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Study of Teen-sized Humanoid Robot Kicking Behavior

Thavida Maneewarn* and Amnart Butsongka

Institute of Field Robotics, King Mongkut's University of Technology Thonburi, Bangkok Thailand

(Tel : +66-2-470-9339; E-mail: praew@fibo.kmutt.ac.th)

Abstract: This paper discusses about the development of a light weight 1.15m tall humanoid robot called 'Ka-Nok' that can walk, kick the ball and withstand the fall in order to participate in the RoboCup teen-sized humanoid robot soccer competition. In this paper we focus our study on trying to understand the physics of ball kicking so that we can design the kicking behavior for our robot which can control the motion of the ball toward the target while maintaining the stability and using minimum energy possible. Three types of kicking were tested: straight shot, inside foot and heel kick. The distance of ball rolling can be controlled from the knee lifting angle in a straight shot.

Keywords: humanoid robot, kicking, robot soccer

1. INTRODUCTION

In order to develop a robot to participate in the RoboCup teen-sized humanoid robot soccer competition, we have developed a light weight 1.15m tall humanoid robot called 'Ka-Nok' that can walk, kick the ball and withstand the fall. In this paper we focus our study on trying to understand the physics of ball kicking so that we can design the kicking behavior for our robot which can control the motion of the ball toward the target while maintaining the stability and using minimum energy possible. The control of ball kicking behavior is important not only in goal scoring but also in team-playing strategy such as ball passing. In ball passing, the kicking robot should be able to kick the ball toward the target position specified by the receiving robot within a given time. In the RoboCup, there are many participants in the teen-sized league [1-3], however no prior study has been given on the kicking motion of a humanoid robot.

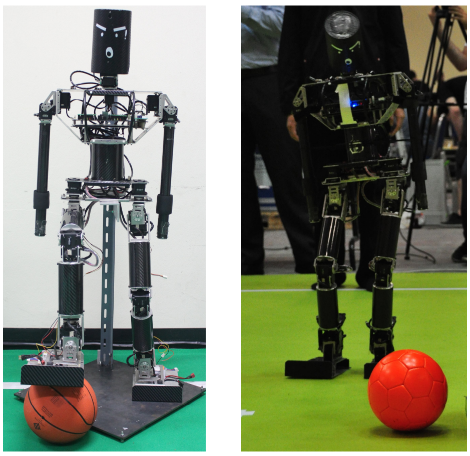

Fig. 1 Ka-Nok, the teen-sized humanoid robot

2. HUMANOID ROBOT SYSTEM

Ka-Nok, as shown in figure 1, is 1.157m tall and weight 5.6 kg. The control system on the robot comprised of a dual-AVR microcontroller. The robot can operate autonomously using visual feedback from a camera on its head. The initial vision processing is performed by a Havimo camera. The dual-AVR processes all sensor data and performs game-play decisioning such as finding and following the ball and kicking the ball toward the goal. The ARM-7 microcontroller is the locomotion module which combines inertial information from gyro sensor and accelerometer then controls the leg trajectory and balancing control. The robot control system is shown in fig.2.

The robot structure is made of aluminum alloy and carbon fiber tube for its lightweight and high strength property. This robot uses 14 Ex-106 and 6 RX-28 Robotis motors. In each leg, there are 3 dofs(roll, pitch, yaw) in the hip joint, 1 dofs (pitch) in the knee joint and 2 dofs(pitch, roll) in the ankle joint as shown in fig.3. In each joint, the angular joint limits can be shown in Table 1. These joint limits directly affects the allowable motion of the kick which will be discussed in section 2,3 and 4. In order to establish the kick by lifting one leg, the robot has to be solely supported by a single leg. The torque required for the hip and ankle joint during the one-legged stand is higher than during the walk cycle. Therefore, additional motors were added to the hip and ankle roll joints as shown in fig. 4. Both joints are driven by dual motors in the master-slave mode, where both motors are always driven together.

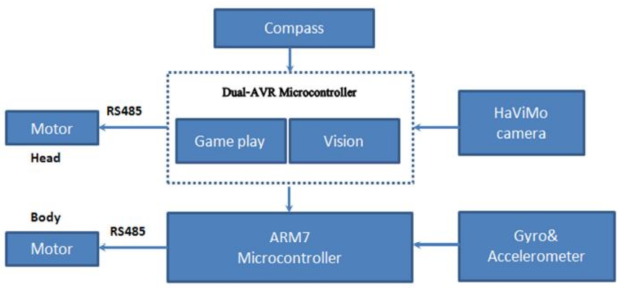

Fig. 2 Kanok's system Design

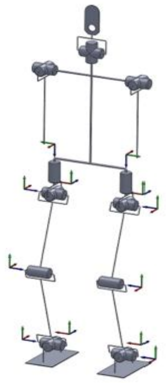

Fig. 3 Ka-Nok's kinematics diagram

Table 1 joint limits of the robot leg

joint	minimum (degrees)	maximum (degrees)
Hip pitch	-28	90
Knee pitch	-60	60
Ankle pitch	-28	90
Hip yaw	-32	32
Hip roll	-75	5
Ankle roll	-65	65

