

Walking Programming for a Low-Cost Easy-Operation Cassino Hexapod

Aviral Shrot¹, Giuseppe Carbone², Marco Ceccarelli^{3*}

¹Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India

^{2,3}Laboratory of Robotics and Mechatronics, DiMSAT – University of Cassino, Cassino (Fr), Italy.

* Corresponding author (email: ceccarelli@unicas.it)

Abstract

This paper presents the operation strategy for a hexapod walking machine that has been designed and built at LARM in Cassino with low-cost easy-operation features. Special care has been addressed in proposing an architecture that can be easily operated by a PLC with on-off logic. The novelty in the system can be recognized in successfully using a low-level PLC through suitable walking analysis and programming. Experimental tests are reported in order to show feasibility and operational capability of the proposed design.

Keywords: Robotics, Walking machines, Design, Simulation, Programming

1 Introduction

Design of intelligent walking machines which can move in uneven terrains and areas which are inaccessible to humans, has been a challenge in robotics since very long times [1]. Stable, efficient and fast robots [2][3] are needed to navigate uneven environments which can help humans in areas such as demining [4], pipe inspection [5][6], inspection and restoration of archeological sites [7][8] and interplanetary exploration [9].

Walking machines can be of several different types. Some are based on crawlers or wheels. Some others are equipped with biologically inspired legs [10]. This type of walking machines can be slow and more difficult to design and operate with respect to the previous ones. Nevertheless, legged robots are more suitable for rough terrain, where obstacles of any size can appear [11][12]. In fact, the use of wheels or crawlers limits the size of the obstacle that can be climbed, to half the diameter of the wheels [13]. On the contrary, legged machines can overcome obstacles that are comparable with the size of the machine leg [14][15]. There is also a third type of walking machines that is called as hybrid since it has legs and wheels at the same time [16]. This type of walking machines [17] may range from wheeled

devices to true walking machines with a set of wheels. In the first case, the suspensions are arms working like legs to overcome particularly difficult obstacles. In the second case wheels are used to enhance the speed when moving on flat terrain.

In this paper, a low-cost Hexapod robot design has been presented without sensor equipment with easy-operation characteristics for walking programming. The operation strategy and programming is discussed together with preliminary laboratory tests. The built prototype has been named 'The Cassino Hexapod' [18]. This robot can be controlled digitally using PLC controllers and the current prototype has been operated successfully in few basic walking modes after a suitable analysis of walking through a small PLC via a suitable programming for the actuator actions.

2 The Attached Problem

A hexapod consists of six legs and proper movement of the robot is possible by properly synchronizing the motion of all the legs. Thus, programming the movement of one leg is very important for the successful movement of the robot. Each leg joint of the Cassino Hexapod is actuated by a DC motor, which is activated by PLC, based on digital logic. Motion of a particular joint stops as soon as it reaches its extreme position, which is sensed by the limit switches.

Suitable walking gait has been implemented for the locomotion of Cassino Hexapod. For maintaining the stability of the robot, at least three legs must be in contact with the ground simultaneously [14][19][20]. In tripod gait, the front and the rear leg of one side and the middle leg of another side perform their swing movements at the same time. Thus the swings of right and left tripods have to be synchronized by adding a software-induced delay. This has to be done to implement a continuous walk. The scheme of Hexapod walking gait of Cassino Hexapod has been shown in Fig 1.

Thus, the attached problem has considered how to achieve a suitable easy programming for a hexapod gait through low-cost programmable power units and fairly simple programming of PLC using on-off logic.

Extension to any other gait mode can be approached by using the same strategy in analyzing the gait as function of the leg actuations for a suitable programming of each actuator in each leg.

