Colloquium on Robotics, Unmanned Systems And Cybernetics 2014 (CRUSC 2014)
Nov. 20, 2014 at Universiti Malaysia Pahang, Pekan, Pahang, Malaysia

Combination of Transverse-Trot Gait Pattern for Quadruped Walking Robot

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Abstract—This paper presents a combination of transverse and trot walking pattern technique for hexa-quad robot after transformation to optimize the multi-legged robot operation and walking performances. Due to the limitation on the stability of hexapod robot, the combination of hexa-quad walking sequence is proposed to stabilize the quadruped configuration and walking modes. Quadruped robot configuration is stand within dynamically and statically stable criteria if compare to the hexapod robot that has only statically stable criteria. Thus, it is very crucial to have a stable walking sequence technique during walking and operation session. Therefore walking sequence technique to perform for hexa-quad transformation is proposed based on robot's Center of mass (CoM) and defined support polygon on positioning the leg in transformation process. A real-time based model of hexapod robot control architecture with proposed walking sequence is designed and validated using separated 3 dimensional (3D) simulators. The analysis of robot stepping foot motion is done to verify the desire designed walking sequences and the Body Mass Coordinate (BMC) is analyzed for way point of robot walking.

Keywords - Hexa-Quad robot, Centre of Mass, support polygon, robot.

1. Introduction

Recently, many researches had shown an increase interest in multi-legged robot. Many applications is endangered for human to be involved. Thus, legged robots have wide range of applications and used in many tasks that cannot accomplish by wheeled robots [1]. Quadruped robots have high adaptability and flexibility. It not only can walk on flat terrain and also move in unstructured terrain [2]. There are two parts of stability studies for quadruped robots which are statically stable and dynamically stable. The stability of the robot will ensures that whatever speed the robot can reach. Locomotion is one of the basic function to control the stability of the robot [3]. The legs of the robot is the main strategy to accomplish the locomotion [4].

Based on the study of reconfiguration of hexa-quad transformation, the walking pattern of the robot is crucial since the walking locomotion is the fundamental problem to be solved for all walking robot during their operation. The development of walking pattern is a challenging task because it needs to consider the degree of freedom (DOF) and the Centre of mass (CoM) within the support polygon pattern of the robot which control the stability of the robot. [5]. According to Uchida H. *et. al* research studied that using mine detection to realize the stability walking of the six-legged robot by considering the attitude control method with the hydraulic actuator. This proposed technique involved the thigh driving torque of every supporting legs and the outputs are the height of the robot's body and the pitching and rolling angle. On the other hands, Tsujita K. *et. al* has overcome the timing problem between varies gait pattern which involve transverse, rotary, pace, bounce and trot gait pattern for quadruped robot. In this studies considered the analysis on the suitable gait pattern for the quadruped robot by proposed the adaptive control [4]. A considerable amount of studies has published about the robot leg failure strategies and the solution to solve the legs failure problem. Yang J.M. *et. al* studies used the term fault tolerant for their alternative gait pattern which proposed the periodic quadruped and hexapod gait that to considered the analysis of the joint failure of the gait pattern so that to control the stability of the robot. [6]. More recently, Yang J.M. do proposed a scheme to overcome the problem on the leg failure by retaining the fault tolerant of the gait pattern. Each joint of the robot's legs joint should lock individually associated to the damage motor so that the locked joint legs could be used for the support rather than moving. Apart from that, Tsujita K. *et. al* discussed the control of motion of quadruped robots with emphasis the dynamics gait of robot's transition control. This paper make a study on investigate the relationship between the locomotion speed which involved transverse and trot locomotion speed and the stability of the locomotion. The studies make analysis on the roll and pitch angle. The stability of the robot locomotion is examined that the roll and pitch angle are concentrate at a fitness point that proven that the locomotion is considered stable. Other effort has been done by proposed the gait regulation technique to increase the robustness in multi-legged robot walking pattern. For a single duty of a developing gait pattern, need just ignore the kinematic mapping and the consideration of keep more legs contact with the surface. Due to the limitation recirculation speed, the trot and tripod gait pattern can perform signification faster than other[7]. According to the lift and release probabilistic events [8] for each leg of

ISBN 978-967-0691-42-8

legged robot, tripod pattern for hexapod robot is less and producing faster movement.

Quadruped robot is considered in between dynamic and static stability which needs a combination of suitable walking pattern. Therefore, in this paper, the combination of transverse and trot walking pattern has been proposed for the quadruped robot. The combination of the transverse and trot walking pattern is depending on the foot motion and end-effector movement of the robot legs so that the CoM is within the support polygon pattern.

