Microcontroller Based Walking Robot

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INTRODUCTION

In this paper, micro controller is used to control the thermal states of Flexinol wires which actuating legs of the insect-like legged robot. The design emphasizes mechanical simplicity as well as power and computational autonomy for lightweight walking robot applications. The kinematics workspace characteristics has been applied on to a test rig to examine and improve the motion feasibility with the consideration of strike length and height the leg can be lifted. Simulations and experiments show that the walking robot can achieve statically stable walking and turning with simple open-loop control strategies.

The project is aimed at design, model and control a micro controller based autonomous walking robot that is activated by shape memory alloy wire called Flexinol. It is aided by simulate the robot walking using 3D studio max simulation software and determine the performance of the leg movement using a test rig in a simplified robot environment.

Walking robots are desired because they can navigate over uneven terrain with obstacles that wheeled and tracked robots cannot be. The essential problems in realizing autonomous walking robots consist of poor actuation systems and high power consumption rate [1]. Autonomous walking robots hence create an interesting area of research to develop and refine the application of possible actuation systems and development of flexible control capability using embedded micro controller. Nowadays, walking robots were emerging from laboratories to serve in a variety of non-industrial roles: as underwater explorers, as toys, as nuclear plant repair and decommissioning tools, and even as extraterrestrial explorers.

Many very early investigations started with six-legged machines, and all heavy robots are based on a six-legged design. Six-legged walking robots are statically and dynamically stable, even with two or three other legs are lifted. The alternating triangle gait is particularly important for six-legged walking robots in fast walking process. They are driven by electric motor, hydraulics or pneumatics actuator systems that provide fast response and easy control capability. However, these actuators possess problems of heavy weight and consume huge amount of energy. Small lightweight walking robots couldn't be built with these actuators. Shape memory alloys (SMAs) thus emerged and used in the development of micro-actuators, which create the possible means of making small lightweight robots. The use of so-called smart materials as actuators in robotic applications attempts to take advantage of their thermal properties in generating motion and transmitting force [2].

SMAs represent a new class of material, capable to transforming thermal energy into mechanical work. They undergo a phase transformation in their crystal structure from the stronger, high temperature form (austenite) to the weaker, low temperature form (marten site). Flexinol wires, which is used as actuator for this project, are highly processed strands of SMA comprises of 55wt% Nickel and 45wt% Titanium, and capable to deform up to 8% of its length. Flexinol is the trade name for actuator wires marketed by Dynalloy, Inc. The actuator is purely rely on heating and cooling of the material, thus increases the motion on the thermal cycle will increases the speed of the response of actuator. This shape memory effect therefore used to create “artificial muscles” for the walking robot application. Flexinol™ are generally expected to function over a large number of cycles based on the excellent fatigue properties. It is also allow simplified actuator designs and require smaller power source of typically 0.3V/cm length [3].

The design principles for this work follow the organization as shown in Figure 1 below, which contains three main blocks: Layout and design, test rigs and simulation, and finally the construction of real robot. All steps for realizing a walking robot are regularly reviews and continuous improvements with respect to performance according to the basic ideas and requirements [4].

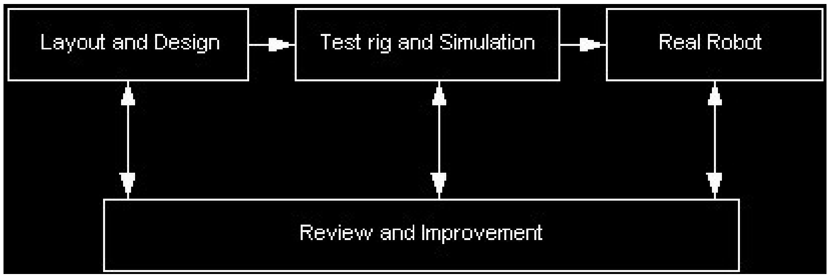


Figure 1 Realizing a walking robot

2 HARDWARE DESIGN

2.1 Kinematics of Leg

The locomotion and basic structure of the six-legged walking robot is imitating an American Cockroach and use bracket joints (Figure 3a) to provide 2 degree of freedom for each leg. Biasing spring acts on the opposite side of the Flexinol wire to allow it fully contracted and maintained optimum speed. A good combination of biological design ideas and technological possibilities is believed to make a good walking robot and discover of some relationships between structure and performance.

