計測自動制御学会東北支部　第 218 回研究集会（2004.10.9）
資料番号 218-22

Groping Locomotion of a Humanoid Robot in Environments with Obstacles

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キーワード：Humanoid robot, groping locomotion, obstacle avoidance, correction of robot orientation, groping front wall, groping side wall, autonomous single arm groping

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1. INTRODUCTION

Humanoid robot research has open new dimension of interaction between human and robot. Humanoid robot is expected to coexist and collaborate with humans in environment where human work and live, e.g., in homes, offices, hospitals, because the design of a humanoid robot is to resemble human physical characteristics. Humanoid robot is also expected to replace human activities in environment where involvement directly of human is highly risk and dangerous, e.g., in hazard site, accident site, etc. These demands make humanoid robot must be able to acknowledge and respond to its surrounding, and create suitable trajectory to attain sophisticate locomotion.

In this study, we propose groping locomotion for humanoid robot. It consists of basic research for humanoid robot to acknowledge its surrounding by touching and groping on wall's flat surface, and responds by performing correction on its orientation and locomotion direction. We also propose a method of obstacle avoidance by applying suitable algorithm to the humanoid robot's system. Previous study has reported a method of obstacle avoidance for humanoid robot which applies vision sensor's images to avoid the obstacle by walking and creeping [1]. Basically, application of sensor is necessary in order for humanoid robot to acknowledge its surrounding. However, some type of sensor, such as vision sensor, ultrasonic wave sensor, etc, sometimes cannot perform well due to interruption of environment factors, e.g., noise, heat, dust, smoke, etc. Therefore, in this study we apply force sensor at humanoid robot's arms, which directly touch with existing object to detect force which allows robot to acknowledge the existing of wall or obstacle.

2. Overview of Groping Locomotion

The main purpose of this study is to develop a groping locomotion method for humanoid robot in order to operate autonomously in closed room environment with existence of obstacles. This method required a reliable algorithm for robot to perform locomotion correctly and safely from start point to the desired end point. Fig.1 shows simulation of room with wall and obstacle to overview path planning of proposed method. Robot will start the locomotion by searching nearest wall using right arm. If no wall is found, robot will perform side-walk to right direction and repeating searching process until the wall is found. When the wall is found, robot arm will grope on the wall surface to obtain wall position and angle so that robot can correct its orientation to walk parallel with the wall surface. Before proceed with correction of angle, robot's left arm will check the existence of obstacle at the correction area. If the obstacle is detected, the robot will perform obstacle avoidance trajectory to avoid the obstacle, before proceed to walk forward. The robot will repeat the process until reach to the desired target point. Fig.2 shows algorithm of groping locomotion applied in the humanoid robot system. In this study, we apply degree 5 polynomial equations in solving interpolation to generate motion trajectory.

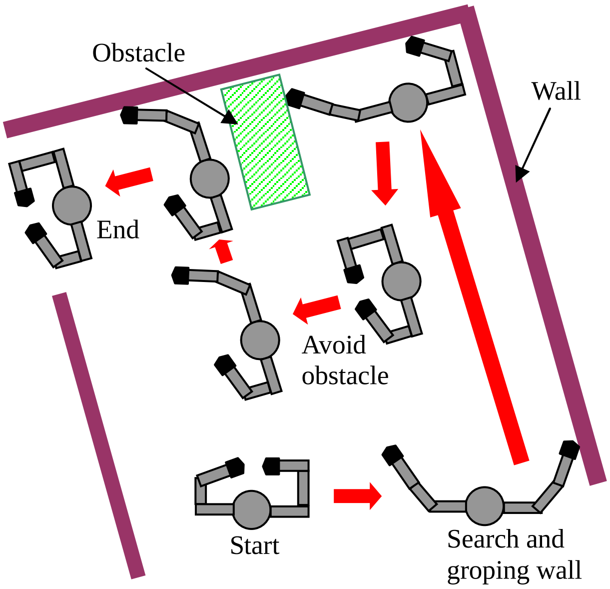


Fig.1 Path planning in groping locomotion.