2. Walking Pattern and Shoulder-Based Coordination System

Shoulder-based coordination system (SCS) was established implemented in the previous progresses for hexapod configuration such reported in [9, 10] but not for quadruped configuration. For the quadruped robot, the combination of transverse and trot walking patterns [4] are proposed for the quadruped walking algorithm. The sequences of the legs for quadruped are presented in finite state machine (FSM) as shown in Fig. 1 on quadruped combination of transverse-trot walking pattern is used to perform walking with minimum area of support polygon in quadruped robot stability.

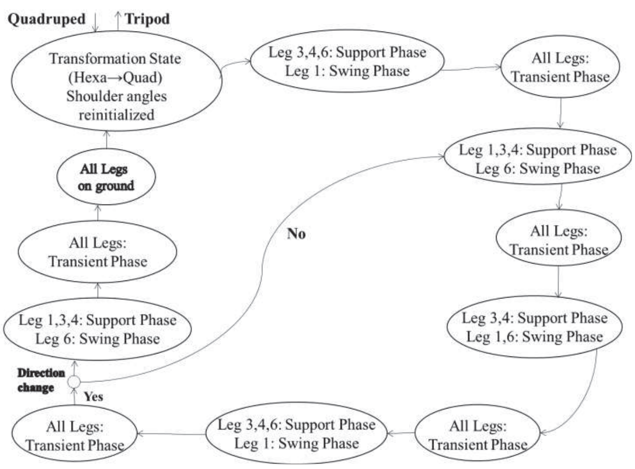

Fig. 1: FSM for quadruped traverse-trot walking pattern

The Quadruped Walking Sequence (QWS), which are the relationship between motions of the legs, are designed. There are two gait patterns that combine to form a statically and dynamically stable walking pattern for this quadruped robot. For this proposed walking pattern that maximum legs contact with the ground is two legs at a time which is the combination of transverse and trot gait pattern during locomotion.

For the transformation walking pattern, the combination of transverse and trot gait patterns are proposed for the quadruped walking algorithm. The sequence of the swing legs are represented by the white circles and the black circles represent stay legs which shown in Fig. 2.

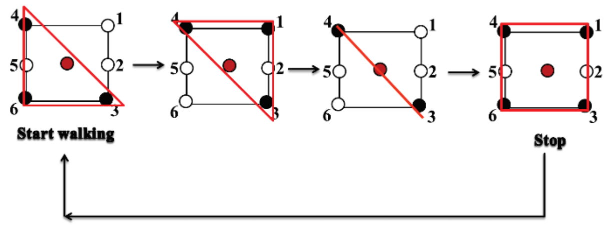

Fig. 2: Proposed Combination of Transverse and Trot QWS

After transformation, the walking gait patterns proposed is depending on the support polygon and the CoM of the robot. At different transient has different support polygon and CoM. The shape of support polygon depends on the stay legs and the CoM will not always at the center. It depends on the movement and the support on the ground. Therefore it will slightly near to the support stay legs This method walking patterns is proposed so that the walking velocity of the robot will not slow and maintaining the stability of the robot. The Fig. 1 shows the FSM of the foot motion of the quadruped robot following the sequence of legs lifting and placing.

In Fig. 1, from the hexapod to quadruped, the 1st sequence is 1st leg swing phase followed by 6th leg swing phase. The sequence followed by the 3rd and 4th legs together as swing phase. For the next sequence, it followed the 1st sequence as 1st leg in swing phase. The transient phase is added for each sequence so that to prevent the legs hitting each other. The system will reset when the walking direction changed. As shown in Fig. 1, in transformation state, θ_a is changed and used on both x and y position of leg on the next sequences. x and y for each n-leg are part of moving frame and kinematics element for each link on each leg as shown in Fig. 3. Both positions including vertical leg position (z) is determined differently in each support and swing phase by using Eq.2 and Eq.3 respectively. Both Eq.2 and Eq.3 were created to realize the motion shape as shown in Fig. 3. This motion shape is important for the force control implementation on each robot foot for walking on irregular terrain. As shown in Fig. 4, (1) leg standing up, (2) swing phase (first step), (3) support phase, and (4) swing phase (next step).