Properties of the Flexinol wire control the way the leg can be moved, maximum weight the robot can carry and speed of the robot walks, thus selecting a suitable Flexinol wire is the core issue in the design stage. A series of experiments were carried out to identify the ability of Flexinol to withstand both the weight of the robot itself and the payload carrying by the robot such as batteries. The Flexinol wire is crimped to a hook-shape steel rod in order to hook the wire to objects.

The results in Figure 2 are the cycle rate (cycle/min) of various 80mm long Flexinol wires tested at constant voltage of 5Vdc and different current flow, loaded with respective recommended loads. Results from the experiment show that, the 250mm diameter wire drains high amount of current and produces low cycle rate. On the other hand, the 50mm diameter wire unable to actuate the walking robot as it can only output a maximum force of 117g, which is too small to perform proper walking of the robot. By comparing the current drain, load and cycle rate between the 100mm and 150mm diameter wires, the 100mm diameter wire is selected. It can lift up a maximum load of 469g that is theoretically sufficient to actuate the robot walking with batteries attached. From experiment, the ideal current flow is 190mA, which gives an average speed of 32 cycles per minutes. From the experiment, it is found that the contraction is 4% to the wire length regardless the wire diameter.

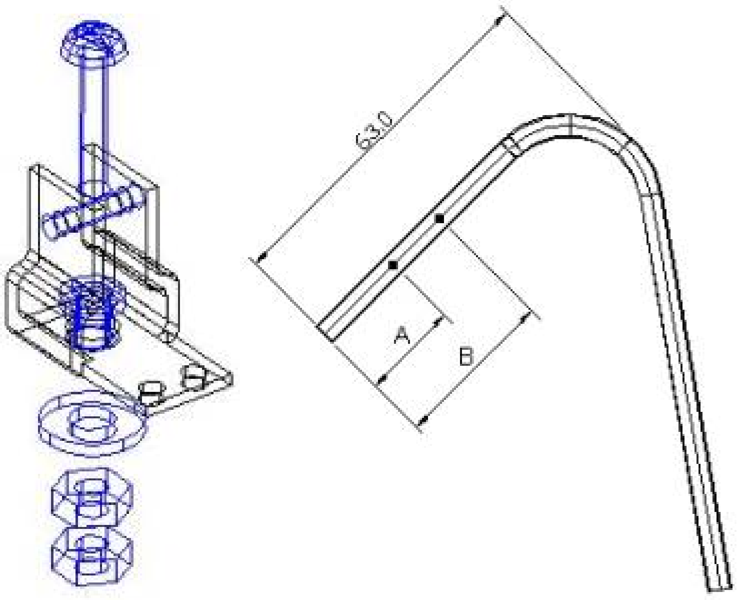
Based on the limitations of the Flexinol wire, such as low maximum payload, low cycle rate, limited amount of contraction etc, the walking robot has to be simple and very light in weight. The legs and the bracket joints of the walking robot are make with aluminum material that is very light and tough to guarantee maximum stability by keeping the majority load to the body, and maintaining the center of gravity at the center of the body throughout the walking process [5].

There are two springs used in each leg, one is to return the lifted leg back to the ground, as well as to support the body weight, which is referred as support spring. Another spring, which referred as transfer spring, is to return the backward swinging leg to its forward position. Springs with 1 mm coil diameter are used in this project. Springs are attached at the opposite side to the muscle wire to pull the muscle wire from austenite state to back to marten site state after cooling. The force provided by the spring is therefore two-folded, to return leg to initial position and act as biasing force to muscle wire.