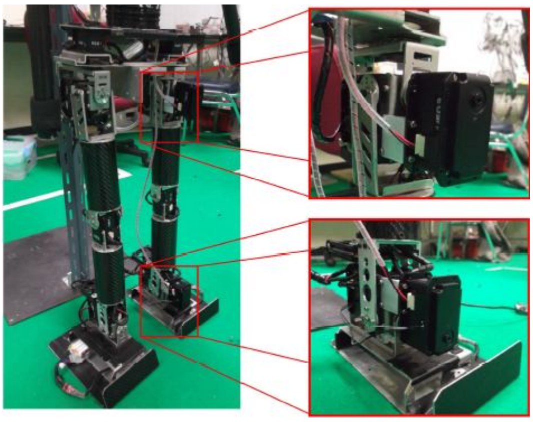

Fig. 4 Robot modification for kicking a) dual motors on the left hip roll joint b) dual motors on the left ankle roll joint.

3. KICKING MOTION

3.1 Type of kicking

The biomechanical movement of kicking motion has been widely studied in sport science [4]. It is important for the soccer players to understand the physics of kicking so that they can kick with high power and accuracy while minimizing injury. Kicking in soccer can be categorized into different types such as standard straight shot, inside and outside foot shot, toe shot and heel shot. Factors that affects the speed of the ball and the ball rolling distance are the angular velocity of the foot at ball impact and the length of body parts. In soccer, the player needs to achieve either high power or high accuracy kicking motion. The high power kick is useful for goal scoring while the high accuracy kick is beneficial for passing the ball to other player. Human kicking motion involves 4 phases as shown in fig. 5: leg back swing, forward movement, ball contact and follow through.

From these studies, we programmed the robot's kicking motion to imitate the movement of three types of kick: The straight kick, the inside foot kick and the heel kick. The straight kick is done by lifting the hip and knee pitch joints then swing the knee joint forward to let the front of the foot contact the ball as shown in fig.6. Fig.7 shows the inside foot kick, where the robot lifts the right foot up by moving the left ankle and the hip roll joint, then swing the right foot to kick the ball using the inside of the foot. Fig.8 shows the heel kick. The robot lift the right foot forward using the hip pitch joint and swing the right leg backward to kick the ball at the rear part of the foot.

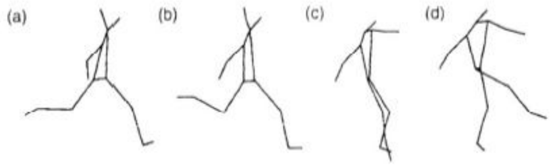

Fig. 5 phases of kicking: a) leg back swing b) forward movement c) ball contact d) follow through [4]

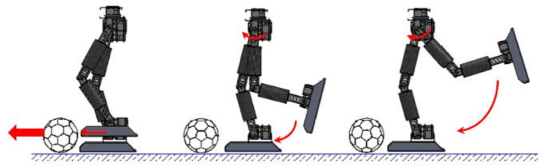

Fig.6 Straight kicking motion

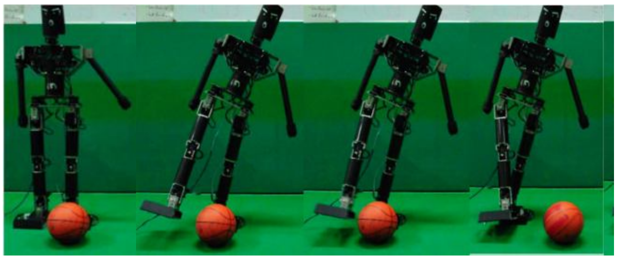

Fig.7 Inside foot kicking motion

Fig. 8 Heel kicking motion

3.2 Parameters of kicking

In order to control the ball to roll and stop at the target position, we will have to understand the physics of ball rolling. The ball rolling distance directly relates to the energy from the robot that transfer to the ball during impact which can be measured from the velocity and force when the robot's foot is touching the ball (shown in fig. 9). It also relates to the friction between the surface of the field and the ball (there is also additional parameters such as the pressure of the ball and the roundness or symmetry of the ball). In our experiment, the ball and the field are the control parameters. The experiment is designed to observe the relationship between the ball rolling distance, the angular ball heading accuracy and the kicking trajectory parameters (i.e. the angular position and angular velocity of the knee joint) during the kicking action.