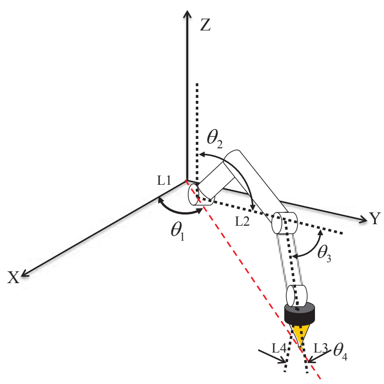

Fig. 3. SCS trajectory kinematics motion for a 4-DOF leg of hexapod robot model

(Support Phase – Step and push on the ground) $0 \le t \le \frac{T_c}{2}$

$$x_{s_n}(t) = x_{0_n} + \frac{S_o}{4}\left(\frac{2t}{T_c} - \frac{1}{2\pi}\sin\left(\frac{4\pi t}{T_c}\right)\right)\cos\theta_{a_n}$$
$$y_{s_n}(t) = y_{0_n} + \frac{S_o}{4}\left(\frac{2t}{T_c} - \frac{1}{2\pi}\sin\left(\frac{4\pi t}{T_c}\right)\right)\sin\theta_{a_n}$$
$$z_{s_n}(t) = z_{0_n} \quad (1)$$

(Swing Phase) $0 \le t \le \frac{T_c}{2}$

$$x_{s_n}(t) = x_{0_n} + \frac{S_o}{2}\left(1 - \cos\left(\frac{2\pi}{T_c}t\right)\right)\cos\theta_{a_n}$$
$$y_{s_n}(t) = y_{0_n} + \frac{S_o}{2}\left(1 - \cos\left(\frac{2\pi}{T_c}t\right)\right)\sin\theta_{a_n} \quad (2)$$
$$z_{s_n}(t) = z_{0_n} + H_0\sin\left(\frac{2\pi}{T_c}t\right)$$

where

T_c = walking cycle time (s),
t = update time (real-time) (s),
t_{ex} = additional period for applying extra force (s),
S_0 = distance of foot placement for one cycle (m), and
H_0 = height of leg lift from the initial position (m).

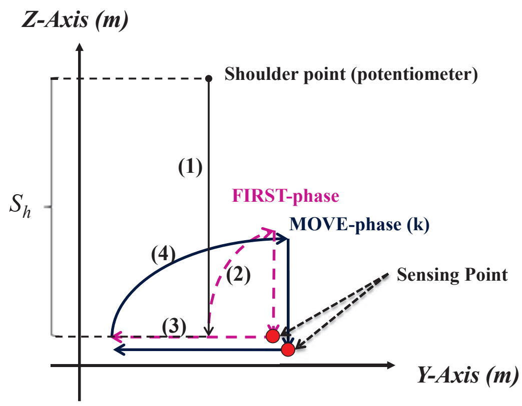

Fig. 4. A leg motion shape used in proposed model Hexa-Quad robot.

3. Simulation and Result

The walking algorithm for the proposed QWS is simulated in the state flow. The supporting legs and the swing legs are separated in the state flow. The input is given to the swings legs so that it can swing and move forward and placed back to the ground. The shoulder angle for every direction has different of the shoulder angle.

Fig. 5 shows the results after the design walking sequence in the simulator. The QWS is shows in the 3D simulator follow the sequence successively. Fig. 4 (a) is the proposed QWS with the stop mode followed by the proposed QWS of 1st leg swing leg as in Fig. 4 (b). The proposed walking technique at 6th swing leg and Fig. 4 (d) is the third sequence of 3rd and 4th leg swing leg. The stepping foot motion of the transformation robot is analyze by studied from the graph. The beginning of each leg will have a trapezium shape. These show the robot at initial at sit down position. The trapezium represented the robot at stand up position. The triangle shape represented which legs is at swing position which away from the ground when its walk at the flat terrain as shown in Fig. 6 (a), (b), (c), (d).

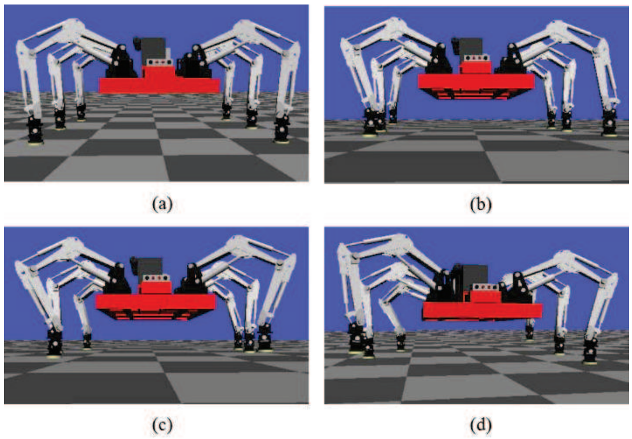

Fig. 5: The Proposed QWS in 3D Simulator (a) robot at stop mode, (b) 1st Leg swing phase, (c) 6th Leg swing phase, (d) 3rd and 4th Leg swing phase

