Gait of Quadruped Robot and Interaction Based on Gesture Recognition

Nguyen Truong Thinh, Nguyen Tan Viet Tuyen, and Dang Thai Son
Department of Mechatronics, Ho Chi Minh City University of Technical and Education, Ho Chi Minh City, Vietnam
Email: thinhnt@hcmute.edu.vn, {ngtvtuyen, dangthaison11144clc2}@gmail.com

***Abstract*—This paper proposed a gait planning for quadruped robot pet. Kinematic structure was established and two-phase discontinuous gait was suggested for straight-line motion of quadruped robot. This system was implemented in a real quadruped pet robot which also embedded smartphone as a powerful computer for data analysis and human-machine interaction based on gesture recognition. Experiment result was carried out to verify the proposed gait planning and the gesture recognition for the interaction.**

***Index Terms*—quadruped robot, smartphone, gait, gesture recognition**

I. Introduction

Legged robotics is a continuously growing technology with more attention focused on dynamic control of such robots during locomotion. Thanks to understanding of locomotion and movement capabilities, motion algorithms can be improve to adapt to more natural dynamic modeled after animal gait patterns. The more complexity of dynamic movements such as walking or running, the more require for computation which demand a high performance process. In the first of 21st century, Smartphone is known as the revolution of technology. Smartphone was inherited results in computer technology, nanotechnology. Smartphones are more intelligent and friendlier. Mobile devices have changed the traditional function as it used to be. Not only using for communication, it has been as a powerful mobile computers with various applications. Smartphone could be used for any complex task, which people have been ever used in computers, with a lower waste-energy and the smoother performance.

In recent years, there are several researchers and commercial products for applying smartphone as an intelligent controller on robots. Based on the Wifi and 3G connection, Swati Tiwari [1] proposed applying cloud computing in smartphone which remove the limit of smartphone on computation power, shortage or battery constraints. Cloud computing on smartphone which also support sharing resources, hardware or software, made smartphone becomes a potential computer for any complex permission. Proposal to apply the simulation motion to analyze human gesture which based on Join Tracking from human Result proved that smartphone performed the high responsibility as well as PC for analysis [2]. In medical fields, Ngai Man [3] successful apply mobile imaging system for early diagnosis of skin cancer. Smartphone is embedded several hardware such as Wifi, Bluetooth and USB connection module, camera and NFC modules. It is also supplied various sensors. Thanks to this supports, robot could be embedded smartphone as a potential computer instead of specialized module. As the result, this paper proposed using smartphone for quadruped robot to perform a particular purpose. Image algorithms are applied to adapt with various human gesture. Mechanical structure of quadruped robot with 13 degrees of freedom is also designed which implemented small size of dog pet. Kinematics of quadruped robot was applied to imitate the dog walking gait.

II. Gait Characteraction

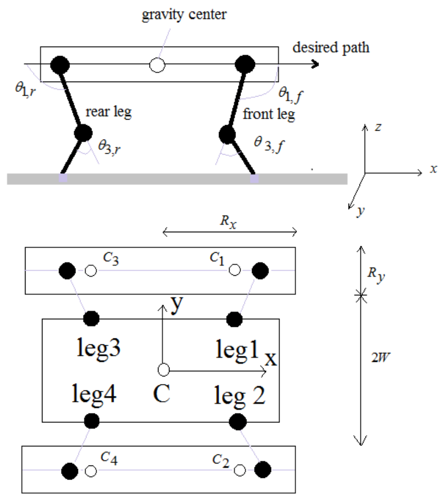

Figure 1. Kinematic model of quadruped robot

Fig. 1 shows the model of the considered quadruped robot. The body coordinate system X-Y is attached to the body center C. X axis is represented for body longitudinal axis. The center of gravity is coincident with the body center C. Each leg has the rectangular working area with the legth R_x and the width R_y and C_i is the center point of the working area of the leg i . $2W$ is the distance between working areas on the left and the right side. In

Manuscript received December 14, 2014; revised March 1, 2015.

doi: 10.12720/joace.4.1.53-58

this paper, we proposed the quadruped robot have straight-line walking where the center of gravity traces on the X-axis and each leg tracks on the middle line of its working area, as the result, the angle between the longitudinal axis of the robot body and the direction of locomotion will be zero [4].

