

A Quadruped Robot with the Wooden Body for Static Locomotion in a Controlled Environment

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Abstract

We present the design and overall development of an eight degrees of freedom (DOF) based *Bioinspired Quadruped Robot* (BiQR). The robot is designed with a skeleton made of cedar wood. The wooden skeleton is based on exploring the potential of cedar wood to be a choice for legged robots' design. With a total weight of 1.19 kg, the robot uses eight servo motors that run the position control. Relying on the inverse kinematics, the control design enables the robot to perform the walk gait-based locomotion in a controlled environment. The robot has two main aspects: 1) the initial wooden skeleton development of the robot showing it to be an acceptable choice for robot design, 2) the robot's applicability as a low-cost legged platform to test the locomotion in a laboratory or a classroom setting.

Keywords: Bio inspired robot, legged Robot, locomotion, position control, walk gait, wooden robot.

1 Introduction

Nature has always inspired us with a lot of ways to improve our understanding of it, and to make use of the learning in order to improve different aspects of human life. In science, bio inspired robotics broadly deals with taking ideas and inspiration from nature. It involves development of robotic systems through the scientific processes available at hand. A lot of work has been done since the last few decades in the area of bio inspired robotic systems, and previous works¹⁻² can be considered as brief resources that can help to provide general familiarization with some of the prominent advancements bio robotics has made historically.

Legged creatures found in nature provide us with ideas of systems that can have versatile mobility in unstructured environments³. Previously, significant efforts have been done in order to replicate design and locomotion of legged creatures found in nature through developing similar artificial systems. The robots⁴⁻¹¹ reported earlier are some of such artificial systems with applications ranging from search, inspection, and security to multipurpose applications. Based on the targeted application, these robots

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employ various design and control approaches. In terms of design, like in most designing practices, robots are desired to have minimum self-weight with maximum output with respect to a task/application for an energy efficient use. In this paper, we explore possibilities of designing a four-legged bio inspired robotic system made of wood. This robot that we call BiQR – Bio inspired quadruped robot, has a skeleton made of cedar wood. It has 8 degrees of freedom (2 at each leg) available through 8 servo motors in order to achieve basic static locomotion in a designed environment. We used inverse kinematics based position control to obtain the walk gait implementation. Most of the system components are designed and fabricated locally using off the shelf components hence making the system low cost and meeting the desired physical specification with respect to the desired size, the weight and the demonstration of the walking gait. Figure 1 shows an overview of BiQR robot.

This paper consists of five segments. After introduction, we briefly discuss the design and control methods used to realize BiQR. In experiments, we have implemented a two-stage methodology to obtain static walking trajectories (we have also explained walking patterns that were aimed to be implemented using our robot) for all the robot legs; implementation of gait pattern at one leg, and expanding results to all the four legs of BiQR in order to implement the static walk gait. Finally, we conclude with a discussion of results followed by the conclusion and the future work.

2 BiQR – A Bioinspired Quadruped Robot

2.1 The Design

Four legged robots that are inspired by four legged animals are usually large, can able to perform certain level of mobility on an uneven terrain, and are complicated systems with yet to achieve a number of standard criteria of four-legged locomotion^{1,11}. Efforts from the recent past show that such systems are either too complicated to bring to a wide general audience or they lack some of the practical situations¹. This work is aimed at developing a low cost four-legged system with potential of being used within academic research community and by the general audience with interest in four-legged static

locomotion. Its simple construction and flexible design allow several possibilities ranging from its use as laboratory teaching experiment setup to testing different algorithms in control system design. Table 1 shows general specification of the BiQR robot. Like many other quadrupeds, design inspiration for BiQR comes from learning interesting biology that includes anatomy and walking behaviors of cats and dogs – widely studied four legged animals by a lot of areas in science⁶. It is an electrically actuated robot with a size similar to a small cat. Electrical actuation was chosen due to relative low costs, higher efficiency, and to make overall system all-electrically driven. Out of several options of materials, wood was chosen based on our interest to explore possibilities of using wooden skeleton that can hold all electronics and actuators installed in the robot. Furthermore, some general properties indicating wood to be a moderate choice for its use in different applications are identified¹³, though its use is not extensively explored in robotics.