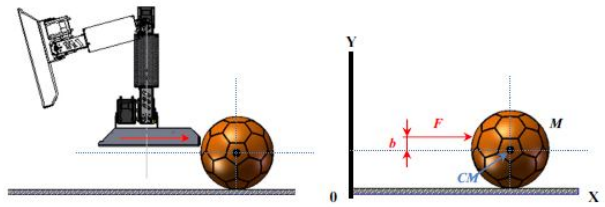

Fig.9 Impulse force at ball contact phase of kicking

4. EXPERIMENT

4.1 Straight kicking forward

The straight kick motion is the standard form of kicking where the front of the foot contacts the ball and move the ball forward as explained in section 3.1. Initially, we experimented with the free-fall kick by vsing the 'kick' testbed.The knee pitch joint is lifted up to various angles (10, 20,..,60 degrees) ,then the knee joint motor torque is disable so that the knee is falling down by gravitational force. The relationship between the ball rolling distance and the knee joint lifting angle is shown in figure 4.

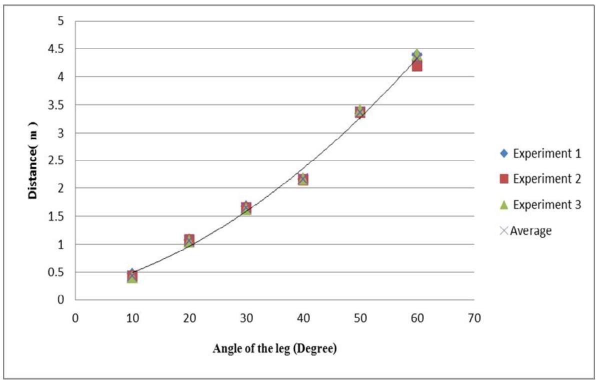

Fig. 10 Relationship between the angle of the knee and the ball rolling distance using free fall knee swing on the testbed

4.2 Straight kicking forward at low and high speed

In the second experiment, the humanoid robot is controlled to lift the right knee at various angles as in the first experiment, but the velocity of the knee joint is controlled at different speeds. We defined the low speed at 6.39 rad/sec and the high speed at 7.04 rad/sec.The robot has additional support on the left leg to secure it on the ground. The experiment is performed at the knee lifting angle which is varied from 10 to 60 degrees (for 10 trials each) at low speed and high speed. The result are shown in fig.11, 12 and 13. At low speed, the ball rolling distance is between 0 to 4 m. At high speed the ball rolling distance is between 0 to 7m.

The relationship between the ball rolling distance and the knee lifting angle at the low speed kick can be described by Eq. (1)

$$y = -7E\text{-}05x^2 + 0.0755x - 0.676 \tag{1}$$

The relationship between the ball rolling distance and the knee lifting angle at the high speed kick can be described by Eq. (2)

$$y = 0.0004x^2 + 0.1181x - 1.13 \tag{2}$$

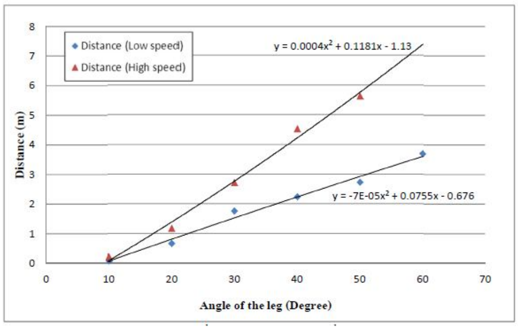

Fig. 11 Relationship between the angle of the knee and the ball rolling distance at low and high speed