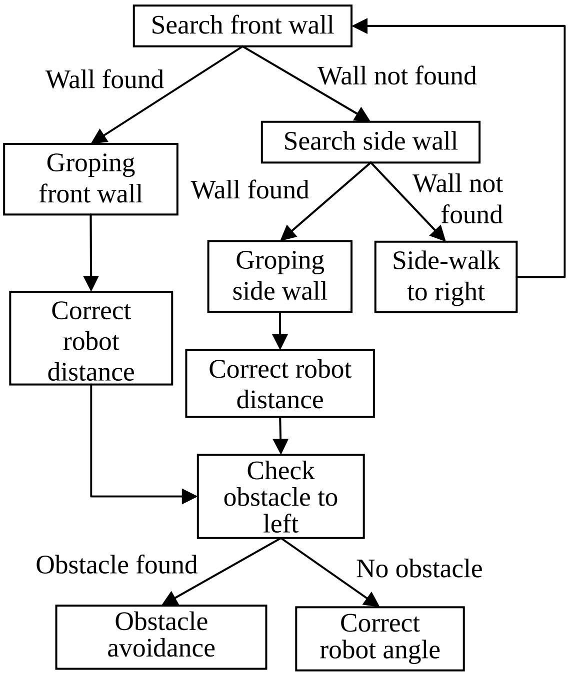


Fig.2 Algorithm of groping locomotion.

3. Searching and Groping Motion of Robot Arm

3.1 Searching wall and checking obstacle

It is important to ascertain the robot's surrounding by find nearest wall or obstacle. In this study, we propose an autonomous single arm groping method. This method is consists of sequent motion of right arm and left arm during groping locomotion and obstacle avoidance. Searching and groping to wall only perform by single arm, which decided in this study as right arm. Left arm is function to check obstacle in order to navigate robot either to proceed correction of its orientation or to perform obstacle avoidance. Application of this method has given reliable relation between groping locomotion and obstacle avoidance.

During searching for wall and checking obstacle, when arm's end effector touches the wall, force sensor will detect force and send the data to robot's system in order for robot to acknowledge the wall. In this study, maximum force control parameter is fixed earlier by results of experiment, so that motion will stop if force value detected is over the maximum fixed value. At this moment, encoders will record each arm's joints angle. By solving the direct kinematics calculation of arm's joints angle, the touch position could be obtained.

3.2 Groping wall surface

The purpose of groping is to obtain end effector position data which can be calculate to result distance and angle between humanoid robot and wall, in order for humanoid robot to make correction on its locomotion direction. During groping, the position and motion of end effector are controlled by calculations which apply values of maximum force $F_{\max}$, minimum force $F_{\min}$ and arm's end effector shift distance in 1 sampling time l, as a parameter values.

Fig.3 shows motion range of right arm during searching wall. If wall is detected at range (a), robot will perform groping which can be described as 'groping front wall'. If wall is detected at range (b), robot will perform groping which can be described as 'groping side wall'.

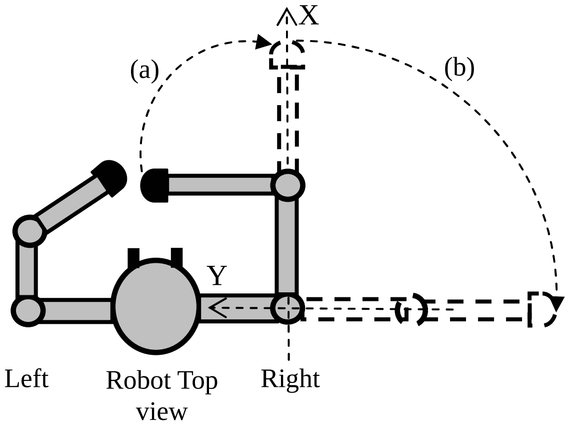


Fig.3 Motion range of robot's right arm during searching wall.