Given the options of making a single leg work with 2 or 3 DOF, we chose 2 DOF in order to simplify the design. With simplification, although control became easy but at the disadvantage in the form of reduced versatility. Nonetheless, within the scope of this work, 2 DOF provide enough support to execute a static walk gait movement. The overall design is oriented to support following performance criteria:

- The capability to perform the static walk gait, and flexibility in design that supports possible addition of other gaits
- The capability to move over plain and slightly rough surfaces without changing the presented robot configuration
- An open loop implementation of a gait pattern that should allow the stability in walking

The robot's design is implemented in two stages. First, we have designed a bioinspired prototype leg using the Creo Parametric sketching module. Figure 2 shows an overview of the prototype leg in 3D and its realized form. Each leg has two joints: hip and knee. Whereas, we have used a pair of MG 996R

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servo motors with a torque of up to 11 kg.cm or a little over 1 Nm to hold a leg link (total link length of 80 mm by the each servo motor). Both actuators can provide an angular range of up to 270° rotary motion to design desired foot trajectory. Tip of the feet has a rubber pad that helps in reducing the drag on ground.

2.2 The Control Methods

To control BiQR, we have formulated a simplified form of inverse kinematics that helps in mapping known angles to get a desired trajectory at the end effector – robot feet. Arduino mega controller board was used due to its enormous available open source support and ease in use. Figure 3 shows an overview of the system component level diagram. Arduino mega board provides data read and data write connection to all 8 servo motors that are providing circular motion with possible available joints positions based on kinematic solution. Different behaviors to drive rotary joints (electrically actuated DOF) are defined based on the kinematics solution which is presented briefly in the following.

For a 2 DOF based link length, a mathematical interpretation can be deduced following the graphical representation given in Figure 4 and 5. Considering inverse kinematics a good tool to solve basic kinematics of BiQR, we can find joint angles (e.g. Φ_1 , Φ_2 , Φ_3) by knowing positional information (P_x , P_y , P_z) of the end-effector.

With the known x, y, and z points in 3D space, joints angles are:

$$\Phi_1 = \sin^{-1} [z/A],$$

and

$$\Phi = \sin^{-1}(\sqrt{x^2 + y^2}) - \tan^{-1}2(y, x)$$

Finding these angles with a known desired trajectory position of end effector (robot feet edge here) in a 3D space provides an complete solution to translate those angles through the control board to the servo motors. For the legged animals, in order to achieve a walking behavior, end effector (feet edge) should make a trajectory identical to an ellipse². Usually, this semicircular and more of an ellipse tra-

jectory is the desired path that the end effector must follow in order to make a DOF based legged robotic system perform a walk or more dynamic gait behaviors.

The presented robot configuration of all rotary joints is such that each can also move independently in addition to the simultaneous movements of all joints. This adds to more flexible design options. In order to design a control scheme for the presented robot configuration, we could use both open and close loop control. An open loop position control that feeds the known range of angular values directly to the actuators without any external feedback was implemented.

3 Experimental Results

3.1 The Experimental Setup

The overall experimental setup included a fixed single leg testing platform. This allowed the robot leg to have a fixed hip actuator base. Initially the robot leg was hanged tightly above the ground in order minimize damage in case of unwanted motor behavior. An arduino mega board running C programming based instruction set was used as the system controller. In the software, we provided the behaviors based on the various pulse width modulated (PWM) signals to the servos, whereas a Li-Polymer direct current (DC) battery (12V) was used with a separately fabricated 12 to 5 volt (DC-DC) converter to provide the power to the robot components. Figure 6 shows an overview of the designed converter.

To actuate one side of the robot - 2 legs motion test, similar testing platform was used to keep the legs hanging firmly from the other side in order to observe the walking trajectory. This was to tune the leg movement in a synchronized manner. The experiments were performed with using the open loop control to obtain the desired robot walking.

