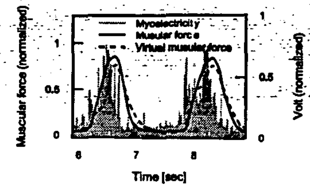

Fig. 1. Relation among myoelectricity, virtual muscular force, and muscular force

The care worker fills a gap of the force for realizing the motion of the person receiving care. The timing which the care worker assists force to the person receiving care at is important. In order to know this timing, the pattern of the force of the person receiving care in the case of receiving the care is compared with the pattern in the case of not receiving the care. It is thought that the period with a distinct difference is a period when the care worker is assisting the force of the person receiving care. The timing in assisting the force is acquired by this method.

When comparing those force patterns, it is not easy to compare the pattern of the whole sections of motion at a time. In order to compare the pattern easily, the acquired motion is divided into the units of meaningful motion, and the force pattern is compared in every divided unit. The unit of meaningful motion is proposed as "Phase". It can be considered that Phase with a definite difference is at the period when the assistance of power is performed. The index to divide a certain motion into Phase is what can judge a change of the motion. It is thought that the point where motion changes is estimated by considering the angle of the joint. However, It can not judge whether a certain motion is passive or active. Since it is useless to assist the passive motion of the person receiving care, this judgment is important. The pattern of force is also considered for this judgment. It is considered that it becomes possible to judge whether a certain motion being performed passively or actively. In this research, the inflection point of joint ange and the pattern of force are adopted as an index of dividing into Phase.

The motion of the care worker in the period corresponding to Phase which the person receiving care is receiving the care in is considered. The knack in the human care exist in this period. The motion of the care worker is also divided into Phase and Phase corresponding to this period is looked for. Since Phase is meaningful motion, it can be estimated easily what motion is assisted by the Phase which the care worker assists the person receiving care in. It is considered that the techniques of realizing the motion in this Phase in are the knack. Abovemet hods which the knack is found by are expressed as the method of acquiring the knack

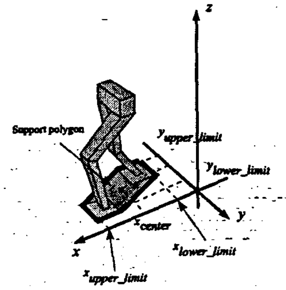

Fig. 2. A support polygon of a humanoid robot

from the motion of care by human. The human care by the humanoid is determined based on the knack.

III. Posture Control System

A. ZMP

Zero Moment Point (ZMP) is ap oint on the level ground, where the total torque generated by both inertial and gravitational force becomes zero. And, ZMP is the ideal point of the reaction force to the Center Of Gravity (COG) position. ZMP is derived from the equation (1).

$$x_{zmp} = \frac{x_{cog}(\ddot{z}_{cog} + g) - z_{cog}\ddot{x}_{cog}}{\ddot{z}_{cog} + g} \quad (1)$$

where x_{zmp} is the x coordinate of ZMP, x_{cog} and z_{cog} are the x and z coordinate of COG position respectively, g is gravity constant.

B. Support Polygon

To realize humanoid's stable posture, it is necessary to control the action force to COG. The area where the humanoid can receive floor reaction force is restricted to the inside of the polygon which consists of sole connected to the floor. This polygon is called the support polygon. In the case of the humanoid, the support polygon is an area shown in Fig.2. If ZMP is inside of the support polygon, ZMP consists with the point of the floor reaction force. But, if ZMP is outside of the support polygon, ZMP does not consist with the pointof the floor reaction force of the humanoid, e.g., if ZMP is outside of the support polygon as shown in Fig. 3, a torque occurs in the circumference of a tiptoe. This torque moment is called the falling force moment. If the falling force momento ccurs, it becomes impossible for the humanoid to fully control COG, and the humanoid may fall down due to unstable posture. It is important to set the support polygon which the action force to COG is derived from, and to know the limitation of the action force to COG which be derived from the support polygon.

