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Static Balancing Control of Humanoid Robot based on Accelerometer

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Abstract: A static balancing control method is proposed and implemented on a humanoid robot so that the robot can stand and balance on a plane. A small-size humanoid robot named TWNHR-IV with 26 degree-of-freedom (DOF) is implemented. A 3-axis accelerometer is installed on TWNHR-IV to obtain the x -axis, y -axis, and z -axis accelerations of TWNHR-IV. Based on the obtained information from the 3-axis accelerometer, a system structure with two two-input-and-one-output fuzzy systems is proposed. The acceleration and the acceleration's variation of the x -axis obtained by the 3-axis accelerometer are considered to be the inputs of forward-and-backward fuzzy system. The acceleration and the acceleration's variation of the y -axis are considered to be the inputs of right-and-left fuzzy system. Some practical tests are presented to illustrate the proposed method can let the humanoid robot stand and balance on a plane.

Keywords: Humanoid robot, Static balancing control, Fuzzy system, Accelerometer

1. INTRODUCTION

The research of building autonomous robot, which is able to make the decisions by itself, has been studied for many years. Because the processing speeds of the microprocessors, a lot of the earlier studies of artificial intelligent (AI) were focused on simulation results. As the improvement of technology, the practical experiments are able to be tested and verified the proposed algorithm. Building the practical robots has to integrate many different technologies, such as mechanism, electrical system, and artificial intelligent [1-4]. Auto-balance of autonomous humanoid robot is always a target problem. Many researchers have been working on this issue [5-7]. The force sensors and accelerometer sensors are usually used to measure the robot situation. These sensors are used to determine the ZMP [8] of the robot for the auto-balance issue. The humanoid robot is regarded as a two-dimension inverted pendulum system [9], where the angle and angle velocity of inclination of the robot are considered to adjust the balance posture.

In this paper, a static balance control of humanoid robot based on accelerometer sensor is proposed. A fuzzy balance control is proposed to adjust the robot's posture for balance issue. A 3-axis accelerometer sensor is mounted on the robot for determining the rotate angle velocity of the humanoid robot. The acceleration and the variation of the acceleration are two inputs of the fuzzy controller. Output is the motions of the robot to adjust the posture of the robot for static balancing.

2. MECHANICAL STRUCTURE OF TWNHR-IV

A small-size humanoid robot named TWNHR-IV (TaiWaN Humanoid Robot-IV) is implemented and considered for the static balancing problem. It has 26 degree-of-freedom (DOF). The height of TWNHR-IV is 46 cm and the weight is 3.1 kg with batteries. The

frameworks of TWNHR-IV are mainly fabricated from aluminum alloy 5052 in order to achieve the concepts of light weight, wear-resisting, high sturdy and wide moveable range. The main design concept of TWNHR-IV is light weight and compact size. Each actuator system for the joint consists of a high torque and a gear. The rotating speed and rotating angle of each joint are designed based on the result of computer program. The mechanical structure of TWNHR-IV is described as follows:

The photograph and DOF configuration of the implemented humanoid robot: TWNHR-IV is described in Fig.1. There are 2 DOF on robot's neck, 2 DOF on the waist and trunk, 4 DOF on each arm and 7 DOF on each leg. The mechanical structure is designed and implemented so that the implemented humanoid robot can find the ball, walk forward, turn right-and-left, and slip right-and-left, and some special motions like the forward modification, backward modification, right modification, and left modification. The DOF diagram of the head, waist and trunk, arms, and legs are described in Fig.2, where each degree is described by the number.

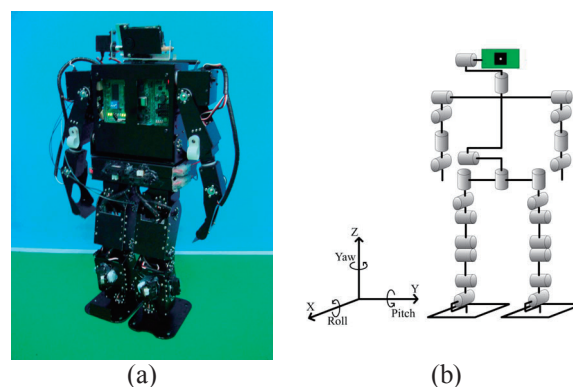


Fig. 1. Photograph and DOF configuration of TWNHR-IV.