To support the total weight from range about 300g to 400g, depends on the batteries use, each of the support spring withstand one-third of the body weight in tripod gait, which is about 100g to 134g. In general, the higher the load can withstand by the spring means that the robot can carry more payload, however, this is offset by the maximum recovery force of the Flexinol wire that require to pull the spring to produce movement of the robot. Thus, the kinematics of leg requires balance of forces between body weight, spring and Flexinol wire. Support spring and Flexinol wire positions is shown in Figure 3b below, where one end of the support spring is attached to the screw, and the other end is hook on the aluminum-tube leg. Spring can exert high force to withstand the body weight, but Flexinol wire does not able to contract at high load, thus Flexinol wire have to place in between spring and point of loading of body weight. For this arrangement, simple balancing calculation is:

One-third body weight x length of leg = spring force x length A
Spring force x length A = Flexinol wire force x length B

These equations are used to find the best position the spring hooks on the aluminum-tube that provides optimum support to the walking robot, and at the same time, does not stressing the Flexinol wire to its maximum recovery limit.



(a) **(b)**

Figure 2 Bracket joint and aluminum tube leg

In order to lift the leg to a minimum of 10 mm height, amplification ratio of 3:1 is required. The effective length of the leg is 63 mm, thus the Flexinol wire is hook at a point 21 mm from the pivot. The support spring can hook at any point between 21mm or less from the pivot. For swinging action, the amplification ratio of 6:1 is used to make a strike of 20 mm each backward swing. However, friction and leg inertia forces may reduce the amount of strike length in practical. The transfer spring returns the leg to its forward position when Flexinol wire is deactivated.

The posture of the leg from forward position to the backward position that provides the robot stable at all times is the best solution to ensure robot stability. The angles in which leg can swing are 9° left and right from the center line, which is calculated from the effective length 63 mm and the strike length of 20 mm.

2.2 Locomotion

Locomotion is the process of causing an autonomous robot to move using stable gaits. Two alternative tripods walking is commonly found in six-legged robot that guarantees statically stable fast walking at all times [2,3]. Three gait patterns are selected for this research work, include tripod gait, quadruped gait and independent gait, which cover the fast, moderate and slow walking speed (see Figure 4). The time taken by a leg to complete a step is known as cycle time, and the fraction of the cycle for which the leg is on the ground (support phase) is called the duty factor, b [2]. Duty factor of these gait patterns are 0.5, 0.6 and 0.75 respectively.

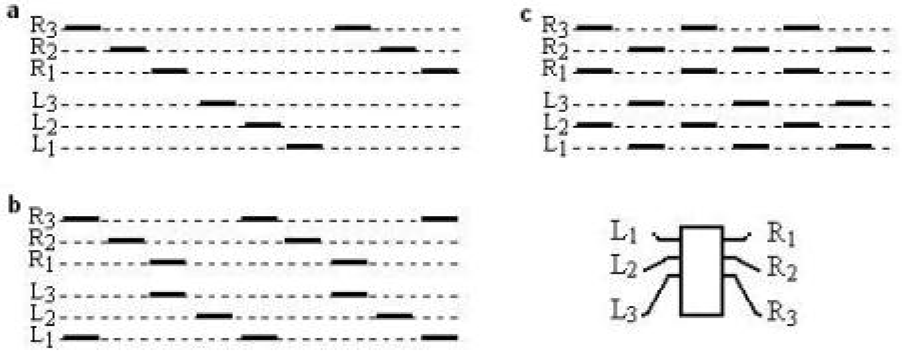


Figure 3 (a) Independent, (b) quadruped and (c) tripod gait patterns

The movement of the leg is planned to be triangle rotation, which involves the transfer phase and support phase of the locomotion. The leg swings backward to move the robot one step forward, and then lifted up and placed to the forward position. Transfer phase is simpler than support phase as it only involves swinging the leg forward and backward without the need to consider the body weight. However, friction between the bracket and the screw has to overcome in order to provide smooth swinging of the leg, and reduce the force require by the transfer spring and the Flexinol wire.

Based on tripod gait locomotion, the average current drained by each single leg is 152mA. Combination of two AA size NiMH batteries and a 9V (PP3) battery, which weights 150g, is used to continuously activate the walking robot for 1.5 hours. AA size batteries that outputs 2.4V and 1500mAh is used to activate the Flexinol wires, and the PP3 battery that outputs 8.4V and 150mAh is solely used to energize the micro controller.