C. Relation between the support polygon and the action force of COG

The relation between the action force to COG and the support polygon is considered. The equation (1) is

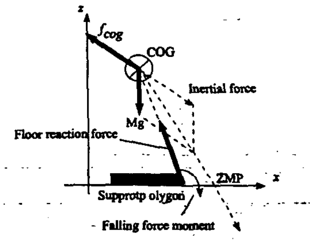

Fig. 3. Relation a falling moment and ZMP

transformed as follows;

$$x_{center} + x_{upper\_limit} \geq \frac{x_{cog}(\ddot{z}_{cog} + g) - z_{cog}\ddot{x}_{cog}}{\ddot{z}_{cog} + g} \quad (2)$$

where x_{center} is center position of the support polygonand and x_{upper_limit} is limitaion value of the support polygon as shown in Fig.2. The equation (3) is solved with respect to $\ddot{x}_{cog}$.

$$\ddot{x}_{cog} \geq \frac{1}{z_{cog}}(\ddot{z}_{cog} + g)(x_{cog} - x_{upper\_limit} - x_{center}) \quad (3)$$

The equation (3) is transformed as follows;

$$\frac{f_{cog}(x)}{M} \geq \frac{1}{z_{cog}}\left(\frac{f_{cog}(z)}{M} + g\right)(x_{cog} - x_{upper\_limit} - x_{center}) \quad (4)$$

where M is mass of the humanoid. Therefore, if the falling force moment does not occur, the relation between the action force to COG and the support polygon is shown by equation (5).

$$f_{cog}(x) \geq \frac{1}{z_{cog}}(f_{cog}(z) + Mg)(x_{cog} - x_{upper\_limit} - x_{center}) \quad (5)$$

The following equation (6) can derive similarly.

$$f_{cog}(x) \leq \frac{1}{z_{cog}}(f_{cog}(z) + Mg)(x_{cog} - x_{lower\_limit} - x_{center}) \quad (6)$$

D. Posture control system

It is necessary to prepare the support polygon that can be derived from equation (5),(6) to stabilize the humanoid's posture, if the action force to the humanoid's COG can know beforehand. If the humanoid receives a disturbance and it becomes impossible to satisfy equation (5),(6), it is necessary to reconstitute the support polygon which satisfy equation (5),(6) by moving the humanoid's foots, or to pull up the limit value of the force to a horizontal direction by reducing force of vertical direction applied to COG using equation (5),(6).

The position control of COG can be performed to stabilize COG by the above method. The humanoid is assumed to be an inverted pendulum of 1 link as shown in Fig.4, and the humanoid's posture is kept stable by controlling COG so that this inverted pendulum stands straight stably. A possibility that the humanoid will

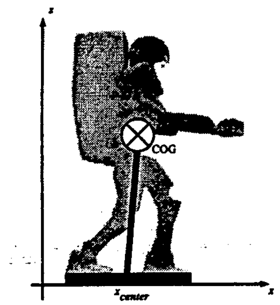

Fig. 4.In verted pendulum model

fall down is judged by calculating of the action force to COG as equation (5),(6). In order to avoid the falling down, it is necessary to reconstitute the support polygon by moving the humanoid's foots or lowering COG. We decided to call the above techniques the posture control system.

IV. Determination of the humanoid motion based on the human knack

The control role to realize the motion exists in each Phase, because Phase is meaningful motion. Since the knack is the technique to realize the motion in Phase, it is considered that the knack consists with the control role of Phase, i.e., it is considered that Phase can describe the knack. The humanoid can realize the motion based on the human knack by performing human's Phase. The general motion consists of two or more Phases, and the motion of the humanoid is also generated by two or more Phases. The conditions which enable a Phase to shift to the next Phase are included in each Phase, and the humanoid shifts Phase according to the condition. The motion obtained by this technique is the motion suited for the humanoid. This technique connects Phase and generates new motion, and is defined as "Phase Sequence". The method using the human knack and Phase Sequence is defined as the method to generate the motion of the humanoid based on the knack.

Cautions are required to the humanoid for using the human knack. The human knack is the technique in order to realize the motion of the human, the posture of the humanoid can not be kept stability by using only the human knack. The humanoid tends to become unstable posture because of the characteristics of the form which are high COG position and the narrow sole. It is necessary to respond to the external force received from the person receiving care timely, because all the external force is not expected force So, the stable posture control system developed in section III is used. It is ensured that the human care by the humanoid based on the human knack is stabilized by the posture control system.

The above techniques is adopted as the humanoid control technique of the human care by the humanoid.