The head is designed based on the concept that the head of the robot can realize the raw and the pitch motions to amend the raw and pitch motions so that the head of the robot can turn right-and-left and up-and-down. The waist and trunk are designed based on the concept that robot can adjust the trunk motions to compensate for the robot's walk motion. The arms of the robot are designed based on some behaviors of human's arms. For example, its arms can hold an object such as a ball. In the legs design, two motors are designed and implemented in one knee joint to improve the robust of the leg. The legs are designed based on the concept that robot can have the human walking motion.

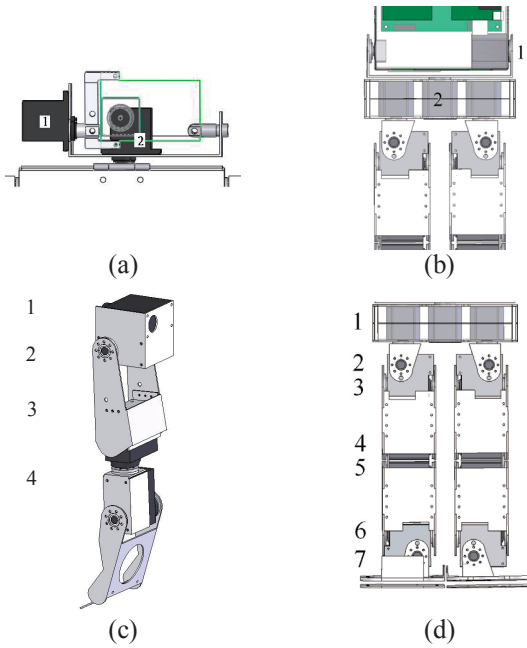


Fig. 2. Mechanism and DOF of TWNHR-IV: (a) Head, (b) Waist and trunk, (c) Left arm, and (d) Legs.

3. FUZZY METHOD FOR OBSTACLE AVOIDANCE

The posture of the humanoid robot is controlled by 24 motors described in Fig.3, where the position labeled by the number of 1, 2, ..., 24 denotes the position of i -th motor ($i \in I_1 = \{1, 2, \dots, 24\}$). In the consideration of static balancing control of the humanoid robot on an inclined plane, five modifications are considered for balance: (a) Forward Modification, (b) Backward Modification, (c) Left Modification, (d) Right Modification, and (e) None Modification. Different angle modification of some motors is suitable for different modification. Forward Modification and Backward Modification need to modify the motors of the ankle, but Right Modification and Left Modification need to modify 8 motors. From experiments, the key point to balancing control of the humanoid robot on an inclined plane is to let its feet must be on the plane. Forward Modification and Backward Modification need to modify the angle of j -th motor ($j \in I_2 = \{16, 23\}$)

and Right Modification and Left Modification need to modify the angle of k -th motor ($k \in I_3 = \{13, 14, 15, 16, 17, 20, 21, 22, 23, 24\}$).

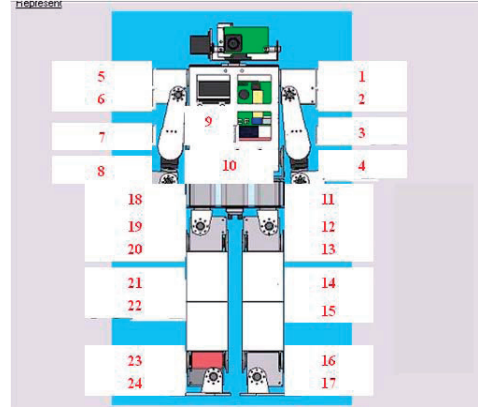


Fig. 3. Diagram description of motor's number.

In order to consider the balancing problem, one 3-axis accelerometer is mounted on the robot so that x -axis acceleration, y -axis acceleration, and z -axis acceleration can be obtained (as shown in Fig.4). The accelerometer is used to measure the gravity, so z -axis acceleration still can be detected when the robot stands up. If the robot changes its posture, x -axis acceleration and y -axis acceleration will be detected and measured by the accelerometer. Based on the obtained acceleration (a_x and a_y) and acceleration's variation (Δa_x and Δa_y) in the x -axis and y -axis, a fuzzy balancing control system structure as shown in Fig.5 is proposed for a humanoid robot so that it can be balanced on an inclined plane. There are a decision module, two Average of Three-step Modifications (ATM) named ATM_x and ATM_y for x -axis and y -axis, and two two-input-and-one-output fuzzy systems named forward-and-backward fuzzy balancing controller and right-and-left fuzzy balancing controller. They are described as follows:

