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Effect of Swing Arm during Gait Transition of a Humanoid Robot

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Abstract: In a humanoid robot that the locomotion is specified by using discrete gaits, the transition between different gait could cause the robot to fall down because of the abrupt change in motion. The method of applying the additional motion in the robots upper body is proposed to help stabilizing the locomotion during gait transition. After the walking gait is generated off-line, the stabilization system is used to control the robot by regulating the angular velocity of the robot to zero. In this research, the effect of swing arm motion during different walking gaits and during the gait transition is studied. The experimental results show that the swing arm motion can reduce the magnitude of a front-back sway of the robot especially during the gait transition.

Keywords: Humanoid Robot, Gait Transition, Walking.

1. INTRODUCTION

Different designs of humanoid robot and its control algorithm have been developed in recent years. The goal of humanoid research is to come up with the biped walking system that is fast and stable as much as possible. Most humanoid walking control focused on the concept of ZMP control [1]. The gait of the robot was generated offline [2] and the joint angles of the robot were compensated on-line to make sure that the ZMP stays within the stable region [3].

In the transition between different gaits such as from slow-walk to fast-walk could cause instability from abrupt change of motion. In order to stabilize the system from falling during these transitions, the swing arm motion was added to these gaits. The idea is that the swing arm motion would counteract with the falling forward effect caused by rapid changed of motion during gait transition. The use of motion of the robot upper body in walking control has been previously proposed by Kim et al. [4]. Their walking gait was generated by simulating the whole body of the robot in order to keep the ZMP trajectory to be within the stable region. The swing arm was also used to compensate for the yaw-motion of the robot to keep the robot walking straight. Haruna et al. [5] proposed the concept of passive dynamic walking by utilizing the arm motion in order to stabilized the walking. In our work, the walking gait of the robot is designed separately between the upper body and the lower body motion. The lower body motion was designed for three different walking gaits in this experiment (slow, medium and fast walk). The upper body motion was designed to either have an arm swinging motion up to 180 degree phase shift to the walking motion or no motion at all. After the walking gait is generated off-line, the stabilization system is used to control the robot by regulating the angular velocity of the robot to zero. In this research, the effect of swing arm motion during different walking gaits and during the gait transition is studied.

2. HUMANOID ROBOT SYSTEM

The humanoid robots called KM-series robots, as shown in figure 1, were developed at Institute of Field Robotics, KMUTT. Our humanoid robot is made from aluminum alloy sheet metal with some parts are made from Kevlar carbon fiber in order to keep the weight low while benefiting from the high strength property. Both robots use 22 RS-485 networked servo-motors. There are 2-axis accelerometer [+/-2g], 2 rate gyros [+/-100 deg/sec] and one CCD USB camera on the robot. The accelerometer tells the robot if there is any longitudinal and/or transversal tilt. The two rate gyros measure angular velocity at longitudinal and transversal axis. The angular velocity information will be used to adapt the attitude of the body during walking. The camera is used to track the ball and other objects of interest, which is crucial for navigation decision-making software.

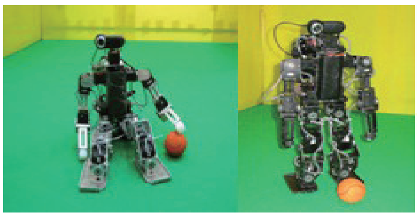

Fig. 1. KM-series humanoid robot

The main computer for all robots is PC-104 with 500MHz processor. The PC-104 board computer receives information from the CCD camera via the USB port. The computer computes the walking path and sends locomotion command to the ARM 7 motor controller via RS485 port. ARM-7 [60MHz] RISC microprocessor is still in use for low-level motors control as shown in figure 2. The inverse kinematics of the robot legs and the pre-programmed (such as self-righting gait, walking straight, turning in place, circular gait, etc.) gaits are stored in ARM-7 motor controller. The robot can choose to execute the pre-programmed gait or adaptable gait such as gyro-assisted walking gait.

