Development of a Controlling Program for Six-legged Robot by VHDL Programming

Saroj Pullteap  
Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology  
Silpakorn University (Sanam Chandra Palace Campus), Thailand  
saroj@su.ac.th

Teerapat Boontuboon  
Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology  
Silpakorn University (Sanam Chandra Palace Campus), Thailand

Abstract
This paper describes the development of a controlling program for the six-legged robot, which has a movement behavior like a cockroach. The name of the designed robot is defined as “Chabata”. Inverse kinematics technique has preliminarily been applied for locating the movement of the eighteen servo motors installed at each leg of the robot. Consequently, a field programmable gate array (FPGA) controlling board cooperated with the VHSIC hardware description language programming called as VHDL has next been employed for the robot operation. The experimental results show that the developed program, which operated on the inverse kinematic technique, has a high capability to control the locomotion of the Chabata robot. Moreover, the designed robot also has an excellent response to carry on the desired functions.

Keyword: Six-legged robot, Inverse kinematics, VHDL programming, FPGA controlling board

I. INTRODUCTION
Nowadays the robot technology plays more important role in facilitating humans, especially in the fields of medicine, industry, military, and entertainment. This kind of technology can generally be classified into two types according to its function. The first one is the fixed robots that cannot move by themselves. Consequently, most of them possess manipulator enabling them to move only their internal joints. They are mostly applied in factories. The other different type is the mobile robots that can move by using their wheels or legs [1]. Moreover, it can thus be further categorized according to its movement into 3 types: wheeled robot, legged robot, and hybrid legged-wheeled robot respectively [1],[2]. The legged robot is interesting and outstanding because its ability to cross barriers is better than that of the wheeled robot. Moreover, it can move on the surface that the wheeled robot cannot enter such as surveyed area or agriculture area that should not come into contact with damaging things. The legged robot can move on this kind of surface because it touches only its tip of legs on the surface.

In this research, the Chabata robot that was a six-legged robot has been designed and developed. FPGA technology was also applied to control servo motors for the robot movement, together with the VHDL that was a high-level programming language [3] providing the convenience to search, input, and connect external tools better than other applied languages. Besides, its programming structure was understandable and editable, leading to easy implement and improvement for developers.

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II. ROBOT THEORY

A. Movement of Legged Robot

To design a legged robot, most designers want its movement like an insect [4] because it can move on every kind of surface, cross barriers, and increase its movement speed by properly changing its movement behaviors. Rasakatla et al [5] designed the six-legged robot whose behavior is like a worm with each leg possessing two degree of freedom (DOF). A distinct quality of this kind of robot is its flexible body because there are motors attached to each joint of each body section, enabling it to move and rise upward or downward. This kind of robot can also move on the surface with different height. Moreover, Botello et al [6] designed a robot whose behavior is like an insect with each leg possessing three DOF.

However, they designed only its thorax and six legs attached. Its distinct quality is the ability to move like a living thing. Besides, Sorin et al [7] developed the software to simulate the six legged robot movement balance in the gravitational field by applying the inverse kinematics technique. This research designed the structure and developed the applied program in order to control the movement of the Chabata robot imitating the movement of the cockroach [8]. The forward movement sequence of each leg of the Chabata robot has been simulated as shown in Figure 1.

Assume that “Swing phase” is stepping forward by raising the tip of the leg from the floor. “Stance phase” is pulling the leg back to the original position with the tip of the leg still touching the floor. “Lift leg” is raising the tip of the leg from the floor a little bit. This research fixes the tip of the leg to rise up from the floor 5 millimeters. “Fix leg” is the leg that stands still, and also “Distance” is the space from the starting position to the point the robot moves to.