3.2 The Single Prototype Leg Test

In order to use inverse kinematics based joint values, a trajectory was initially proposed. Figure 7 indicates the single leg trajectory when it was mounted on a fixed platform. Useful motor angle ranges with current motor configuration (all the four motors on each side are mounted with a specified initial

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angular position and hence have different useful angles though the same in reciprocity for the opposite side. See figure 1 (c) for the motor configuration) are following:

- Range of angles at the *hip joint* on one side: 131 (degrees) to 145 (degrees); with $+1^\circ$ per time unit increment.
- Range of angles at *knee joint* on one side: 131 (degrees) to 145 (degrees); with an increment of approximately 6° at each run.
- Range of angles at *hip joint*: 44 (degrees) to 58 (degrees); with $+1^\circ$ per time unit increment.
- Range of angles at *knee joint*: 44 (degrees) to 58 (degrees); with an increment of approximately 6° at each run.

A graphical illustration of these motor rotations is illustrated in Figure 9 for the pairs of servos on both sides of BiQR. These values provided a closer to an ellipse-like toe trajectory. The hip joint moved slower whereas the knee joint used the same joint angle values but moved faster. This resulted in the robot toe following a closer to an ellipse trajectory.

Furthermore, a frame by frame depiction can also be seen in Figure 8 with image sequence extracted from a camera video recording.

3.3 Implementation of the Walk Gait

From the single leg experiments, results were expanded to all the four legs which lead to implementation of the walk gait. As it is known that the legged robots show more stable mobility with higher number of ground contact points². With four legs, walk gait is suitable to allow a legged robot to move one step at a time (In BiQR's case, 3 legs in the stance phase, and one leg took a step followed by the second leg of the same side and so on). A graphical illustration of walk gait with indication of how PWM signal from controller board was modulated is shown in Figure 10. We used time delay function to appropriately tune the walk gait. Each step copied the walk gait pattern such that each step is matched according to its defined number based on our computer program. With the presented robot configuration

and code design which is based on PWM definitions shown in Figure 10 (e), each toe of BiQR was able to lift up to the height of 0.4 inches (approx. 1 cm; sufficient for the very low altitude to avoid the drag over the ground surface). For more practical purposes, this height can be adjusted by manually tuning the PWM signals with newly defined toe trajectory. Figure 11 shows the foot height graph, whereas Figure 12 illustrates the step walk sequence taken at run time, and synchronized motion which is exhibiting simultaneous static walk trajectory generation.

4. Discussion

Electrically actuated low-cost legged robots such as BiQR with wooden skeleton that are driven through position control are good to handle a limited scope of implementation as compared to their counterparts - hydraulically actuated or force controlled legged systems¹⁰. However, we observed from the robot walking experiments that they can be sufficient to match the locomotion needs under low intense conditions.

We also identified a few problems such as jittery motor motion which was due to the limitation of the used servo motors when tested beyond the torque ratings with a payload. This mechanical jitter-based fault could be troublesome for a position control strategy; however, continuous track of mapped angular positions can be useful to retrack the motor position and deal with such perturbations. For the available workspace across each joint, the robot walk gait was insufficient in terms of providing a good enough feet height to climb obstacles. The idea of using a body height adjustment-based algorithm to make the robot perform dynamic motion could be utilized. Also, advanced forms of control algorithms can be explored to obtain advanced robot postures as well as specific movements¹².

5 Conclusion

In this paper we have presented a low cost bio-inspired quadruped robot – BiQR. The robot used electrical actuation based position control, and had a skeleton made of cedar wood. With a compact design, robot was tested to perform the *walk gait* in a controlled environment. Inverse kinematics for a 2

DOF segment was modeled and used to actuate the single leg experiment. The single leg experiments of walk gait were mapped to all the four legs and the results were shown. Application prospects of the robot include its use as a low-cost test bench in an introductory robotics class.

On a broader level, the current version lacks some essentials that a quadruped must have for the versatile mobility. However, with an upgradation of the controller i.e. more bandwidth and computation capable controller, high torque, robust and efficient actuators, and most importantly a highly dynamic and optimized feedback-based gait design, the robot perform locomotion in complex environments.