Two-phase discontinuous gait are suggested as an alternative fault-tolerant gait for quadruped robot. Firstly, leg 1 and leg 4 will be moved, respectively. After leg motion, the body is propelled forward half the stroke. The remaining two legs : leg 2 and leg 3 will be moved forward in the next and the body is translated another half the stroke. As the result, after completing a cycle, the body center C has been moved forward a range of $\lambda(r_1)$ which represented for the stride length of the gait with the foot point of leg 1 at r_1 was calculated as under:

$$\lambda(r_1)=\begin{cases} R_X/2 & -R_X/2<r_1\le 0 \\ Rx/2-r_1 & 0<r_1<R_X/2 \end{cases} \tag{1}$$

Consider as the initial gait a creeping slow one: the crawl gait for straight-line walking. This is a statically stable regular symmetric gait which a leg in the air is set down (event φ) before the next one is lifted (event ψ), with at least three legs in the ground contact at all times. Accordingly, the gait event sequence and its timing can be defined using the duty factor β and the relative phase of the left hind left, the gait phase from now on to simplify reading. The relative phases for all the limbs are given by [5]

$$\begin{aligned} \varphi_{LF} &= 0 \\ \varphi_{RF} &= 0.5 \\ \varphi_{RH} &= \varphi_{LH} - 0.5 \end{aligned} \tag{2}$$

In order to have three legs in ground contact at all time, it is further required that the duty factor fulfills $0.75 \le \beta \le 1$ and the gait phase $1-\beta \le \varphi_{LH} \le \beta$ .Fig. 3 shows the gait event sequence for this proposed gait, with the gait event sequence given by

$$\{\varphi_{LF}, \psi_{RH}, \varphi_{RH}, \psi_{RF}, \varphi_{RF}, \psi_{LH}, \varphi_{LH}, \psi_{LF}\}$$

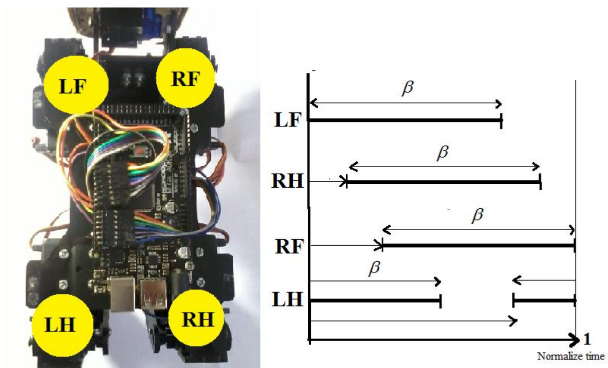

Figure 2. Event sequences for proposed gait.

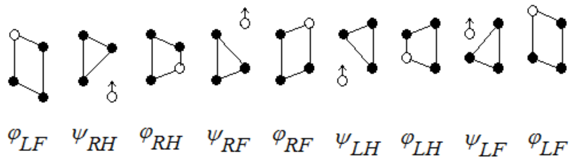

Figure 3. Gait events was represented as sequent frame

III. Kinematic Structure

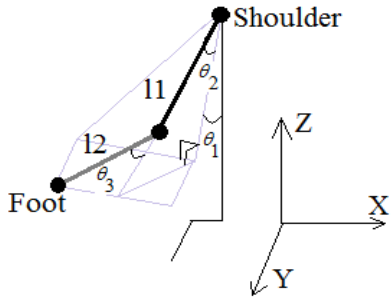

Figure 4. Simple kinematic model represents for left front leg of considered quadruped robot

Fig. 4 shows the left front leg of the proposed quadruped robot. A commonly used convention for selecting frames of reference in robotic application is the Denavit-Hartenberg (D-H) convention [6], forward kinematic problem consist in the calculation of resulting foot position which gives set of joint angles. Finding solution to this problem will allow us to solve the inverse kinematic problem. In this parameter, each matrix homogeneous transformation A_i is represented as a product of four basic transformations. Matrix ${}^{i-1}A_i$ $(i=1,2,3)$ transforms the coordinates of a point from reference frame i into reference frame ($i-1$).

