論 文 の 要 旨

Study of Dynamic Control for Balanced Walking of Humanoid Robots
（ヒューマノイドロボットのバランス歩行のための動的制御に関する研究）

氏名： SUNANDAN DUTTA

Humanoid Robots are important targets by roboticists to automate the human-centered society. Therefore humanoid robots are most popular research topics in the field of robotics. At the same time it is very challenging to implement a humanoid robot in the real world where the environmental factors like surface profile, rigid obstacles pose serious problems. Also, the dynamics of humanoid robot is highly nonlinear and difficult to control. Due to the presence of multiple joints, it is very difficult to implement control system hardwares to control all joints at a time. Also the computational complexity for this implementation is too large to be implemented using open-source hardware platform, making the development very much restricted to laboratory rooms.

Therefore a lightweight humanoid robot is very much suitable over a heavy human-size robot for analyzing the postural stability of the robot on inclined surface. KONDO KHR-3HV robot of 1.5 Kg weight and 0.6m height is used for the investigation of the postural stability on an inclined surface. A force-sensor based position control system is proposed. The ankle motor is controlled by force-sensor feedback from the robot foot. This control system enables the robot to walk on inclined surface up to 8.5^{o}. Beyond 8.5^{o}, a gyro based control system is designed control the hip motor allowing the robot to stabilize its posture up to 10^{o} of surface inclination. Theoretically the Inverted Pendulum Model is extended to include the effect of the surface inclination in order to model the stability of the robot. The model predicts the effect of feedback gain and initial motor-rotation in order to reduce the maximum overshoot in the transient response of the angular velocity of the robot.

After implementing static stability control system for the robot on inclined surface, the dynamic walking of the robot was investigated on the inclined surface. In that case a gyro sensor was used to control the ankle motor upto a surface inclination of 8.88^{o}. The torso-angular velocity is analyzed in both time domain and frequency domain for studying the vibration in the robot. Vibration in the robot is observed to be an effect due to the harmonics of the fundamental walking frequency of 1.73 Hz. In addition to the harmonics, the damped natural frequency due to the gyro feedback effects the frequency response of the robot. This causes increased vibration when the feedback control is introduced. One way to reduce the vibration is to increase the friction between the robot feet and surface. Increasing surface friction allows the robot to walk more stably with reduced vibration.

The thesis consists of six xhapters. The research topics discussed in the chapters are summarized as follows:

Chapter 1 discusses the basic objective of the work outlining a brief overview of the design and application of the humanoid robot. It discusses the motivation of the work and concluding with the outline of the thesis.

Chapter 2 discusses the previous work carried out in the field of humanoid walking stability. Two main aspects of the robot stability are discussed namely, the control methods for postural stabilization and the vibration control in humanoid robots.

Chapter 3 presents the investigation of the static stability of the robot. The static stability of the robot is analyzed on an inclined surface. The proposed position-control system is based on the force-sensor feedback from the robot feet. The robot can stabilize its posture on inclined surface up to a surface inclination of 8 degrees. Beyond 8 degrees, a gyro sensor based position control system is used to stabilize the robot on inclined surface up to a surface inclination of 10.2 degrees.

Chapter 4 discusses the application of gyro sensor to the humanoid robot. An electromechanical model of the gyro sensor is experimentally verified from the dynamic characteristics of analog gyro sensor KRG-4. The gyro sensor model is used to model the push recovery strategy for the robot on a plane surface. The model was experimentally verified by the push-recovery experiments.

Chapter 5 discusses the robot walking control based on a novel gyro sensor based feedback control system. The achievements are divided into two parts. The first part discusses the walking pattern modelling of the robot and the frequency response of the robot walking on an uninclined surface. In order to stabilize the robot walking on an inclined surface, a gyro-sensor based feedback control systems is proposed. The experimental results shows that as the surface inclination is increased higher harmonics of the fundamental walking frequency and damped natural frequency of the control system effects the robot walking. This increases the vibration in the robot, thus making the robot walking unstable. So an optimization of the controller gain is implemented based on the tradeoff between the surface friction and the vibration. Therefore adjusting the controller gain, the vibration is reduced.

Chapter 6 concludes the thesis work outlining the main achievements and novel contribution of the thesis.