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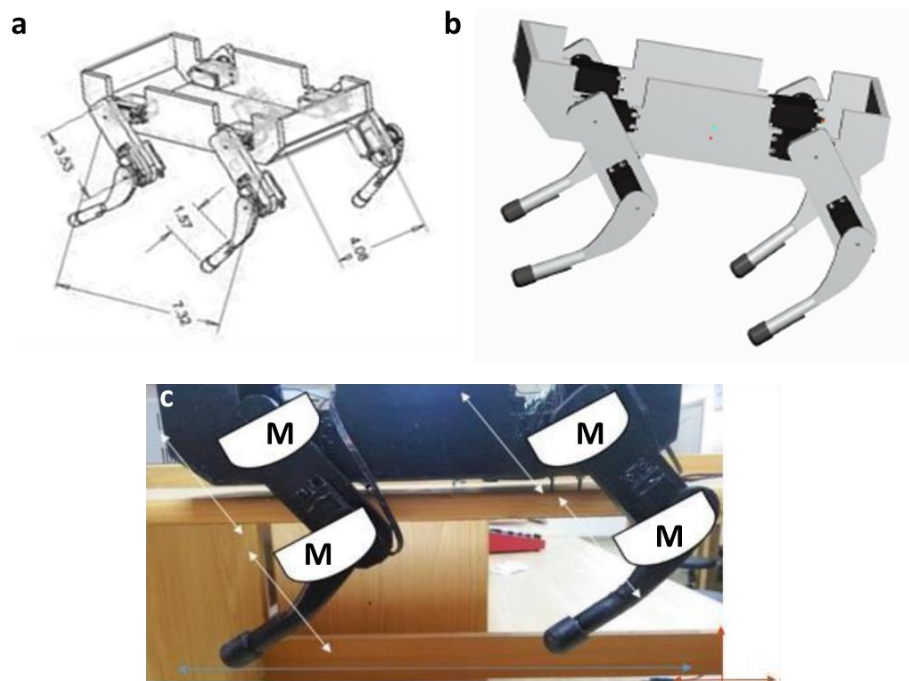


Figure 1 BiQR: Bio inspired Quadruped Robot: a) the drawing of the robot. b) the *Creo parametric* based CAD model of the robot. c) a side view of actually realized robot with the indication of the hip/knee motor joints.

Table 1 Specifications of BiQR

Main body dimensions	Length = 305 mm, Width = 127 mm
Weight	1.190 kgf (Completely assembled)
Active DOF	8; 2 per leg (all electrical)
Available range of motion	0-180-270 (degrees)
Electrical actuation	DC Servo motors (MG996R)
Onboard controller	Arduino (mega)
Sensor	A distance measuring module
Power	Li-Polymer battery (12V)

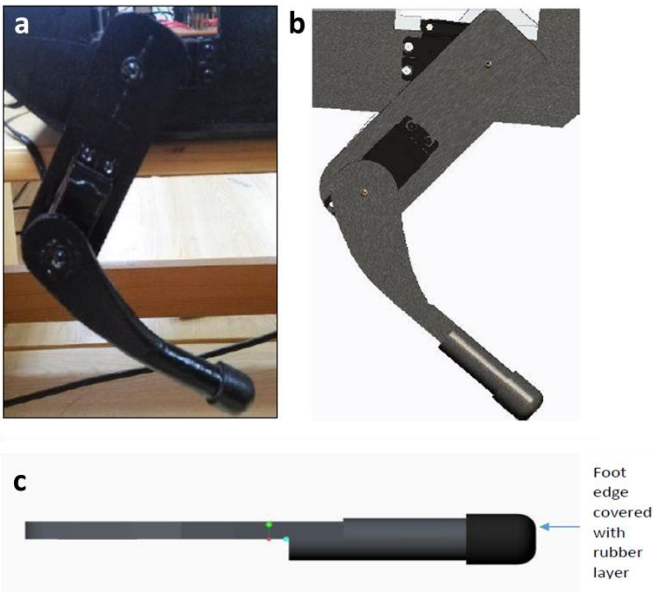


Figure 2 An overview of the 2 DOF prototype leg with mounted actuators. (a) shows the real robot leg, (b) shows the CAD model, whereas (c) shows a 3D side view of the robot leg indicating rubber toe of the robot leg. Note: Manufactured robot was spray painted to stop absorption of atmospheric moisture into wooden assemblies.