The homogeneous transformation matrix [7] associated to the joint I in the most general case can be illustrated by

$$A_i = \begin{pmatrix} \cos\theta_i & -\cos\alpha_i \sin\theta_i & \sin\alpha_i \sin\theta_i & \alpha_i \cos\theta_i \\ \sin\theta_i & \cos\alpha_i \cos\theta_i & -\sin\alpha_i \cos\theta_i & \alpha_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{3}$$

As the result, the homogeneous matrix that transforms the coordinate of a point from reference frame foot into the reference frame hip is given by:

$${}^{0}A_3 = {}^{0}A_1 {}^{1}A_2 {}^{2}A_3 \tag{4}$$

With the transforms expressed using homogeneous coordinates we obtain:

$$\begin{pmatrix} x_{Root} \\ y_{Root} \\ z_{Root} \\ 1 \end{pmatrix} = \begin{pmatrix} l_2\cos(\theta_1)\sin(\theta_3)+l_2\sin(\theta_1)\cos(\theta_2)\cos(\theta_3)+l_1\sin(\theta_1)\cos(\theta_2) \\ l_1\sin(\theta_2)+l_2\sin(\theta_2)\cos(\theta_3) \\ l_2\cos(\theta_1)\sin(\theta_3)-l_2\cos(\theta_1)\cos(\theta_2)\cos(\theta_3)+l_1\cos(\theta_1)\cos(\theta_2) \\ 1 \end{pmatrix} \quad (5)$$

By using the algebraic approach, the inverse kinematic solution of joint angles θ_i is derived as [8]:

$$\begin{aligned} \theta_3 &= ar\cos\left(\frac{(x_{Root}^2+y_{Root}^2+z_{Root}^2)-l_1^2-l_2^2}{2l_1l_2}\right) \\ \theta_2 &= ar\sin\left(\frac{y_{Root}}{l_1+l_2\cos(\theta_3)}\right) \\ \theta_1 &= ar\tan\left(\frac{z}{x}\right)+ar\tan\left(\frac{(l_1+l_2\cos(\theta_2)\cos(\theta_3))}{l_2\sin(\theta_3)}\right) \end{aligned} \quad (6)$$

IV. System Architecture

Mechanism, which was played an important role for robot's gait, is one of the main concerns of this paper. It also impact to the implementation of control and programming. As the result, by being able to design the robot from scratch, this project was tried to simplify its mechanic behavior allowing for more robust prototype in the sense that we can focus on the main issues which are lightweight and robust.

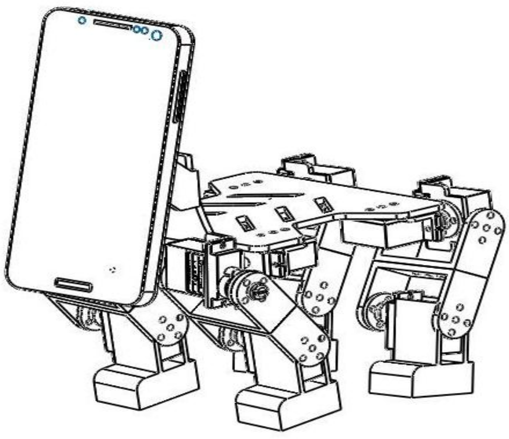

Figure 5. Proposed design of smartphone robot

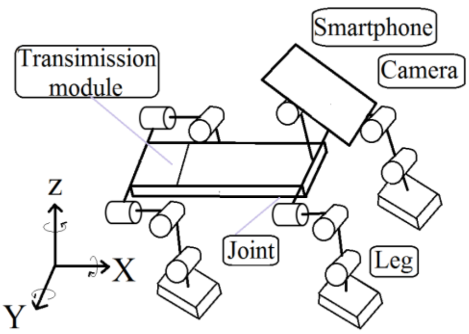

Figure 6. Mechanical configuration of robot

TABLE 1. Specifications of Proposed Quadruped Robot

Size and Weight	
Size	190x85x100 mm
Weight	1.1 kg
DOFs	13
l_1	40 mm
l_2	35 mm
Actuators	
Torque	8 kg/cm for legs
	6 kg/cm for hips
Sensors	
Sensors	Camera which embedded in Smartphone
	3D Accelleration sensors
	Strereo micro phone
CPU_ Using CPU from Android phone	
Clock	1.6GHz
RAM	2 GB
ROM	64 GB
Transsimission Module	
Clock	16 MHz
RAM	8 KB
ROM	4 KB