Here, end effector's position P can be described as equation (1). From this equation, force and position control of arm's end effector during groping front wall and side wall can be describe as equations (2) and (3).

$$P_{ref} = P_{cur} + l \tag{1}$$

For groping front wall:

$$P_{ref} = \begin{cases} \begin{bmatrix} P_{cur} - l \\ 0 \\ 0 \end{bmatrix} & (F \rangle F_{\max}) \\ \begin{bmatrix} 0 \\ P_{cur} - l \\ 0 \end{bmatrix} & (F_{\min} \le F \le F_{\max}) \\ \begin{bmatrix} P_{cur} + l \\ P_{cur} - l \\ 0 \end{bmatrix} & (F \langle F_{\min}) \end{cases} \tag{2}$$

For groping side wall:

$$P_{ref} = \begin{cases} \begin{bmatrix} P_{cur} - l \\ P_{cur} + l \\ 0 \end{bmatrix} & (F \rangle F_{\max}) \\ \begin{bmatrix} P_{cur} - l \\ 0 \\ 0 \end{bmatrix} & (F_{\min} \le F \le F_{\max}) \\ \begin{bmatrix} 0 \\ P_{cur} - l \\ 0 \end{bmatrix} & (F \langle F_{\min}) \end{cases} \tag{3}$$

These formulations provide smooth motion to robot's arm during groping on wall surface. At this moment, series of end effector's position data are taken, which can be compute to results distance and angle between robot and wall.

4. Correction of Robot's Orientation

4.1 Formulation

Distance between robot to wall L and angle between robot and wall ϕ can be defined by using end effector's position data obtained during groping, to be calculate with least-square method calculation. The calculation gives results to variable factors a and b in linear equation as shown in equation (4). Here, distance L is the shortest distance from robot's reference coordinate origin at right arm shoulder to linear equation (4), which can be drawn as perpendicular line. Angle between robot and wall ϕ, which described as groping angle is an angle from the perpendicular line to X-axis. Formulations of L and ϕ is shown in equations (5) and (6), respectively.

$$y = ax + b \tag{4}$$

$$L = \frac{b}{\sqrt{a^2 + 1}} \tag{5}$$

$$\phi = \tan^{-1}\left(-\frac{1}{a}\right) \tag{6}$$

From equation (6), correction of robot's locomotion direction angle can be defined as $90° - \phi$, so that robot's orientation is parallel with the wall.

4.2 Correction of robot's orientation in groping front wall and side wall

Correction of robot orientation refers to trajectory of both legs by performing interpolation of joint's angle and position of fore leg's center point by applying the values of L and ϕ. Degree 5 polynomial equations are consists in solving the trajectory generation for both legs. In the case of groping front wall, position of wall that facing the robot creates possibility for collision during correction of robot's orientation. Therefore, correction of robot's distance simply performs by generating trajectory for legs to walk backwards. In the case of groping side wall, correction of the robot's distance involves trajectory generation of legs to walk to side direction, like crab. Here, step size is required to be defined. Base on the distance between robot to the wall, which described as L and reference distance between robot to the wall, which described as L_b, the correction of distance can be defined as $L_b - L$. The side step size, described as S can be defined with following formulations.

$$S = (L_b - L)\sin\phi \tag{7}$$

Here, from equation (7),

$$S = \begin{cases} \alpha & (L_b - L \leq 0) \\ (L_b - L)\sin\phi & (L_b - L \rangle 0) \end{cases} \tag{8}$$

From equation (8),

$$S = \begin{cases} \beta & ((L_b - L)\sin\phi \rangle \varphi) \\ (L_b - L)\sin\phi & ((L_b - L)\sin\phi \leq \varphi) \end{cases} \tag{9}$$

α , β and φ are parameter values considering maximum step size of humanoid robot legs to walk to side direction. Above formulations allows robot to correct distance at any value of L and ϕ, where $0 \leq \phi \leq 90°$.

Figs.4 and 5 shows respectively a correction of the robot orientation in groping front wall and groping side wall, geometrically. Axis X-Y and X'-Y' are robot's orientation during groping and after correction of distance and angle, respectively.

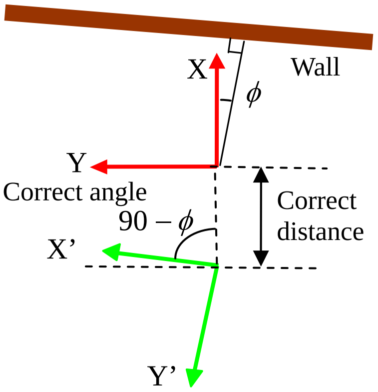


Fig.4 Correction of robot distance and angle in groping front wall.