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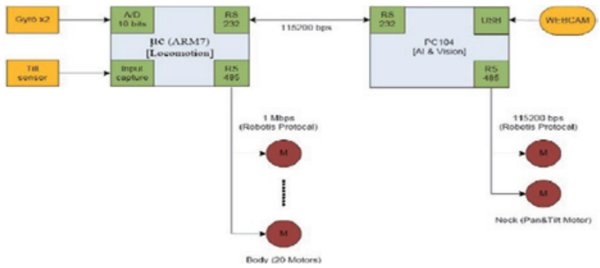

Fig.2 System diagram of the KM humanoid robot.

3. HUMANOID WALKING GAIT

3.1 Balancing control

The walking gait of this humanoid robot is achieved by a PD balancing control. When the robot loses its balance, the angular velocity can be sensed from the gyro sensors. The angular velocity is measured so that the robot can lean its body to compensate for the angular rotation which can help balancing the robot before the foot placement. The angular position of four motors attached to the robot's ankle are adjusted directly from the sensed angular velocity. When the inverse kinematics is used to calculate joint positions from the predefined walking trajectory which is used as the reference trajectory, the PD controller is used to adjust the position command which is the input for these motors at the ankle and knee as shown in Eq.(1) The PD controller is designed to regulate the angular velocity to zero during the walking cycle.

$$\theta_c = \theta_c + K_p(\dot{\theta}_i) + K_d(\dot{\theta}_i - \dot{\theta}_{i-1}) \qquad (1)$$

θ_c is the command angular position

K_p, K_d is the PD gain

$\dot{\theta}_i$ is the angular velocity error at the current time

$\dot{\theta}_{i-1}$ is the angular velocity error at the previous time step

Three different walking gaits were designed for various walking speeds: slow, medium and fast. The parameters of the balancing control and the walking parameters such as step length and step height were manually adjusted for these different walking gaits. The walking gait parameters for different walking speed is shown in table I.

Table I Parameters for walking gait

Parameter	slow	medium	fast
Step length (cm)	3.5	5.5	8
Step height (cm)	3.5	3.5	3.5
Step time (ms)	15	15	15
Hip angle (deg.)	5.02	11.72	19.63
Shoulder angle (deg.)	5.02	11.72	19.63

3.2 Applying swing arm motion during the walking gait

After the lower body motion was designed for three different walking gaits in this experiment (slow, medium and fast walk). In addition to the lower body motion, the swing arm motion can generate the moment around y axis of the robot (pitch moment). The moment generated by the swing arm can either reduce or enhance the moment around y-axis from the lower body motion depending on the phase shift between in walking and arm swinging cycle. The swing arm motion is generated at 180 degrees phase different from the hip swinging motion around y axis. The motion of the swing arm is simplified as the single pendulum motion where only the shoulder joint is symmetrically pivoted around y-axis. The elbow joint is kept to its zero position. In the KM humanoid balancing controller, the angular velocity is regulated to zero. However, the PD gain for the balancing controller has to be tuned to the value that would allow a small angular velocity to be maintain so that the robot can continue to move forward but sufficiently small so that the robot does not fall.

4. EXPERIMENT

4.1 Experimental setup

The experiment consisted of 10 walking trials as shown in table II. The first 6 walking trails (#1-#6) show the effect of swing arm on different gaits (slow, medium and fast walk). The walking trial #7 and #8 compare the effect of swing arm when gait transition between medium to fast. The walking speed and the gyro reading in front-back sway and side sway were recorded in each walking trial. The robot is commanded to walk 10 steps for 5 times for each trial.

Table II Ten different walking trials

Experiment	Slow-walk	Swing arm	Medium-walk	Swing arm	Fast-walk	Swing arm
1	Yes	No				
2			Yes	No		
3					Yes	No
4	**Yes**	**Yes**				
5			**Yes**	**Yes**		
6					**Yes**	**Yes**
7			Yes	No	Yes	No
8			**Yes**	**Yes**	**Yes**	**Yes**
9			**Yes**	**Yes**	Yes	No
10			Yes	No	**Yes**	**Yes**

The experimental results are shown in the next section.