The outputs of the decision module are the desired angle $ma_i(k)$ of i -th motor ($i=1, 2, \dots, 24$) at k -th time step to let the robot balance on the plane and can be described by

$$ma_i(k) = \begin{cases} ma_i(k-1) & \text{if } i \in I_1 - I_3 \\ ma_i(k-1) + \bar{m}_x(k) & \text{if } i \in I_2 \\ ma_i(k-1) + \bar{m}_x(k) + \bar{m}_y(k) & \text{if } i \in I_3 \end{cases} \quad (1)$$

where $k \in \{1, 2, \dots\}$ and $ma_i(k-1)$ is the angle of i -th motor at the previous $(k-1)$ -th time step. \bar{m}_x and \bar{m}_y are respectively the outputs of ATM_x (Average of Three-step Modifications for x -axis modification) and ATM_y (Average of Three-step Modifications for y -axis modification). The function of the ATM_x can be described by

$$\bar{m}_x(k) = \text{int}\left(\frac{m_x(k) + m_x(k-1) + m_x(k-2)}{3}\right) \quad (2)$$

where $\text{int}(a)$ denotes the integer value of the real value a , $m_x(0) = m_x(-1) = 0$, $m_x(k)$, $m_x(k-1)$, and $m_x(k-2)$, are the outputs of forward-and-backward fuzzy balancing controller at the time steps of k , $k-1$, and $k-2$, respectively. Similarly, the function of the ATM_y can be described by

$$\bar{m}_y(k) = \text{int}\left(\frac{m_y(k) + m_y(k-1) + m_y(k-2)}{3}\right) \quad (3)$$

where $m_y(0) = m_y(-1) = 0$, $m_y(k)$, $m_y(k-1)$, and $m_y(k-2)$, are the outputs of right-and-left fuzzy balancing controller at the time steps of k , $k-1$, and $k-2$, respectively.

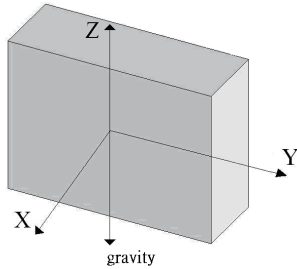


Fig. 4. 3-axis accelerometer gauge the acceleration directions in the robot.

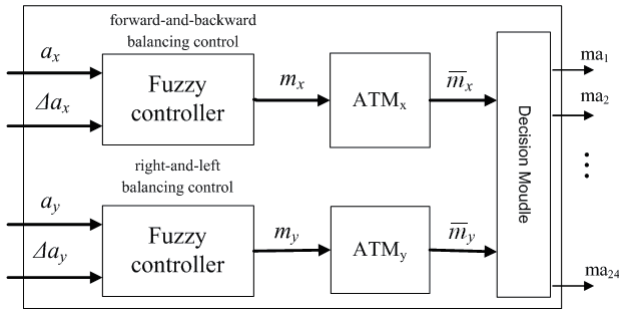


Fig. 5. Block diagram of the proposed fuzzy balancing control system structure.

In order to construct a 360 degrees balancing controller, there are two two-input-and-one-output fuzzy systems named forward-and-backward fuzzy balancing controller and right-and-left fuzzy balancing controller. a_x and Δa_x are the inputs of forward-and-backward fuzzy balancing controller and m_x is its output. a_y and Δa_y are the inputs of right-and-left fuzzy balancing controller and m_y is its output. The forward-and-backward fuzzy balancing controller will decide three motions: (a) Forward Modification, (b) Backward Modification, and (c) None Modification. The right-and-left fuzzy balancing controller will decide three motions: (a) Right Modification, (b) Left Modification, and (c) None

Modification. In this way, a 360 degrees balancing controller can be constructed based on these two fuzzy controllers for x -axis and y -axis. The fuzzy system design is described as follows:

A single-axis fuzzy system design method is described for these two fuzzy systems named forward-and-backward fuzzy balancing controller and right-and-left fuzzy balancing controller that has two inputs and one output. There are four steps in the fuzzy controller design. They are described as follows:

(a) Determine input/output variables and their universe discourses

The two-input-and-one-output fuzzy system for one-axis balancing control is described in Fig.6, where one input is the acceleration (a), the other one is the acceleration's variation (Δa), and the output is the angle of modification m . In this paper, 12-bit is applied to process the acceleration data (a) so that its universe discourse is defined as $a \in [0, 4095]$ in Fig.7. The value of acceleration's variation (Δa) could be positive or negative so that its universe discourse is defined as $\Delta a \in [-300, 300]$. The angle of modification is the times of the modification; the way of the modification is sign of reference so that its universe discourse is defined as $m \in [-3, 3]$.