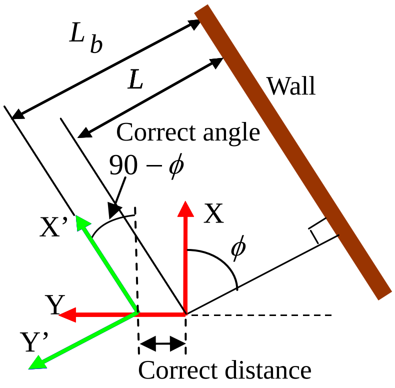


Fig.5 Correction of robot’s distance and angle in groping side wall.

5. Obstacle Avoidance

The concept of obstacle avoidance’s algorithm is based on trajectory generation of robot’s legs by manipulation of leg’s joints rotation angle. It is assist by force sensor to detect existing of obstacles on robot’s left side. The detection range angle of left arm is equal to the correction angle $90^\circ - \phi$, as shown in fig.6. Any object detected within this detection range is considered as an obstacle. Fig.7 shows the algorithm of obstacle avoidance method. The algorithm consist 3 important mode; ‘checking obstacle to left’, ‘whirl back left leg’ and ‘confirm obstacle’. The result of robot left arm in ‘checking obstacle to left’ after correction of distance will decide either robot will proceed correction of angle or to avoid obstacle. If obstacle detected, mode of ‘whirl back left leg’ will avoid the obstacle by changing the robot’s orientation facing the ostacle. Mode of ‘confirm obstacle’ will recheck the obstacle before robot proceeds to walk forward direction or to walk to left side direction. Fig.8 shows geometrical analysis of robot center coordinates after groping front wall to avoid obstacle. Axis X-Y, X’-Y’ and X”-Y” shows orientation of robot during groping, after whirl back left leg and after side walk to left, respectively.

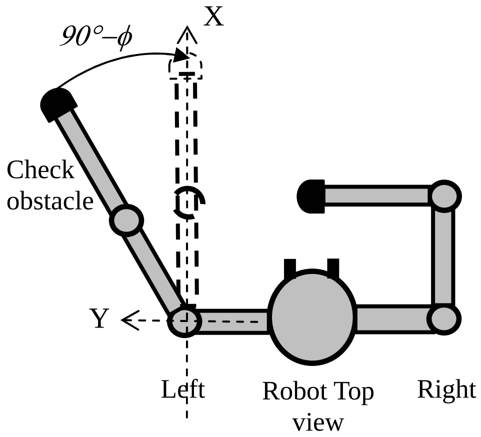


Fig.6 Motion range of robot’s left arm during checking obstacle.

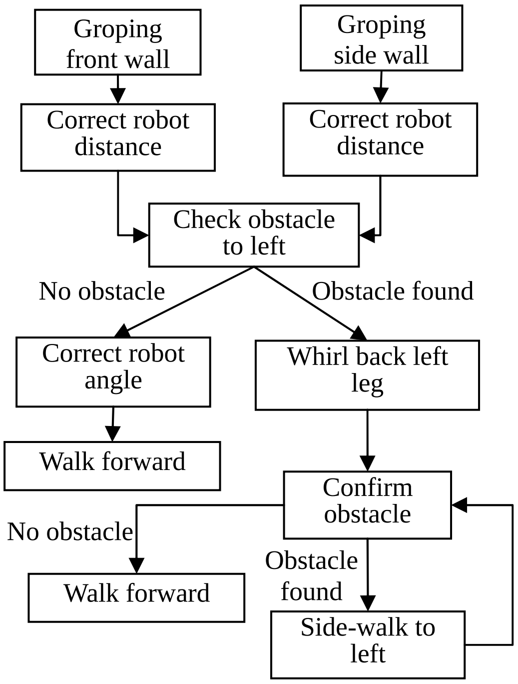


Fig.7 Algorithm of obstacle avoidance.

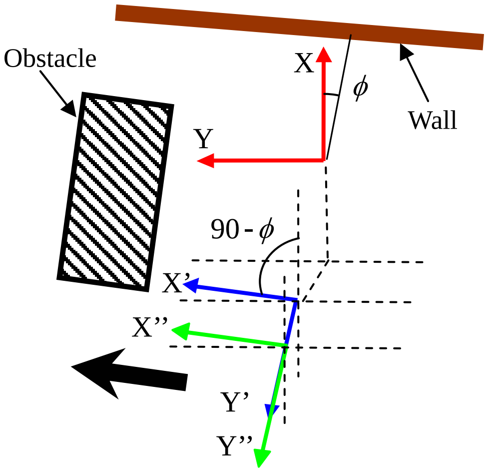


Fig.8 Correction of robot's orientation to avoid obstacle after groping front wall.