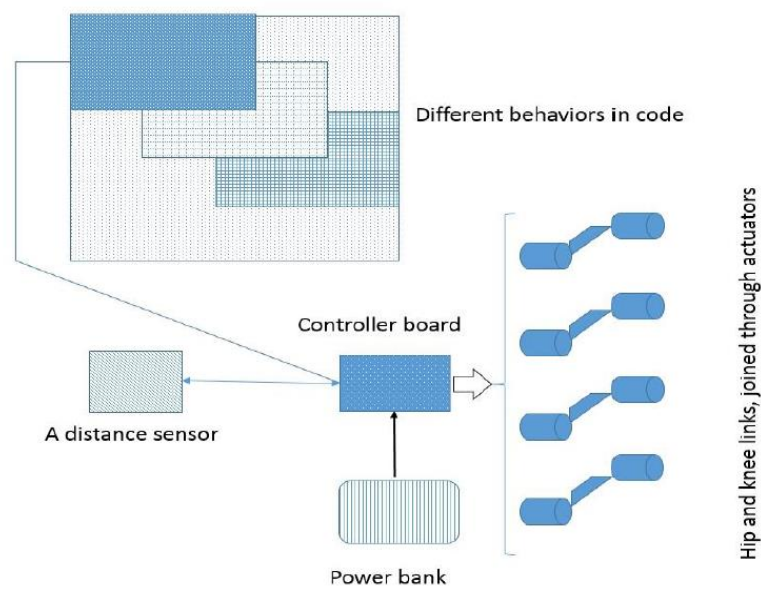


Figure 3 A component level system overview.

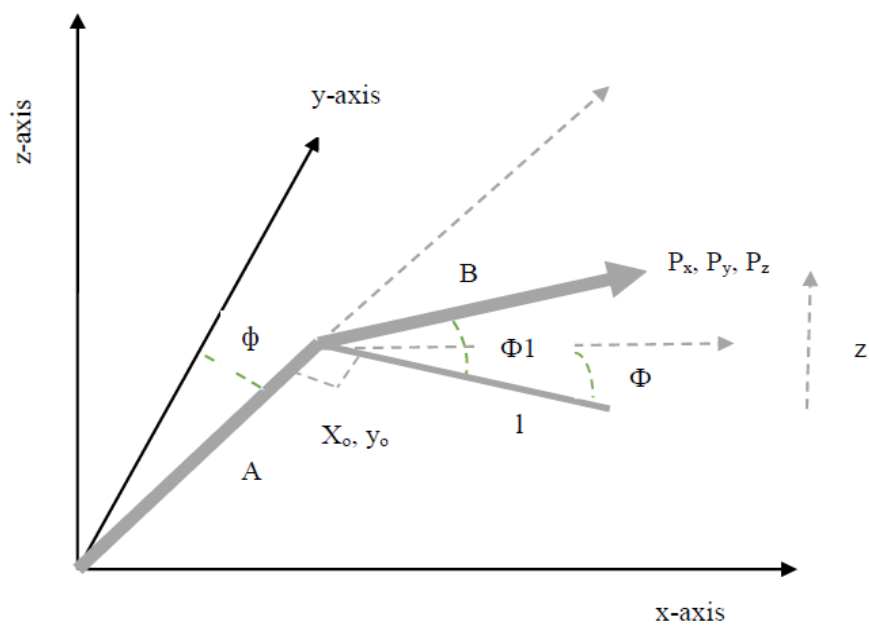


Figure 4 A symbolic kinematic representation of a leg indicating hip and knee rotary joints.

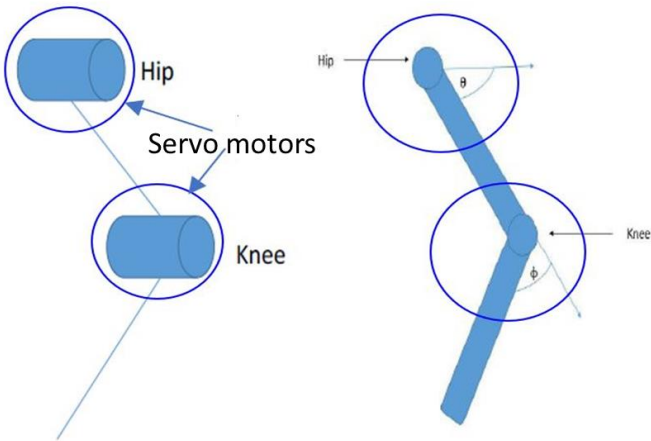


Figure 5 A single robot leg shown as a schematic and used to solve the 2 DOF inverse kinematics