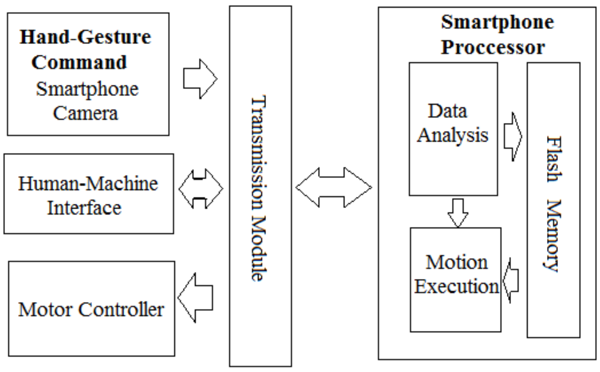

Figure 7. Model of communication between smartphone and Quadruped robot

Mechanical struture design was shown in Fig. 6**,** there are 13 degrees of freedom (DOFs)are implemented in smartphphone robot. In order to realize the normal walking motion of dog, 3 degrees of freedom are adopt to implement the joint of each leg. The primary goal of the mechanical design is to let the implemented robot can imitate equivalent dog walking motion. A mechanical struture is also designed that considered quadruped robot can kick the ball, walk forwad, turn right and left.

Increased complexity and sophistication of advanced walking robots has led to continuing progress in building software environment to aid in the development of robust functionally. The benefit of developing a suitable software environment includes the ability to process the voluminous data which is received from environment. At the first of 21st century, Andy Rubin had built Android Operating System as free and open source software. In Google I/O conference 2011, they introduced Accessory Development Kit (ADK) which is a reference implementation for hardware manufactures. ADK use the Android Open Accessory (AOA) to communicate with Android devices over a USB connection [9].

Fig. 7 shows the overall architecture of the system. The image of field is capture by the camera which was embedded in smartphone, the resolution of input video was 480x800 pixels and ten frames were received per second. In order to build a fully autonomous vision based on dog motion, CPU of Samsung GALAXY S4 which is 1.6 GHz speed played a role as a powerful computer to process images from the environment. Several functions were implemented on CPU to process image smoothly and control the gait of smartphone robot robustly.

V. Experiment and Discussion

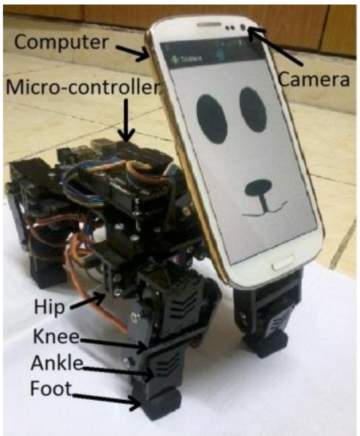

Figure 8. Real quadruped robot for implementation

Base on the mechanical structure and the kinetic structure, the proposed gait had been implemented in real quadruped robot as Fig. 8. Smartphone had been used as CPU for robot. Available camera in Smartphone was used to capture images for gesture recognition. The experiment was carried out indoor to analyze the performance of the proposed image process method and the kinematic model

A. Gesture Recognition Experiment

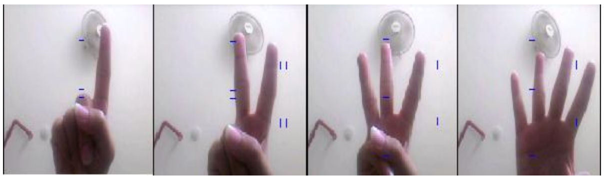

Figure 9. Hand gesture for training

Figure 10. Isolation between desired object and environment.

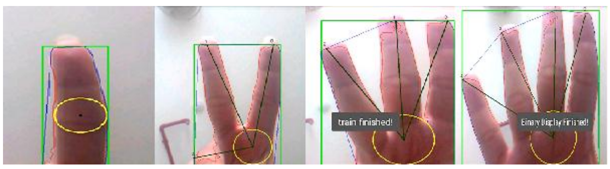

Figure 11. Hand gesture recognition after training.