6. Experiment

6.1 Humanoid robot "Bonten-Maru II"

In this study, we use "Bonten-Maru II" humanoid robot [2]. The robot has total of 21 Degree Of Freedom (DOF). 6-DOF for each leg, 3-DOF for each arm, 1-DOF for waist and 2-DOF for head. Fig.9 shows the photograph of humanoid robot "Bonten-Maru II" and distribution of DOFs. The height, wide and total mass are 1250 [mm], 540 [mm] and 32.5 [kg], respectively.

Each joint has relatively wide range of rotation angle, as shown in table 1. Especially for both leg's hip yaw which permitting both leg to rotate in wide angle during obstacle avoidance. Every joint is driven by DC servomotor with a rotary encoder and harmonic drive reduction system, and PC with Linux (CPU: Caleron 2.4GHz) is utilized for control. The motor driver, the PC and the power supply are placed outside of the robot. Fig.10 shows the layout of control system.

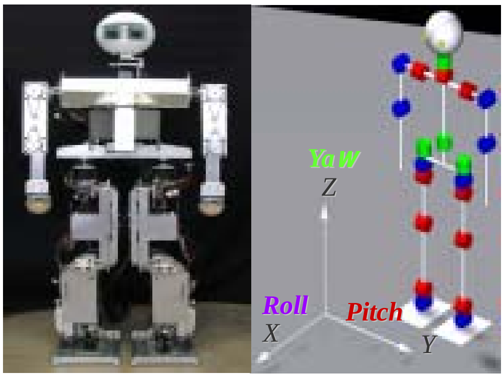


Fig.9 Photograph of humanoid robot "Bonten-Maru II" and distribution of DOFs.

Table.1 Range of joint rotation angle

Axis	Range of rotation angle (deg)
Neck (roll)	-90 ~ 90
Neck (pitch)	-90 ~ 90
Shoulder (pitch)	-180 ~ 120
Right shoulder (roll)	-135 ~ 30
Left shoulder (roll)	-30 ~ 135
Elbow (roll)	-90 ~ 90
Waist (yaw)	-45 ~ 45
Hip (yaw)	-90 ~ 90
Right hip (roll)	-90 ~ 25
Left hip (roll)	-25 ~ 90
Hip (pitch)	-130 ~ 45
Knee (pitch)	-20 ~150
Ankle (pitch)	-90 ~ 60
Right ankle (roll)	-90 ~ 20
Right ankle (roll)	-20 ~ 90

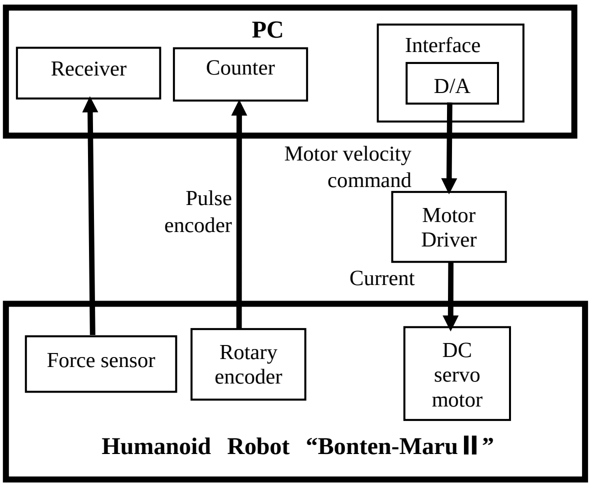


Fig.10 Control system of Humanoid Robot "Bonten-Maru II".

6.2 Force sensor

In order to measure the force applied during groping locomotion and obstacle avoidance, force sensor are attached at both arms. It positioned between arm and end effector as shown in fig.11. In this study, we use 6-axis force sensor IFS-67M25A50-I40 developed by Nitta Corporation. It consist 3 elements of force and 3 elements of moment at each axis X-Y-Z. Maximum load at X and Y axis are 400 [N], while at Z axis is 200 [N]. Fig.12 shows a photograph of force sensor used in this study.