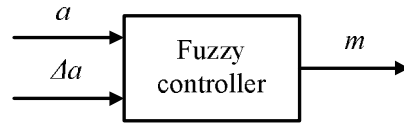


Fig. 6. Two-input-and-one-output fuzzy system for one-axis balancing control.

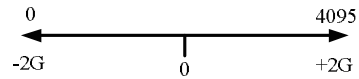


Fig. 7. The range of acceleration

$$\Delta a(k) = a(k) - a(k-1), \quad k = 1, 2, \dots, n, \quad (4)$$

(b) Determine linguistic values and their membership functions

The term sets of the input and output variables are selected as follows:

$$T(a) = \{A_1, A_2, A_3, A_4, A_5\} = \{NF, NC, M, PC, PF\}, \quad (5)$$

$$T(\Delta a) = \{B_1, B_2, B_3, B_4, B_5\} = \{BN, SN, Z, SP, BP\}, \quad (6)$$

and

$$T(m) = \{C_1, C_2, C_3, C_4, C_5\} = \{NBM, NSM, WM, PSM, PBM\}, \quad (7)$$

where fuzzy sets $A_1, A_2, A_3, A_4,$ and A_5 are respectively denoted Negative Far (NF), Negative Close (NC), Middle (M), Positive Close (PC), and Positive Far (PF) for the input a . Fuzzy sets $B_1, B_2, B_3, B_4,$ and B_5 are respectively denoted Big Negative (BN), Small Negative (SN), Zero (Z), Small Positive (SP), and Big Positive (BP) for the acceleration's variation Δa . Fuzzy sets $C_1, C_2, C_3, C_4,$ and C_5 are respectively denoted Negative Big Motion (NBM), Negative Small Motion (NSM), Without Motion (WM), Positive Small Motion (PSM), and Positive Big Motion (PBM) for the angle of modification. The partitions and the shapes of the membership functions are shown in Fig.8, where triangular-type membership functions and fuzzy singleton-type membership function are respectively used for the input and output variables.

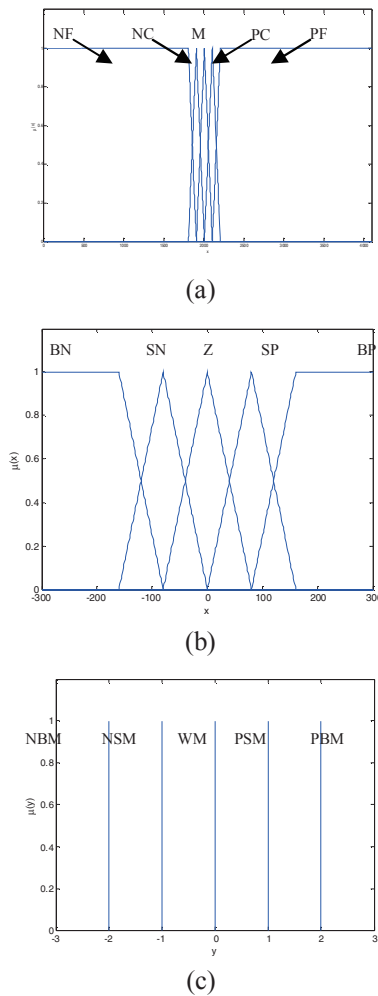


Fig. 8. Membership functions used in the proposed fuzzy system: (a) Input variable a , (b) input variable Δa , and (c) output variable m .