4.2 Results

The angular velocity around y-axis (pitch) was sampled during the walk every 0.75 ms. The angular velocities are then averaged during one walking step (20 samples). The average, minimum and maximum angular velocities are the averaged value from 5 experimental trials of each case. The forward walking velocity for the different walking trials is shown in table III.

Table III Average walking velocity and angular velocity around y-axis in different walking trials

Exp.	Average velocity (m/sec)	Average angular velocity (deg/sec)	Max. angular velocity (deg/sec)	Min. angular velocity (deg/sec)	Max – Min angular velocity (deg/sec)
1	0.08	-11.69	-2.26	-17.36	9.42
2	0.14	-11.66	-3.21	-20.37	8.45
3	0.23	-11.46	-4.07	-18.06	7.39
4	**0.06**	**-13.11**	**-7.8**	**-19.94**	**5.31**
5	**0.12**	**-13.3**	**-6.14**	**-22.2**	**7.17**
6	**0.21**	**-10.87**	**-2.01**	**-19.78**	**8.86**
7	0.22	-13.03	-2.68	-20.76	10.34
8	**0.21**	**-10.31**	**-3.83**	**-18.89**	**6.48**
9	**0.21**	**-9.1**	**-0.33**	**-18.09**	**8.77**
10	**0.21**	**-10.61**	**-3.91**	**-21.48**	**6.7**

Fig. 3 Graph of the angular velocity during the slow-walking gait with no swing arm (experiment 1).

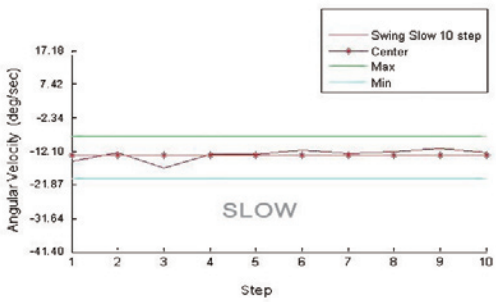

Fig. 4 Graph of the angular velocity during the slow-walking gait with swing arm (experiment 4).

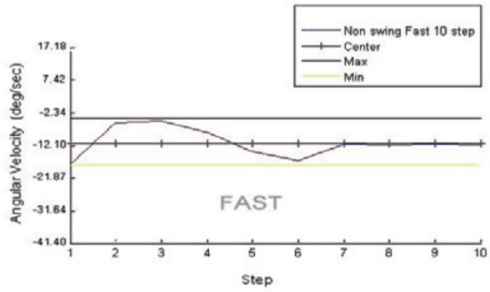

Fig. 5 Graph of the angular velocity during the fast-walking gait with no swing arm (experiment 3).

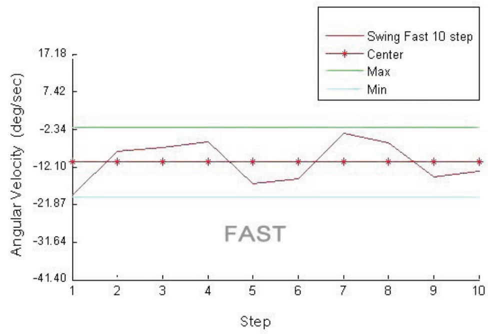

Fig. 6 Graph of the angular velocity during the fast-walking gait with swing arm (experiment 6).

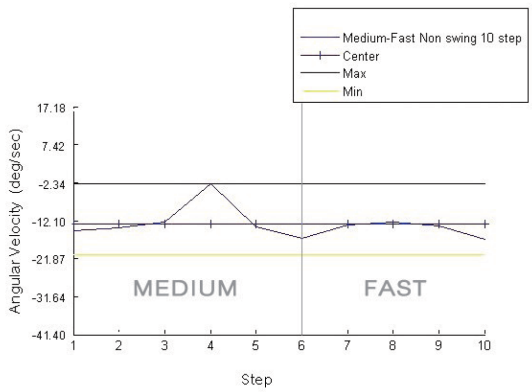

Fig. 7 Graph of the angular velocity during the transition from medium to fast walking gait with no swing arm (experiment 7).