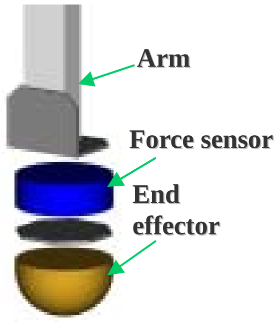


Fig.11 Assembly of force sensor at robot arm.

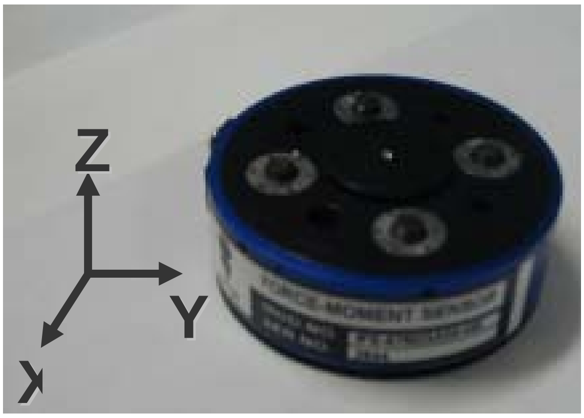


Fig.12 Photograph of force sensor.

6.3 Experiment method

In this study, we performed 3 types of groping locomotion experiment; (a) groping front wall, (b) groping side wall and (c) obstacle avoidance, with humanoid robot “Bonten-MaruⅡ”.

In this experiment, series of motion’s programs are created initially and saved in robot’s system. During experiment, the robot performs groping locomotion and obstacle avoidance autonomously. During groping, robot’s system calculates end effector’s position data using formulations of equations (4) ~ (6), to results robot distance and groping angle to the wall. Robot system responds to the defined results by performing either correction of robot orientation or obstacle avoidance.

6.3 Result and discussion

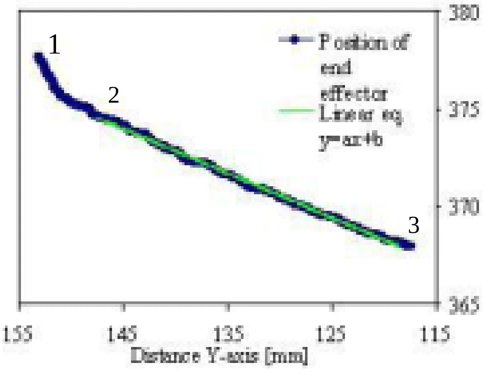
Fig.13 (a) and (b) shows graph of end effector’s position data during groping front wall and side wall, respectively. In both cases, useful data only considered at area 2 until 3. Area 1 until 2 shows unreliable data due to reflex force of robot rigid body when end effector touches the wall, which causes robot‘s origin to shift from its original position.

The data at area 2 until 3 are calculated using least-square method. Calculation of the data gives values to variable factors a and b, which solve equations (4) ~ (6) to generate results of robot distance L and groping angle ϕ. Linear equation of equation (4) can be drawn as shown in fig.13 (a) and (b).

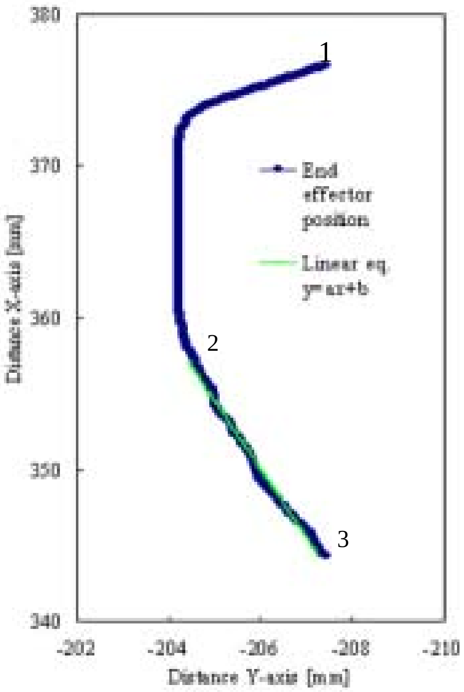
In this experiment, during groping front wall, respective values of a and b are 4.395676 and -1498.91, which results $L =$ 389.7 [mm] and $\phi =$ 29.1 [deg]. Meanwhile, for groping side wall, respective values of a and b are 0.223005 and -284.075, which results $L =$ 343.7 [mm] and $\phi =$ 62.9 [deg].