The simulation was performed in Android phone for skin detection as well as hand gesture recognition. Firstly, group image of human's gesture with different skin tones were used for training. Hand was detected as reference image based on RGB- space. Several small region noises were removed and the binary mask of the hand region is obtained. As the result, algorithms for each desired gestures were established based on border of the hand which adapt to different skin tone and the dissimilarity from particular gesture of various people. Instead of tracking all information as the first frames, it is possible to track the object smoothly by tracking the movement of the hand's border, as the result, the inputted information for analysis was reduced and the performance of image task was improve. The experiment for hand gesture realization proved that trained gesture could be realized exactly in a group of people who are highly similar from skin-color. The hand gesture algorithm's success depends heavily on skin-color. However, the similarity between environment and skin-color was caused the noticeable noises for the image process.

B. Walking Experiment

The basic walking motion: Straight walking was carried out base on the parameter of mechanical structure which contained 13 degrees of freedom and the above kinetic model. Several of variables were modified base on the try and error method. For simplify, we ignore the other three legs. The considered object which drawn in simulation figure is a single leg.

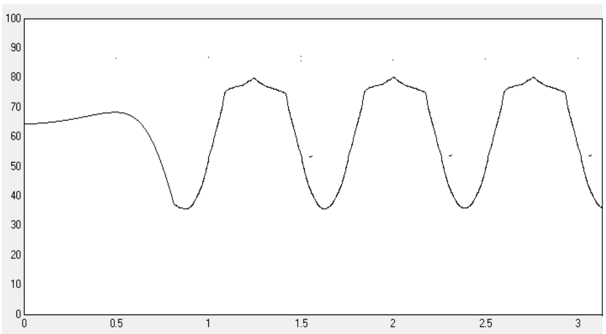

Figure 12. Experiment of hip angle of left front leg.

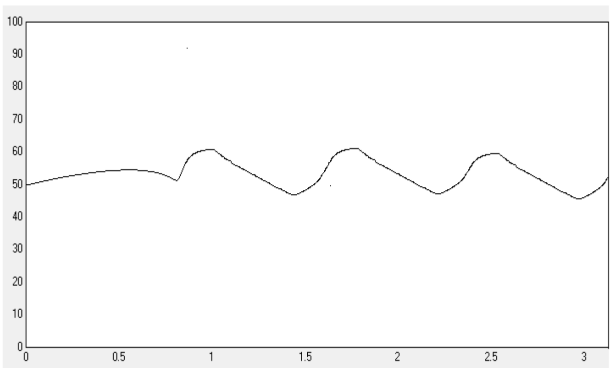

Figure 13. Experiment of knee angle of left front leg.

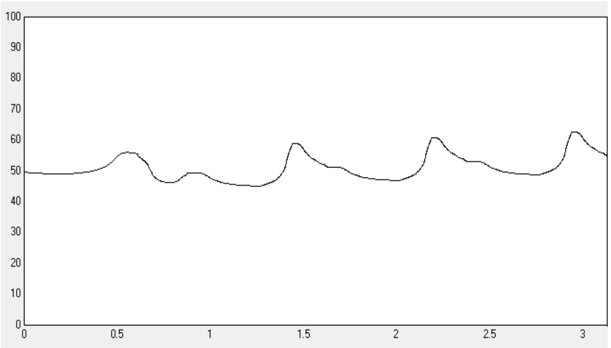

Figure 14. Experiment of ankle angle of left front leg.

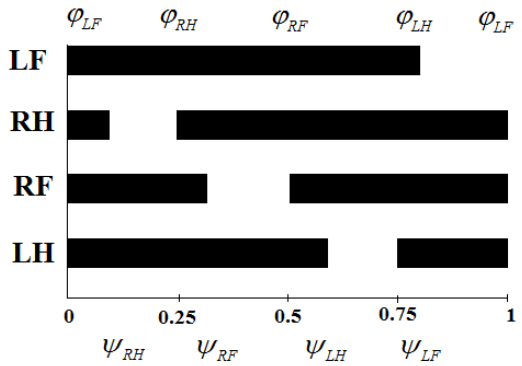

Figure 15. Wave gait of quadruped robot

Figure 16. The sequence of the straigh-walking obtained.