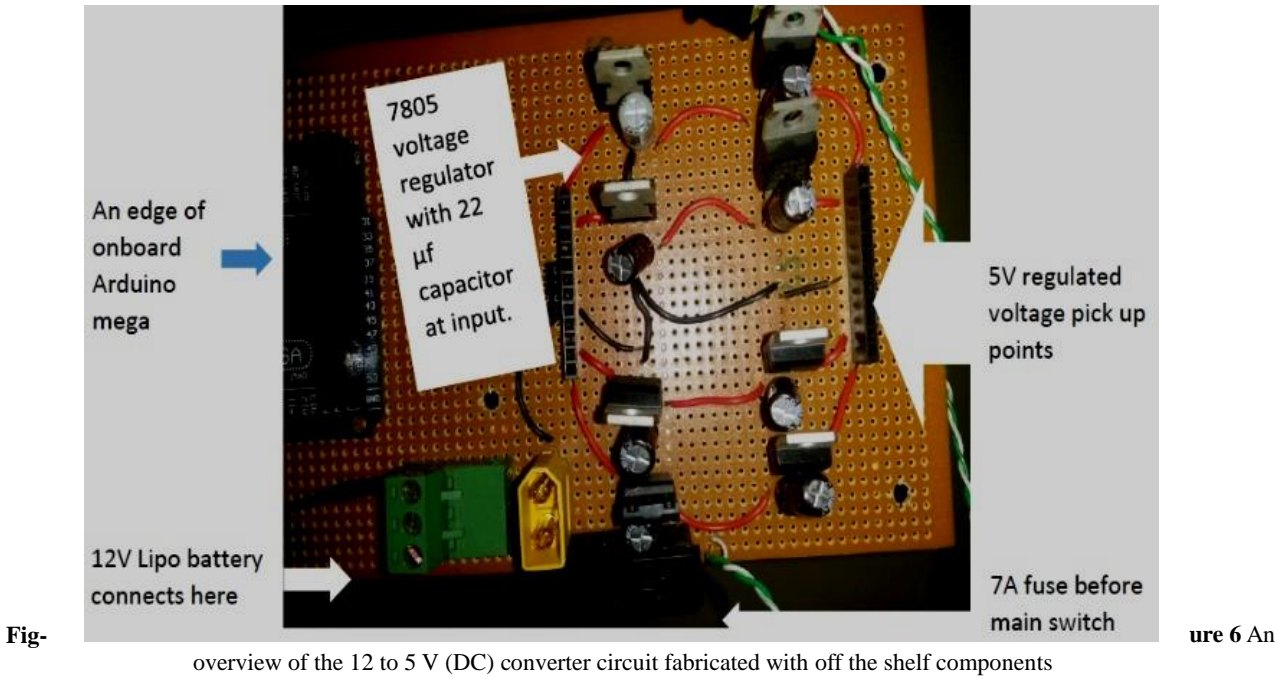




Figure 7 Single leg test configuration indicating the foot trajectory path (Left: simulation, right: real).