Fig.14 (a), (b) and (c) shows series of actual robot’s locomotion capture photographs during experiment of groping front wall, groping side wall and obstacle avoidance, respectively. Fig.14

(a) and (b) shows reliable results where robot performed correction of distance and angle according to theoretical calculation. Applied algorithm of obstacle avoidance also shows good performance as shown in fig.14 (c).

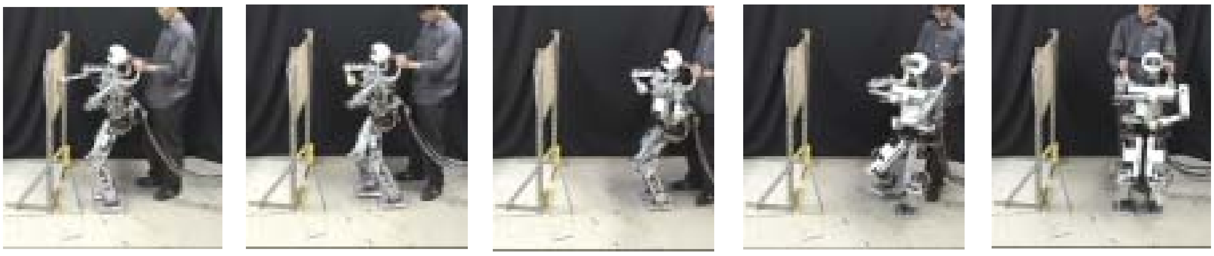


(a) Groping front wall



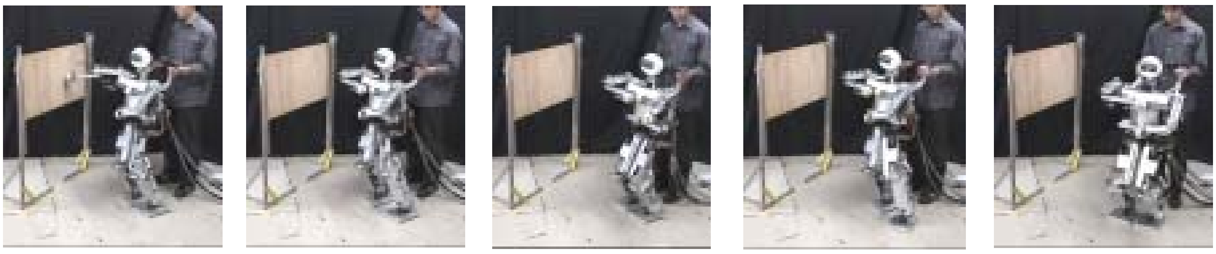
(b) Groping side wall

Fig.13 End effector position data during groping



1. Groping wall. 2. Correct distance 3. Check obstacle. 4. Correct angle. 5. Final orientation.

(a) Groping front wall.



1. Groping wall. 2. Correct distance. 3. Check obstacle. 4. Correct angle. 5. Final orientation.

(b) Groping side wall.

1. Search and touch obstacle. 2. Whirl back. 3. Confirm obstacle. 4. Side walk. 5. Reconfirm obstacle. 6. Walk forward.

(c) Avoid obstacle.

Fig.14 Photograph of robot locomotion.

7. Conclusion and Future Works

In this study, we proposed groping locomotion and obstacle avoidance for a humanoid robot. We apply a reliable algorithm for both cases and perform simple force and position control to fulfill the desired purpose in this study. We also apply an autonomous single arm groping method to relate humanoid robot's motion between groping locomotion and obstacle avoidance.

The result shows that by applying proposed groping locomotion and obstacle avoidance method, the robot is able to acknowledge and responds to its surrounding condition. The results also shows that by applying an autonomous single arm groping method, humanoid robot is able to perform reliable trajectory between groping locomotion and obstacle avoidance.

In the future, we going to improve force and position control by applying impedance control method. We believe groping locomotion and obstacle avoidance proposed in this study will be a good basic platform for humanoid robot researches in the future.

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