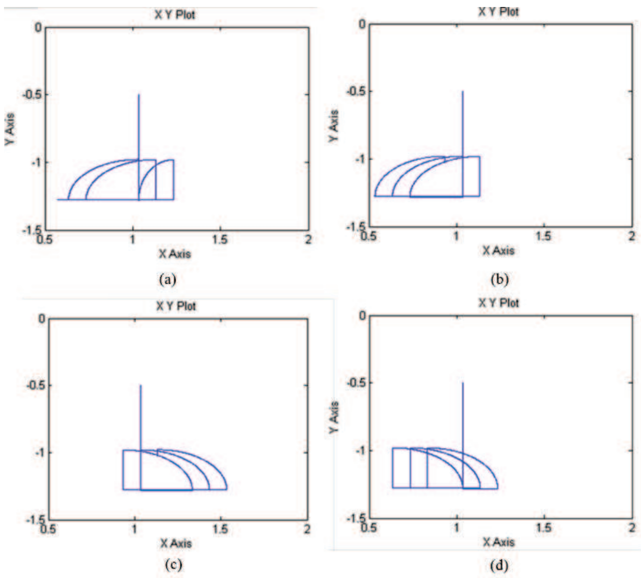

Fig 6: Stepping Foot Motion of Proposed QWS (a) Leg 1, (b) Leg 3, (c) Leg 4, (d) Leg 6

For the end-effector Movement point, the leg motion shape is plotted for y and z axis of each leg motion. From this analysis, the stability can be observed from the graph. Each leg show the different leg motion shape. The leg motion shape depends on each leg motion either in swing phase or in support phase as in Fig. 6 (a), (b), (c), (d).

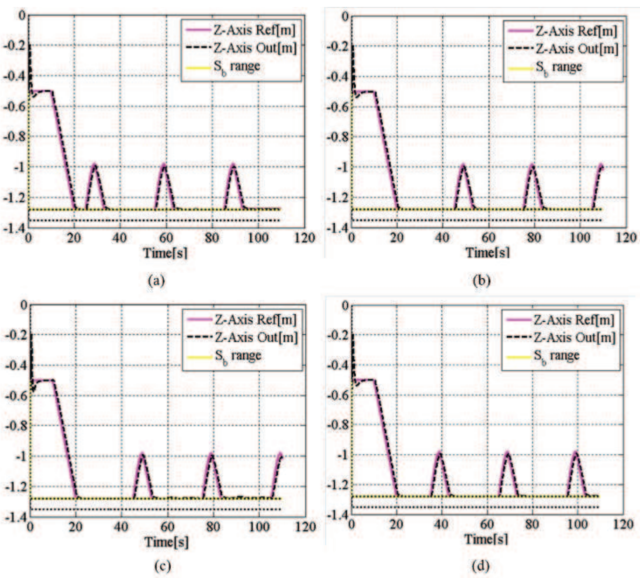

Fig 7: End-effector Movement Point of Proposed QWS (a) Leg 1, (b) Leg3, (c) Leg4, (d) Leg 6

During the support phase, the leg is at drag so that the robot can be move forward. The swing legs will step astride to forward direction. During the leg drag, the shape is showed at horizontal while the move phase is showed as half hemisphere as in the Fig. 7(a), (b), (c), (d). Quadruped mode walking is verified by simulating the performance of robot CoB with shown in Fig. 8. The CoB represented the body way point of the quadruped robot. Straight line of the BMC shows that it is detecting in only a direction not omnidirectional.

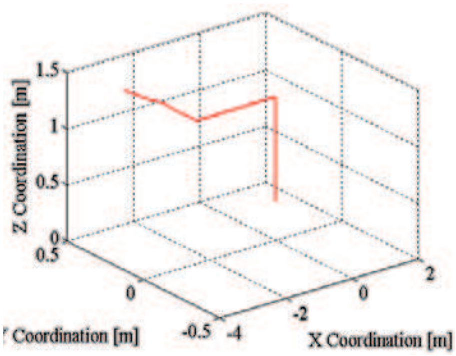

Fig 8: Body Mass Coordinate of Proposed QWS Way Point

4. Conclusion

In the conclusion, the concepts support polygon pattern and the CoM in the consideration of transformation technique which the robot disable the two legs from the others that to configure in the quadruped configuration. The algorithm of reposition transformation technique hexapod robot to quadruped is design by investigate quadruped walking gait design with considering the stability of the robot depends on the CoM and support polygon of the leg position in transformation process. A real-time based model of hexapod robot walking algorithm is designed in the core control architecture with proposed hexapod-to-quadruped transformation and validated using separated 3 dimensional (3D) simulators.

Acknowledgement

I would like to thank the Research and Innovation Centre, University Malaysia Pahang on funding support on this research project. A very appreciate thanks to my supervisor, Dr. Addie Irawan Hashim regarding his support and guide on this research project.

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