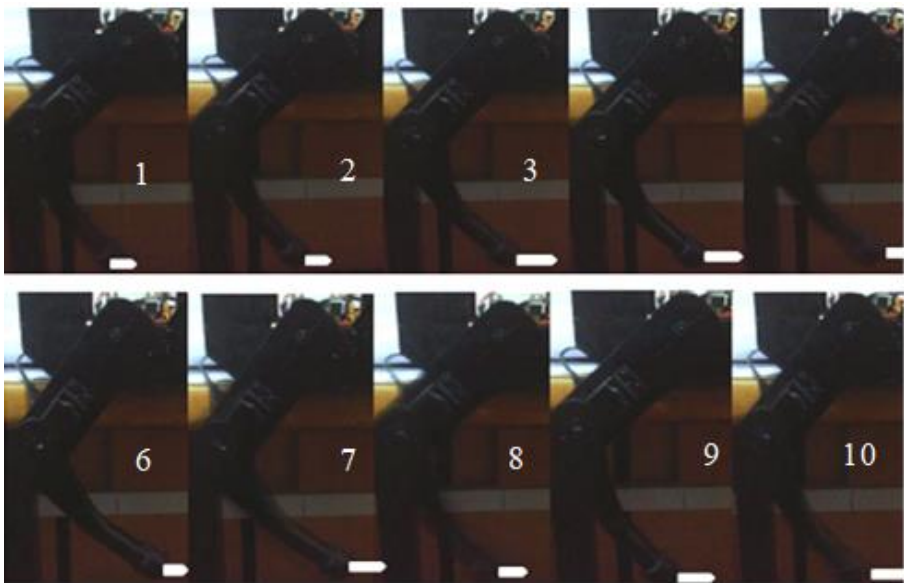


Figure 8 An image sequence (time between frames is 0.063 seconds) indicating the variation of the foot edge while following a trajectory based on fed joint values.

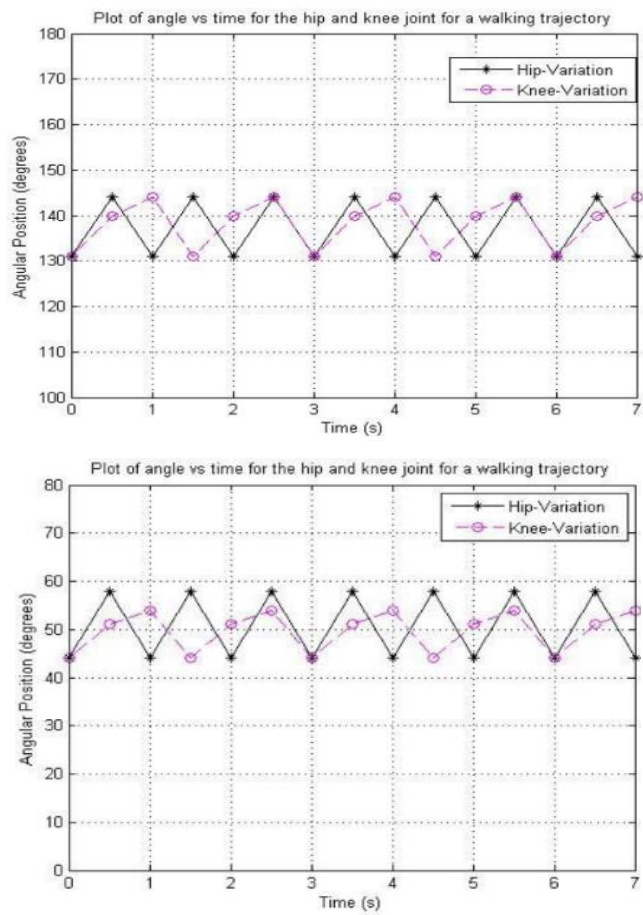


Figure 9 A graphical illustration of the motor joint angles: (a) Variation of angles at the hip the knee joints for the 4 servos on the one side; (b) Variation of angles at the hip and the knee joints for the 4 servos on the opposite side.