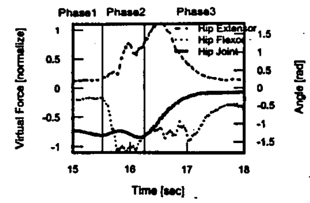

Fig. 5. Relation among the virtual muscular force and the hip joint angle of the person of rising from the chair

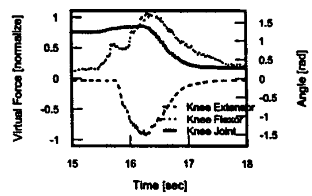

Fig. 6. Relation among the virtual muscular force and the knee joint angle of the person of rising from the chair

V. Simulation of the situation which the humanoid care for rising from chair in

In order to verify the effectiveness of this technique, we simulated the situation of the humanoid caring for the human rising from a chair. The humanoid's foot movement is dangerous motion in this human care, because the person receiving care and the humanoid are close. Therefore, in order to maintain the stable posture, it is decided that humanoid's foot be not moved in this human care. So, the humanoid is performed to care with more stable motion, although there are various methods to care for rising from the chair. The human care in this case is the motion that the care worker opens the legs forward and backward, and pulls up the person receiving care. To realize stable motion, the care worker can set the support polygon widely by opening a leg forward and backward. In this research, the motion was used for the simulation of the care by humanoid.

A. Acquisition of the human motion

In order to acquire the data of the human knack, we measured the motion of the humans in the care and the motion in the case of not receiving care. Subjects are two healthy adult male persons. The motions of the care worker and the person receiving care are simultaneously immeasurable on account of the human's motion acquisition system. Therefore, the same motion was repeated and the motions of the care worker and the person receiving care was obtained.

The data about the person receiving care is indicated in Fig.5-8. Fig.5-8 show data about the hip joint and knee joint in the case of not receiving the care and receiving the care, respectively.

B. Decompositon the human motion to Phase

The human's motion is divided into Phase based on the data of the person receiving care.

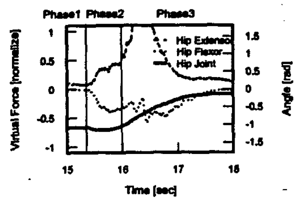

Fig. 7. Relation among the virtual muscular force and the hip joint angle of the person receiving care of rising from the chair

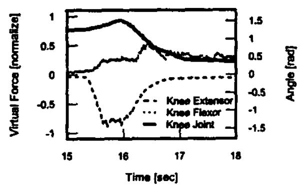

Fig. 8. Relation among the virtual muscular force and the knee joint angle of the person receiving care of rising from the chair

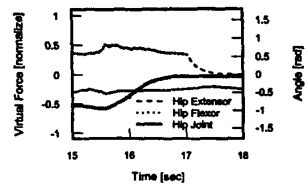

Fig. 9. Relation among the virtual muscular force and the hip joint angle of the care worker who care for rising from the chair

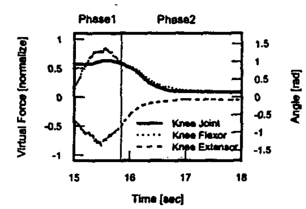

Fig. 10. Relation among the virtual muscular force and the knee jointangle of the care worker who care for rising from the chair

We consider the motion of the human in Fig.5 The virtual muscular force of the extensor and the flexor of the hip joint has hardly responded to the motion of the hip joint in the beginning. Concerning the flexor, there is a peak of the virtual muscular force aournd 16 seconds and a value continuing around 16.5 to 17 seconds. Concerning the extensor, the virtual muscular force has a small peak around 16 second and the large peak around 16.5 seconds. Concerning the extensor and the flexor, the large virtual muscular force begins to occur from the around 15.5 seconds. The angle information shows the hip joint is crooked at first and extending from around 16.2 seconds.

Before 16 seconds, It is thought that he pushed down the upper part of the body ahead by the relationship among the virtual muscular force of the flexor, the extensor and the angle of the hip joint. Behind 16 seconds, it also is thought that he extended the hip joint to rise from the chair by the relationship. Around 16 seconds, it is estimated that he fixed the hip joint by the relationship.

Hence, it is estimated that the motion of the human rising from the chair can be divided into the following three Phases.

Phase 1: The upper body is pushed ahead, and the center of gravity is moved to the front.

Phase 2: The COG is moved to the sole using the angular momentum generated in Phase 1 by making the body stiffen.

Phase 3: Each joint extends, COG position is raised, and standup motion is accomplished.

This classification is shown also in Fig. 5. The motion in the case of receiving the care is compared with motion in the case of not receiving the care in every Phase.