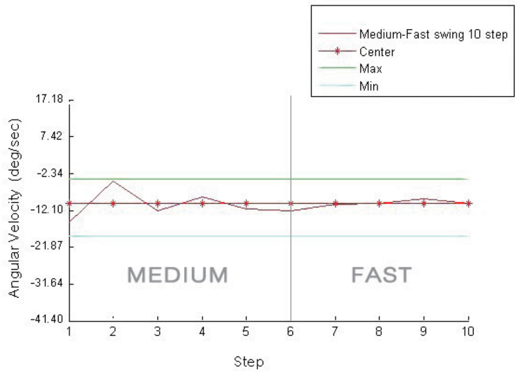

Fig. 8 Graph of the angular velocity during the transition from medium to fast walking gait no swing arm in both gaits (experiment 8).

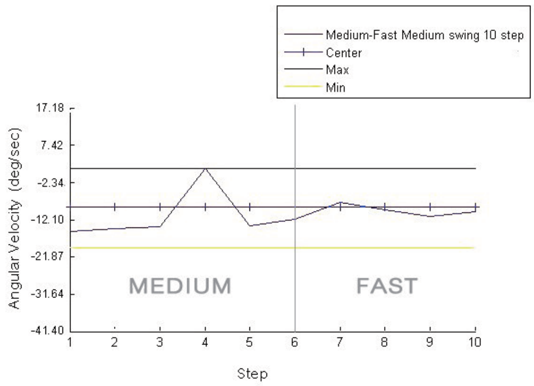

Fig. 9 Graph of the angular velocity during the transition from medium to fast walking gait with swing arm in medium and no swing arm in fast (experiment 9).

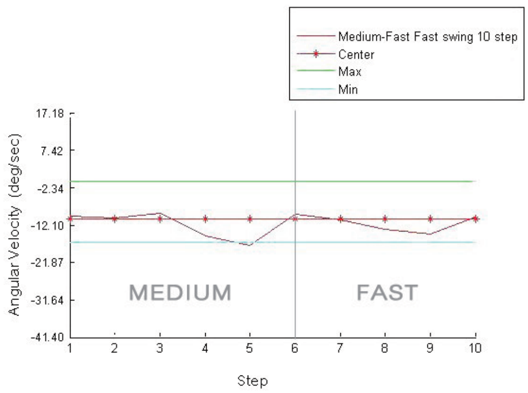

Fig. 10 Graph of the angular velocity during the transition from medium to fast walking gait with no swing arm in medium and swing arm in fast (experiment 10).

4.3 Analysis

From the experimental results, table III shows that the swing arm motion can affect the walking velocity by reducing the walking speed by 25 % in the slow-walk case and 8.5% in the fast-walk case. However, the amount of front-back swaying motion which is undesirable during the walk can be considered by the different between the minimum and maximum angular velocities. In most cases, these numbers are smaller in the experiment that swing arm was added except in the fast-walk case (exp. 3 and 6). In the case when the gait transition was occurred, from medium-walk to fast-walk, the different between the minimum and maximum angular velocities was large. When the swing arm is applied either in both gaits, or only one gait, the front-back sway can be reduced significantly.

5. CONCLUSIONS

The experimental results show that the swing arm motion can reduce the magnitude of a front-back sway of the robot especially during the gait transition. With no swing arm, the robot would fall forward with larger angular velocity which leads to larger control effort for the robot stabilization system. Conversely, the swing arm also reduces the walking speed by 25% especially in the slow-walk gait. However, if the swing arm is applied during the fast walk only, it would not reduce the front-back sway as much as before and after the gait transition.

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