As shown in Figure 1, the robot movement sequence starts from the first step (1) when the robot stands still. For the second step (2), its right foreleg (FR) and right back leg (BR) go forward one step. For the third step (3), its left middle leg (ML) steps forward. After three legs step forward, for the forth step (4), the other three legs that are left foreleg (FL), left back leg (BL), and right middle leg (MR) are raised up slightly. After that, the three legs that have already moved forward are pulled back to the starting position, and the other three legs that have risen up slightly are pulled back to the floor. These steps enable the robot to move forward. For the fifth step (5), the left foreleg (FL) and the left back leg (BL) go forward, followed by stepping the right middle leg (MR) as the sixth step (6). For the seventh step (7), the other three legs are risen up, and the three legs that have already stepped forward are pulled back, causing the robot to come back.
to the original position as in the first step (1). However, for the robot to further move forward, the second step (2) can thus be immediately executed.

Consequently, this forward movement sequence can finally be applied to the movement to other directions with the same sequences of leg movement but different directions.

\[
\theta_1 = \tan^{-1}\left(\frac{y}{x}\right)
\]

\[
\theta_2 = \sin^{-1}\left(-\frac{L_1 - L_2 - z - C}{2L_2\sqrt{z^2 + C^2}}\right) - D
\]

\[
a_3 = \sin^{-1}\left(C^2 + z^2 - L_2^2 - L_3^2\right) - a_2
\]

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For controlling the movement of each leg of the robot, the robot is accessed to move to the desired direction with inverse kinematic equation [9], which changes the position value to the angle value in degree, in order to push motors rotating to the position making the robot legs move correctly as desired. The variables of the robot leg are shown in Figure 2.

When \(x\), \(y\), and \(z\) are the position of the robot’s tip of the leg, \(L_1 - L_3\) are the length of each leg section, \(M_1 - M_3\) are 1 - 3 servo three legs step forward, for the forth step (4), motors, and \(\theta_1 - \theta_3\) are the angles of the first, the other three legs that are left foreleg (FL), second, and third servo motors respectively.

To be applied, the initial position of the robot legs is input to be at the original position of the joint of servo motor in order to input the original angles to each leg of the robot. The position of the tip of the robot legs for the robot to move is next assigned by using (1) - (3) to calculate the degree of the servo motor that they have to rotate.

\[
C = x \cos \theta_1 + y \sin \theta_1 - L_1
\]

\[
D = \sin^{-1}\left(\frac{C}{\sqrt{x^2 + y^2}}\right)
\]

B. VHSIC Hardware Description Language

VHDL is a high-level programming language used to design digital system like PASCAL. Moreover, VHDL is easy to understand and its circuit can be designed in many different levels in the functioning format, contributing to the convenience to change or retrieve the circuit. It can also use the high-level language to write codes to check the correctness of the designed circuit by using simulation. The composition of VHDL is shown in Figure 3. VHDL can be divided into 4 parts according to its functions as follows:

1) Package: Package is a unit that collects sub codes. It is a central that all the codes retrieve such as sub program defining a type of data to facilitate code programming.

2) Entity declaration: Entity declaration is a part to input the format of interface. In other words, it is a designing unit telling how I/O Port of the digital system connects to the external circuit.

3) Architecture: Architecture is a design unit that explains the relationship between input and output of the tools and describes digital logic that has the designing function

4) Configuration: Configuration is a designing unit that matches the designing unit in entity declaration to the architecture section. Moreover, writing codes can possibility to have various architectures.

However, generally the circuit designed by VHDL is comprised of the two fundamental
C. FPGA Controlling Board

FPGA chip is a kind of semiconductors with the ability to program in the chip or integrate circuit (IC). Its internal connection is metric [3]. The internal structure of FGPA can generally be programmed to function like basic logic gate such as AND, OR, XOR, NOT, and/or in combinations. Apart from being comprised of programmable logic circuit.

Designing the digital circuit with FPGA installed inside the circuit (Print Circuit Board: PCB) assists the designer to decrease the circuit size, save the designing time, design the circuit board without completely testing the internal conditions/functions, and have the ability to input the function of FGPA later. However, FGPA data will disappear after the circuit is switched off. Therefore, it is necessary to have flash memory to retain the data, which has the automatic reading procedure after obtaining from the supply source.