C. Determination of the humanoid motion

The virtual muscular force in the case of receiving the care is compared with the case of not receiving. In Phase 2, compared with the case of not receiving the care, the virtual muscular forces of the flexor and the extensor are decreasing greatly in the case of receiving the care. Therefore, in Phase 2, it is thought that sufficient care is received from the care worker. In Phase 2, the angular momentum generated in Phase 1is used. So, if the motion in Phase 2 is cared, the motion in Phase 1 is assumed to receive the care similarly. In Phase 3, it is thought that the weak care was received in this Phase, because there is no decrease of the virtual muscular force as against Phase 2

Next, we consider the care worker's data. Fig.9 and Fig.10 is data of the hip joint and the knee joint of the care worker, respectively. The motion of the care worker is divided into Phase like that of the person receiving care. The motion is divided into two Phases around 15.8 seconds by the relationship among the motion of the knee joint and the virtual muscular forces.

It is shown that the care worker is generating large force in Phase 1 corresponding Phase 1-2 of the person receiving care in Fig.10. It is thought that the care worker is considering to emphasize care in Phase 1.

Hence, the humanoid was decided to care in Phase 1 corresponding to Phase 1-2 in the motion rising from the chair. Movement of COG of the person receiving care is performed in Phase 1 of the care worker. Humanoid was decided to care for movement of COG of the person receiving care by pulling ahead. After judging that COG moved to the sole fully, the humanoid pulls up the person receiving care synchronizing with the standup motion, as Phase 2 of the care worker.

The humanoid receives the large force from the per-

Fig. 11. The simulation the humanoid care for rising from the chair

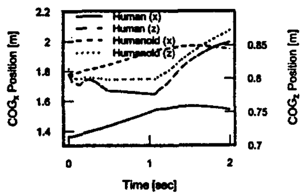

Fig. 12. The motions of Humanoid's COG and Human's COG of the result of simulation the humanoid care for rising from the chair

son receiving care during the human care. In order to prevent a falling, it is necessary to set the support polygon which the humanoid can take the force to respond to this force with. We calculate the force beforehand applied to the care worker from the posture of the person receiving care during the human care. The humanoid is decided to set up the initial posture with the support polygon that can fully respond to this force. In addition, it is presupposed that the area of the support polygon is calculated using equation (5),(6).

D. Simulation

We used the humanoid simulator OpenHRP [6][7] and HRP1S mode [8] which are developed by the National Institute of Advanced Industrial Science and Technology (AIST) of Japan, for this simulation, and we used the human model which is 160cm and 60kg, and has the moment of inertia of each link with the value near an actual person.

It is important how the simulation of the motion of the person receiving care during the human care is performed. So, the motion of the person receiving care is determined. The humanoid is decided to use Phase in section V-B for performing the motion of the person receiving care. First, wes imulated the motion of the human model rising from the chair. Next, in order to realize the situation where the human model needs the care, the exerted torque of this human model is restricted The motion of the human model which can rise by receiving care was determined. This motion was applied to the simulation that the humanoid cares for the human rising from the chair, which was performed.

The result of the simulation is shown in Fig.11. The humanoid had judged COG position of a person requiring care on the sole around 1.0 second, and changed to the motion of pulling up the person in Fig.11. It is shown that the humanoid and the human synchronize moving in Fig.12.

The result of the simulation is shown in Fig.12.

As the result of the simulation on various conditions, the humanoid was able to respond except for the too large force of the sagittal plane from the person receiving care. There were cases that the humanoid became the sole floating and tiptoeing depending on the motion to the lateral plane of the person receiving care however. And the humanoid will havefalle n down if the person receiving care shifts in the direction of the humanoid's hind foot (left leg on this simulation) widely. Since this direction has the thin support polygon, it is thoughttha t the humanoid has not fully responded to the force derived from the person receiving care. In this simulation, since the humanoid did not move the foot, it is considered that the posture control system built in section III not fully copes with the force from the human model. When the humanoid is close to people, such as in this human care, the humanoid's foot may be unable to be moved. It is necessary to develop the control system to stabilize the posture in the human care which the foot cannot be moved in.

As ares ult of the simulation with this method, it turned out that the human care by the humanoid was realizable. However, on the conditions which do not move the foot, it turned out that this system is not enough to stabilize the posture.

VI. Conclusion

We developed the control system to stabilize the humanoid's posture, the method to acquire the human knack from the motion of the human, and the method to generate the motion of the humanoid based on the human knack and Phase Sequence. Moreover, the simulation was showed that these mothods worked effectively for the human care by the humanoid.

VII. Acknowledgment

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