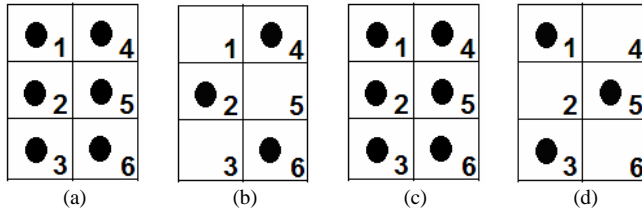


Fig 1. Scheme of steps in hexapod gait of Cassino Hexapod (a) All the legs in contact with the ground (b) Legs 1-3-5 are lifted together and moved forward (c) All the legs come in contact with the ground momentarily (d) Legs 2-4-6 are lifted together and moved forward, before the sequence of steps is repeated

3 A Prototype of Low-Cost Easy-Operation Cassino Hexapod

A single link module can be defined as link module, which contains in itself, the needed actuators, transmissions, and sensors, which can be connected together to form a mechanical leg [21][22]. The leg consists of several single link modules [23]. Since each module consists of a separate motor, hence increasing the number of links results in increasing the number of degrees of freedom of the robot. For our purposes we have used 3 links to compose a single leg. Each leg has 4 degrees of freedom, the fourth being arranged for the wheeled foot. Six of such legs are required for building the Hexapod robot.

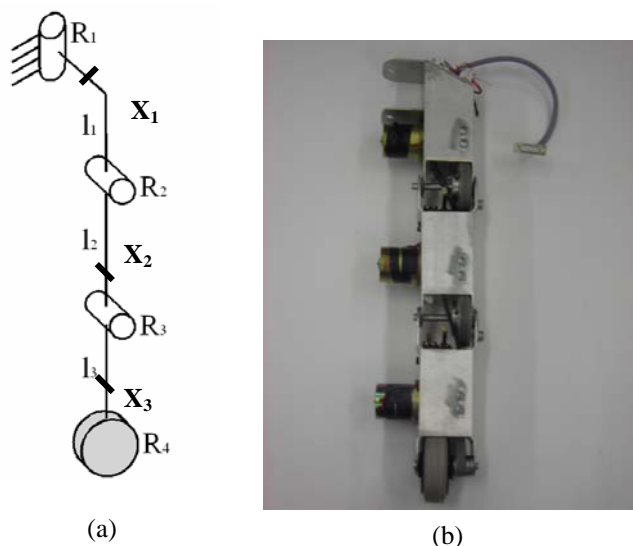


Fig. 2. The Cassino Modular leg (a) A Kinematic scheme of the Cassino leg (b) An assembled robotic leg prototype with the motors and the cabling

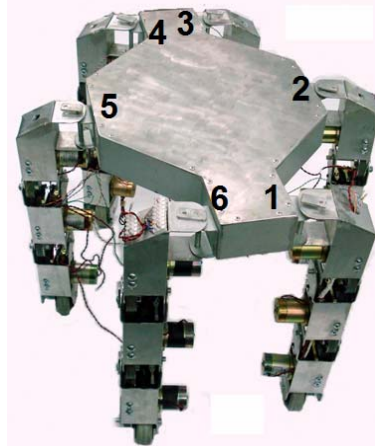


Fig. 3. The Assembled Cassino Hexapod Prototype

The leg consists of 3 modules; l_1 , l_2 and l_3 , each of which is driven by a motor, represented by R_1 , R_2 and R_3 (as shown in Fig 2(a)). Another motor R_4 is used as power source for the wheeled foot, enabling the smooth movement of the hexapod in a flat environment. The motor R_1 can be modeled as the hip joint, for turning the leg inside and out. The motor R_2 is used to lift the leg up and down and finally the motor R_3 is equivalent to the knee joint. Each motor is equipped with a corresponding limit switch X_i , which signals to stop the motion of the motor when joint limit is reached. The robotic leg has been made up of commercially available components, which have been assembled together to give the final form of the leg, which is shown in Fig. 2(b). The weight of each anthropomorphic leg is 2.5 kg. the sensor equipment has been limited to a commercial limit switch for each motor to delimit the motion range of each joint.

The assembled prototype of the low-cost easy-operation Cassino Hexapod is shown in Fig. 3. Aluminum alloy has been used as the material for constructing the hexapod and hence leads to savings in weight and cost of the robot. It can fit a cuboid of 60 cm x 60 cm x 50 cm without any payload or PLC installation. The weight of the robot without any payload or PLC installation is 17.7 kg. The weight of the Hexapod with PLC and other circuits is 21.6 kg.