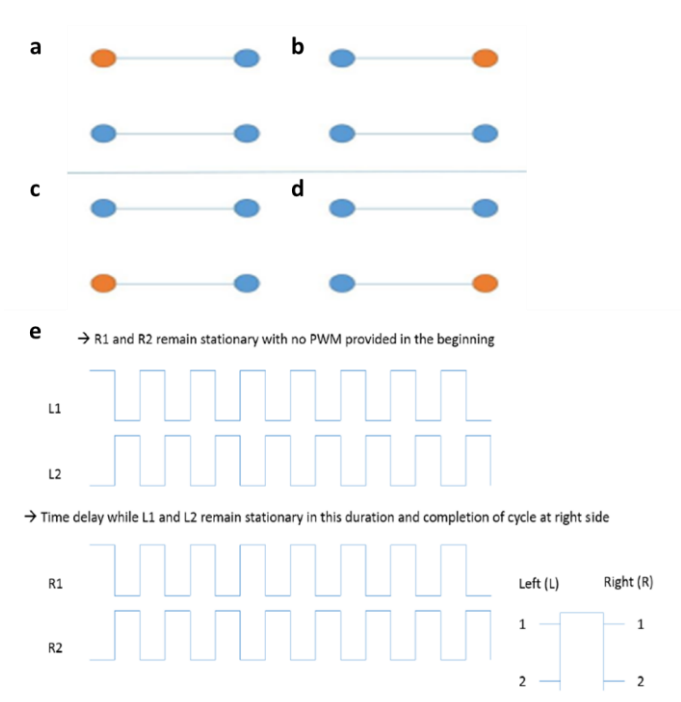


Figure 10 The walk gait rules for BiQR: (a) – (d) show a simple walk gait foot print pattern (the blue circles indicated the robot legs in stance whereas orange circles indicate the legs in swing mode); (e) indicates the graphical illustration of mapped PWM variations to servo joints in order to implement a walk gait. Time delays are added in order to synchronized the robot step movement.

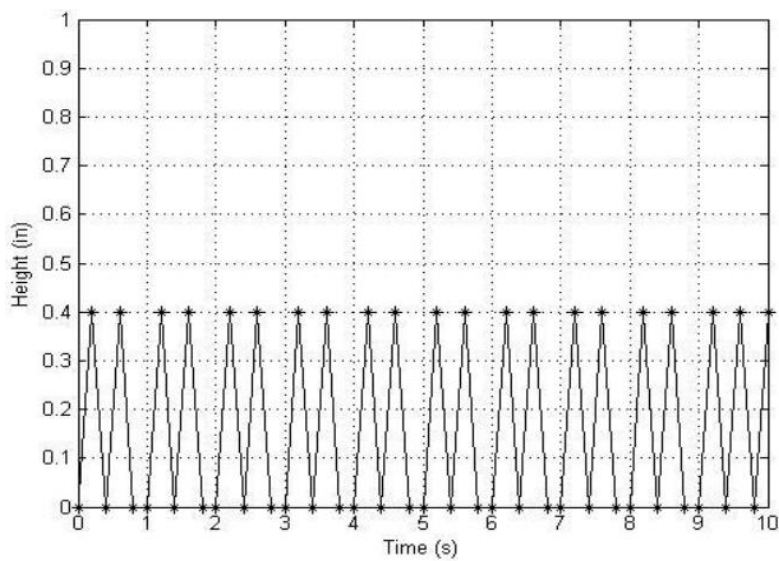


Figure 11 A graphical representation of the height noted at the run time showing the robot toe location during the swing and the stance phase in the robot walking experiments.

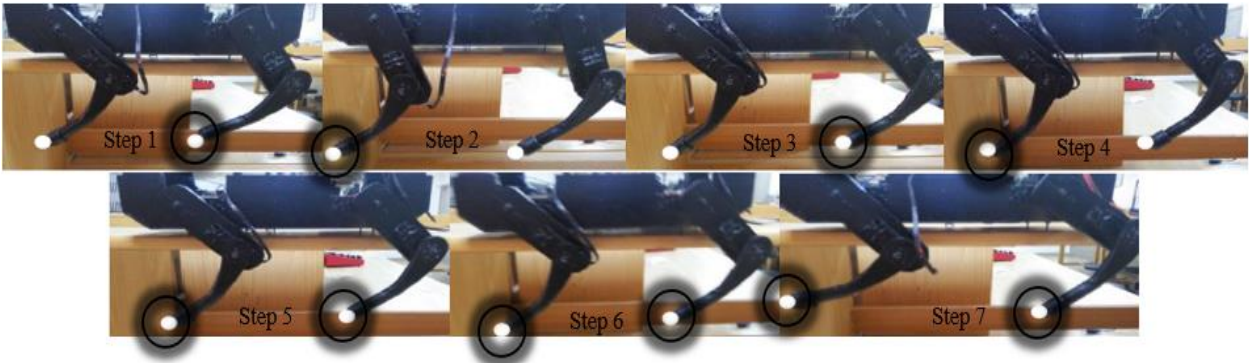


Figure 12 An image sequence taken at run time during the robot walking. As illustrated, step 1 to 4 were configured such that each leg could move once at a time, whereas step 5, 6 and 7 are showing two legs on each side moving in a synchronized manner.