2.3 Test rig

The results of test rig are encouraged where the average cycle rate is 29 cycles per minutes using current flow of 190mA. It is energized by two AA NiMH batteries and controlled manually by pressing the constant current switch on and off to activate and deactivate the Flexinol wire repeatedly. The length of each strike of swinging is 14mm and the final lifting height is 15mm, which is much greater than the theoretical calculated result. The efficiency of the leg is further improved by adding a rubber material at the end effectors. With the rotation speed planned in the Locomotion Section, the walking robot could walk at speed of 33cm/min using tripod gait. Figure 5 shows one leg test rig with the leg lifted up.

3 SOFTWARE DESIGN

3.1 3D Studio Max Simulations

3D Studio Max Release 3.1 is used to make the animation of the robot walking. To make the robot model walk, the bone structure, which includes bone chain for the individual leg and the body bone, is created on the robot model, and setting up the Inverse Kinematics (IK) controllers that limit the rotation angle of the bones. The robot model is then attached on to the bone structure using skin modifier because the model cannot be animated directly, but it is performed the posture set up on bone structure. Animation process is achieved by moving the time slider to setting up the respective posture. The speed of generating a simulation video clip is depends on the memory and speed of the computer, the resolution required and number of frames to be generated.

3.2 PBASIC Programming

Parallax's BASIC Stamp 2sx micro controller is selected to serve as the processor for the walking robot, because it offers a much simpler programming interface and ease of use than other embedded micro controller. BASIC Stamp program is written in PBASIC programming language, a high level language, which eliminates the need to understand how individual bits and bytes flow through the processor. There are total 16 general-purpose I/O pins available on chip, which is sufficient to connect each Flexinol wire to an individual I/O pin, and remaining four I/O pins that may connect to sensors or other devices in further works.

Since the walking robot is controlled using open-loop control method with no sensor to feedback real-time condition, the program is written to read the signal come from the switches board and tested with the LEDs test board prior to the actual walking robot, to speed up the evaluation process and to enhance the visualization of the program. The program is first checking the input signal from the switches board via pin 12 to 15 of the chip. Various gait patterns include turning gaits can be presented by using different combination of the four bits switching modes. When the result is satisfied, the program is loaded on to the chip to perform real walking. The final walking robot walks using tripod gait as it default gait when switches board is not connected. The decision making program can be modified to use in closed-loop control when sensors are attached to the robot instead of using switches.

4.DISCUSSIONS

Voltage regulator use in the circuit requires a minimum input voltage of 4.5V; four AA batteries are required, instead of using two AA NiMH batteries, to supply sufficient voltage to activate the Flexinol wire. The load of the robot is thus raised by 100g to about 400g and the finish constructed walking robot no longer can walks steadily with this amount of load, and collapsed when additional batteries are loaded on to it. In order to overcome this problem, 8.0mm long spring is used as the support spring, which can withstand the total load up to 430g, instead of using a 10.0mm long spring. However, this replacement causing the Flexinol wire loaded approaches its maximum limit and the spring does not help much in load carrying capability. This is because of the load is not death load as in the test rig experiment, walking robot become unstable when the life load is greater than the support strength during the transition between alternating tripods.

Alternative solution is replacing the combination batteries of PP3 and four AA batteries with one 9V (PP3) battery. The PP3 battery is used to energize both the BS2x IC and the Flexinol wires. The capacity of PP3 battery is very small and can only continuously energized the walking robot for about 10 minutes using tripod gait. The final walking robot is thus using a PP3 battery with shorter walking distance.

Furthermore, due to different contraction ratio of the Flexinol wires, and friction force exerted on each joint, the height of the leg can lift and the length of strike for individual leg is slightly different. The different strike length causing the walking robot does not move on exactly straight line, but towards some angle. This problem cannot be solved 100%, it is minimized by replacing those inefficient Flexinol wires with the new wires, and minimize the friction between parts.

5 CONCLUSIONS

In this research study, the six-legged walking robot is successfully constructed and the BASIC Stamp micro controller is able to control the legs' motion sequence to perform various gait patterns. The design of the walking robot is simple where the leg structures are mounted directly to the circuit board to reduce weight. Besides, the proposed approach of using 3D Studio Max Simulation software, which provides visualize solution to determine the feasibility of the various gait patterns use on the walking robot, has demonstrate the effectiveness of the proposed gait strategies.

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