This study used the Altera’s FPGA controlling board, Max II Micro Kit Model, to control the robot movement as there was a requirement to have a controlling part having a fast processor with many ports of input and output. The example properties of the controlling board are as follows: 272 input/output, 2,210 digital logic elements for memory storage, ability to program via USB port directly, and also functioning at 50 MHz frequency.

III. DESIGN AND DEVELOPMENT OF PROGRAMMING

To develop the controlling program, VHDL language was applied to control 21 servo motors; 18 of them were leg parts, while the rest was the head and the wings respectively. The chart showing the robot’s movement control is shown in Figure 4.

The development of the controlling program based on the VHDL from Quartus II programming started from inputting the sequence of leg movement as shown in Figure 1 and then assigning the position of the tip of each leg as designed. Next, inverse kinematic equation was applied to convert the position value of the tip into the degree of each servo motor. Finally, it was next converted into the pulse-width modulation: PWM to further control servo motors.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The preliminarily structure of the Chabata robot is consequently shown in Figure 5.
This research is preliminary divided the experiment into 2 investigations: forward direction and rotating direction. For the first experiment, the robot walked forward from the initial position with the distance of 0 - ~30 cm as shown in Figure 6. As shown in Figure 6 (a), the initial position of the robot has been indicated, while Figures 6 (b) and (c) show the robot movement at the position of ~15 and ~30 cm. respectively. Next, the tip of every leg was measured to find out the movement distance by comparing with the position value of the tip of the legs where the robot was designed to move to in order to find out the possible error. The measurement was then repeated 20 times for the reliability of the developed robot.

It was found from conducting the experiment of the robot’s forward movement for 20 times that, at ~15 cm. distance, its average movement distance was 14.58 cm or 2.77% of the average error, while at ~30 cm. distance, its average movement distance was 31.16 cm. or 3.88% of the average error. The error could be made by 3 factors: the instable torque of the servo motors caused by the low battery, the inefficient measuring tools including the human error in reading the results from the tools, and inefficient materials used to invent the robot.

Later, the experiment on rotating movement of the robot was conducted by inputting the robot to rotate 30 degree from the initial position. Then there was the measurement on the tip of the robot legs to find out the degree the robot could rotate to, compared with the initial position. The measurement was repeated 20 times. The example of the results can thus be seen in Figure 7. As shown in Figure 7 (a) the initial position has been exploited, while Figure 7 (b) shows the rotating position of the robot at the angle of 30 degree.

From the experiment repeated 20 times, it was found that the robot could rotate to the correct position every time. However, when there was the angle measurement at the tip of the robot legs compared with the position the robot was designed to move to, it was found that the average degree the robot moved was 31.45 degree, while the average error percentage of the measurement was 4.83%. The cause of the error was supposed to be similar to that of the first experiment mentioned earlier. Moreover, the error might be caused by the surface roughness, affecting the results of the measurement different from the reality as designed.

V. CONCLUSIONS

The Chabata robot is a six legged robot designed and developed to imitate the movement of the cockroach. Altera’s FPGA controlling board, MAX II Micro Kit Model, was applied via program development by using VHDL programming to control the robot movement. The developed program has 2 basic functions: forward function and rotating function. Inverse kinetics equation was applied to convert the position value of the tip of the robot legs into rotating angle of the servo motors attached to 6 legs of the Chabata robot. It was found from the experiment of the forward movement at the distance of 0 - ~30 cm. that the robot could move correctly with the error percentage of 3.88%. The experiment of the rotating movement at the angle of 30 degree had the average error of 4.83%. The error was caused by the instable torque of the servo motors, the inefficient measuring tools, inefficient materials, and the surface roughness.
REFERENCES