Fig. 16 shows snapshots of straight walking of smartphone robot. The distance between every line is 25 mm. Each period of individual leg, it demanded $\beta = 0.8$ second to complete its performance as illustration of Fig 15. The time for smartphone robot complete fully a cycle is 1 second as the result from equation (2). After completing a full cycle, the coordinate C which represented for body center had been moved forward $\lambda = 25mm$.

VI. Conclusion

This paper has described the implementation of forward motion for quadruped robot. Mechanical structures were designed and the kinematic structures were established based on mechanical parameter. We proposed using two-phase discontinuous gait for straight line walking of quadruped robot. Smartphone also applied as a CPU to solve the human-machine interaction based on gesture recognition, behavior from quadruped robot as a feedback for human's gesture based on the communication between smartphone and quadruped robot. The experiments and analysis carried out on quadruped robot, the result convince that proposed gait was appropriated considered gait although several joint angle variables also slightly modified to make the reliability of straight line walking. A few algorithms also applied in image process for gesture recognition, the experiment convinced that hand gestures which had been trained for quadruped robot could be realized exactly in group of people who are highly similar from skin color. The proposal could be applied absolutely in smartphone to make the more flexible approach in using CPU for entertainment robot.

Acknowledgment

Special thanks are given to Department of Mechatronics and in particular to Mechatronics Laboratory in Ho Chi Minh City University of Technical and Education for helping us all along the project of application of smartphone for quadruped pet robot.

References

[1] S. Tiwari, "Energy consumption of smartphone using multimedia cloud computing," *International of Journal of Adavance Research in Computer Science and Management Studies*, vol. 2, July 2014.

[2] N. J. Kwak and T. S. Song, "Joint tracking and transmission for simulation motion of the human body on android smart phone," *International Journal of Control and Automation*, vol. 4, no. 4, December 2011.

[3] Bourouis, M. Feham, and M. A. Hossain, "An intelligent mobile based decision support system for retinal disease diagnosis," *Decision Support Systems*, vol. 59, pp. 341-350, March 2014.

[4] J. M. Yang, "Two-phase discontinuous gait for quadruped robot walking machines with a failed leg," *Robotics and Autonomous Systems 56*, pp. 728-737, 2008.

[5] C. P. Santos and V. Matos, "Gait transition and modulation in a quadruped robot: A brainsten-like modulation approach," *Robotics and Autonomous Systems 59*, pp. 620-634, 2011.

[6] P. G. D. Santos, E. Garcia, and J. Estremera, "Quadrupedal locomotion: An introduction to the control of four-legged robots," *Springer Press*, pp. 143-146.

[7] M. W. Spong, "Modeling and control of elastic joint robots," *ASME Journalof Dynamic Systems, Measurement, and Control 109*, pp. 310–319, 1987.

[8] (2003). Diploma Thesis. Quadruped Walking model-ing and Optimization of Robot Movements. [Online]. Available: http://uwe-dueert.de/publication/dueert04diploma.pdf

[9] M. Bhmer, "Beginning android ADK with Arduino," Apress, 2012, pp. 33-100.

Nguyen Truong Thinh received B.S degree in mechatronics engineering from University of Technical, Viet Nam in 1985. He received M.S and Ph.D, degrees in Robotics from Cheonan University, South of Korean in 1990 and 1995, respectively. He currently is an Associated Professor with the Department of Mechatronics, Ho Chi Minh City University of Technical and Education. His research interests in service robot, industrial robot and computer vision.

Nguyen Tan Viet Tuyen is studying B.S degree in mechatronics engineering from Ho Chi Minh City University of Technical and Education .In 2014, he joined Mechatronics Laboratory at Ho Chi Minh City University of Technical and Education as software engineering. His interests are in service robot, automatic control, computer vision .

Dang Thai Son is studying B.S degree in mechatronics engineering from Ho Chi MinhCity University of Technical and Education .In 2014, he joined Mechatronics Laboratory at Ho Chi Minh City University of Technical and Education as automatic control engineering. His interests are in service robot, automatic control.