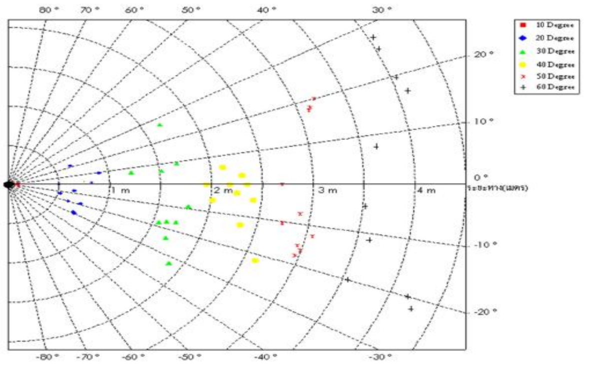

Fig. 12 Ball stopping position for various knee lifting angle at low speed kick

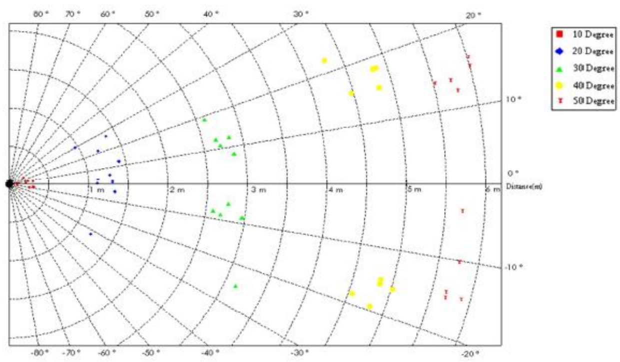

Fig. 13 Ball stopping position for various knee lifting angle at high speed kick

4.3 Ball rolling distance control

From the results of the experiment in section 4.1 and 4.2, the knee lifting angle has a direct relationship with the ball rolling distance. Therefore, we should be able to control the ball rolling distance of the straight kick by varying the knee lifting angle according to Eq. (1) and Eq. (2) for the low and high speed kick. In this experiment, the robot performed a straight kick without an additional support as in the second experiment. The experiment was performed 10 times for each target distance in both low and high speed kick. The target distance was set at 1, 3 and 5m for the high speed kick and 1,2 and 3m for the low speed kick.

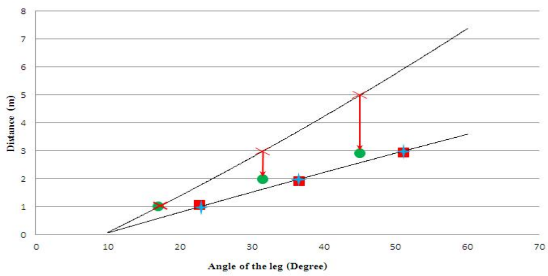

Fig. 14 The ball rolling distance control experiment
The ball rolling distance at high speed
The ball rolling distance at low speed
Target distance at high speed
Target distance at low speed

The results of the ball rolling distance control experiment is shown in fig.14. We found that at high speed, there are large errors between the actual ball rolling distance and the target distance. At low speed kick, the errors are much smaller. We observed that the error may come from the additional force which is created when the knee swings at high speed. When the knee swing at low speed, the ball rolling distance can be sufficiently controlled by adjusting the knee lifting angle.

4.4 Inside foot kicking

The inside foot kicking motion was also tested. The motion of inside foot kicking is previously explained in section 3.1. The foot yaw angle can be adjusted at the ankle of the robot which would affect the direction of the inside foot kick. Fig.15 shows the results of the inside foot kick experiment. The average ball rolling distance is 1.85 m. The inside foot kicking is useful for kicking at the perpendicular direction of the robot at the angle between 45 to 90 degrees.

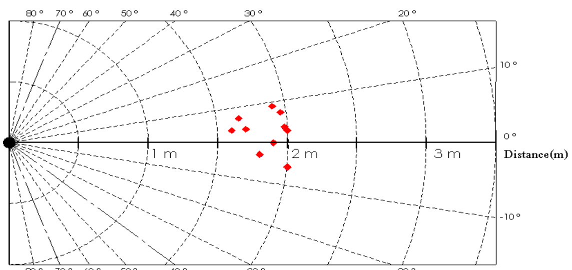

Fig. 15 Ball stopping position for the inside foot kick experiment

4.5 Heel kicking backward

The heel kicking is used for kicking the ball backward using the heel of the robot. The experiment was performed to test the heel kicking motion. The result of the heel kicking experiment is shown in fig. 16. The average ball rolling distance is 2.79 m (backward from the robot).

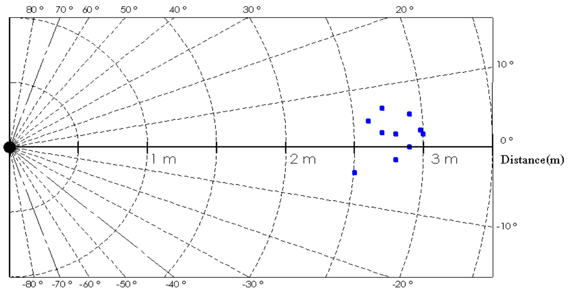

Fig. 16 Ball stopping position for the heel kick experiment

5. CONCLUSION

This paper discussed about the kicking motion of 'Ka-Nok', a 1.15m tall humanoid robot which was the striker robot in the RoboCup soccer competition. Three type of kicking was implemented on Ka-Nok including straight kick, inside foot kick and heel kick. In order to achieve the kicking accuracy, the ball rolling distance can be controlled by adjusting the knee lifting angle for the straight kick. The low speed kick resulted in better accuracy than the high speed kick. The inside foot kick and the heel kick were also tested. These three types of kick can be used under different conditions such as ball passing or goal scoring which will be determined by the high level decisioning control of the robot.

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