(c) Construct fuzzy rule base

The fuzzy rule base used for the proposed fuzzy system is described in Table 1, where each rule can be described by

Rule $R(i, j)$:

If a is A_i and Δa is B_j THEN m is $C_{(i,j)}$,

$$i \in \{1,2,3,4,5\}, j \in \{1,2,3,4,5\} \quad (8)$$

Table 1. Fuzzy rule base

m		a				
		NF	NC	M	PC	PF
Δa	BN	PBM	PBM	PSM	Z	Z
	SN	PBM	PSM	Z	Z	Z
	Z	PSM	Z	Z	Z	NSM
	SP	Z	Z	Z	NSM	NBM
	BP	Z	Z	NSM	NBM	NBM

(d) Determine fuzzy inference method

The weighted average method is used to determine the final output of the fuzzy system so that it can be described by

$$m = \frac{\sum_{i=1}^{i=5} \sum_{j=1}^{j=5} w(i, j) \cdot \mu(C_{(i,j)})}{\sum_{i=1}^{i=5} \sum_{j=1}^{j=5} w(i, j)} \quad (9)$$

where $\mu(C_{(i,j)})$ is the crisp value of the fuzzy set $C_{(i,j)}$, $w(i, j)$ is the fire strength of the rule $R(i, j)$ and can be described by

$$w(i, j) = \min(\mu_{A_i}(a), \mu_{B_j}(\Delta a)) \quad (10)$$

4. Simulation and Experiment Results

There are some practical experiments to test the proposed balancing control can let the robot balance and stand on an inclined plane by itself. They are described as follows:

Experiments of the balancing control of the robot to stand on a platform which is lifted up and put down slowly in front of and behind of the robot are shown in Fig.9 and Fig.10, respectively. Experiments of the balancing control of the robot to stand on a platform which is lifted up and put down slowly at the left and right of the robot are shown in Fig.11 and Fig.12, respectively. When the platform is lifted up and put down slowly, the center of gravity of the robot will be changed gradually. From these experiment results, we can see that the proposed balancing control can modify the center of gravity of the robot immediately so that it still balances to stand on the platform.

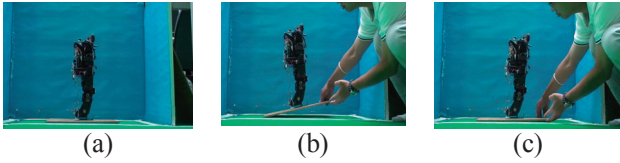


Fig. 9. Experiments of the forward balancing control: (a) Robot stands on a platform. (b) Lift up the platform slowly in front of the robot. (c) Put down the platform slowly.

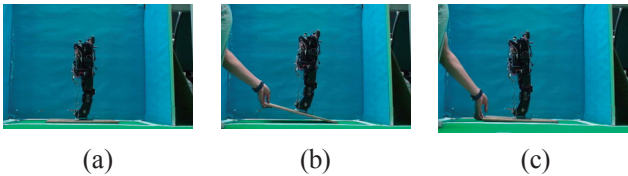


Fig. 10. Experiments of the backward balancing control: (a) Robot stands on a platform. (b) Lift up the platform slowly behind the robot. (c) Put down the platform slowly.

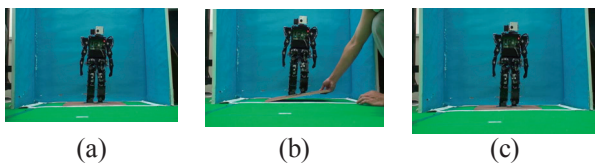


Fig. 11. Experiments of the left balancing control: (a) Robot stands on a platform. (b) Lift up the platform slowly at the left of the robot. (c) Put down the platform slowly.

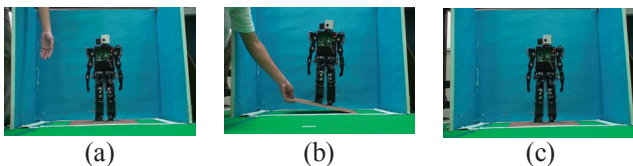


Fig. 12. Experiments of the right balancing control: (a) Robot stands on a platform. (b) Lift up the platform slowly at the right of the robot. (c) Put down the platform slowly.

5. CONCLUSIONS

An accelerometer is installed on TWNHR-IV so that it can detect the different standing environment. A fuzzy control system structure based on the obtained acceleration and the acceleration's variation from this accelerometer is proposed to change the posture of the robot for static balancing. From some practical experiments, we can see that the proposed fuzzy control method can adjust the posture of the robot to change its center of gravity for different standing environment so that TWNHR-IV can balance and stand on an inclined plane by itself.

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