The operation of the Cassino Hexapod has been achieved by using PLC to control the different motors of the hexapod. Siemens PLC Simatic S7-200 [24], which is fixed onboard the hexapod, is used for the operation of the Cassino Hexapod. The program for the hexapod operation has been written in a windows PC, which has STEP-7/Micro WIN 32, installed into it. The program from the PC can be downloaded onto the flash memory of the PLC using a RS 232/PPI Cable.

4 Operation Strategy and Programming

The operation of a single leg is the most basic strategy and is operated in conjunction with other legs to perform complex

walking tasks. The Grafcet logic for the movement of a single leg has been designed as shown in Fig. 4. First the knee motor is actuated in the counterclockwise direction and simultaneously the ankle motor is actuated in clockwise direction. The motion of the motors is stopped, when they reach the joint extreme positions, which is sensed by their respective limit switches (X_i in fig 2(a)). The leg moves to its rightmost configuration, as shown in Fig 5(b).

Thereafter, the knee motor can be activated in the clockwise direction and ankle motor in the counterclockwise direction. The motion is stopped again at the extreme joint positions. At this point of time, the leg is in the leftmost position as shown in Fig 5(c). In order to bring back the leg to the vertical position, the knee motor has to be moved in the counterclockwise direction and the ankle motor has to be moved in clockwise direction. The motors are actuated for a certain period of time till the leg attains the vertical configuration. This time period is a function of Voltage provided for actuation of the joint, and is determined experimentally.

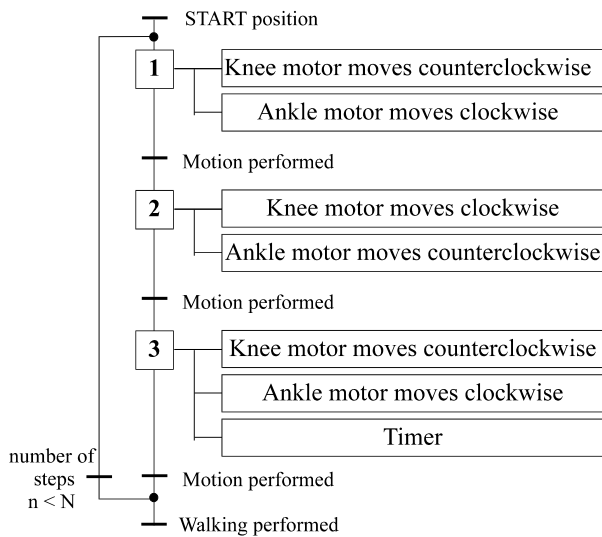


Fig. 4. Descriptive Grafcet for forward and backward motion of one leg.

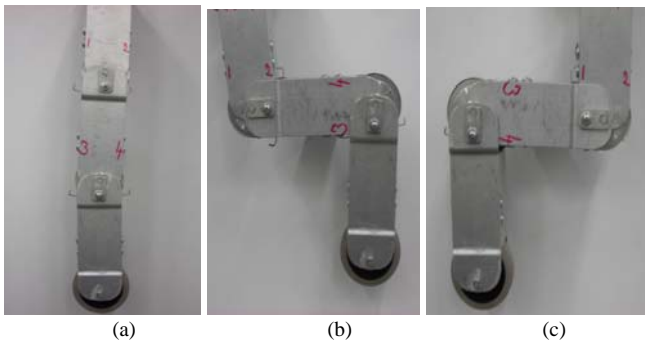


Fig. 5. Robotic leg of the Hexapod showing the extreme limits of its motion (a) The leg in the straightened position (b) The leg in the rightmost position (c) The leg in the leftmost position.

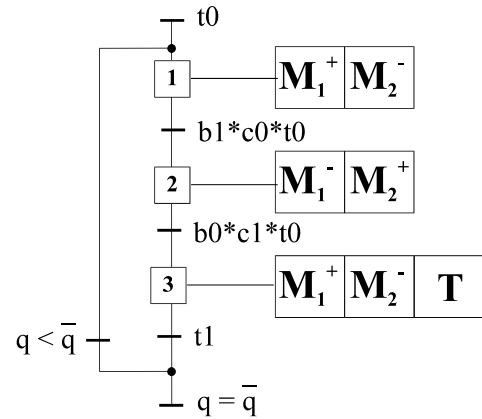


Fig.6. Functional Grafcet of forward and backward motion of a leg.

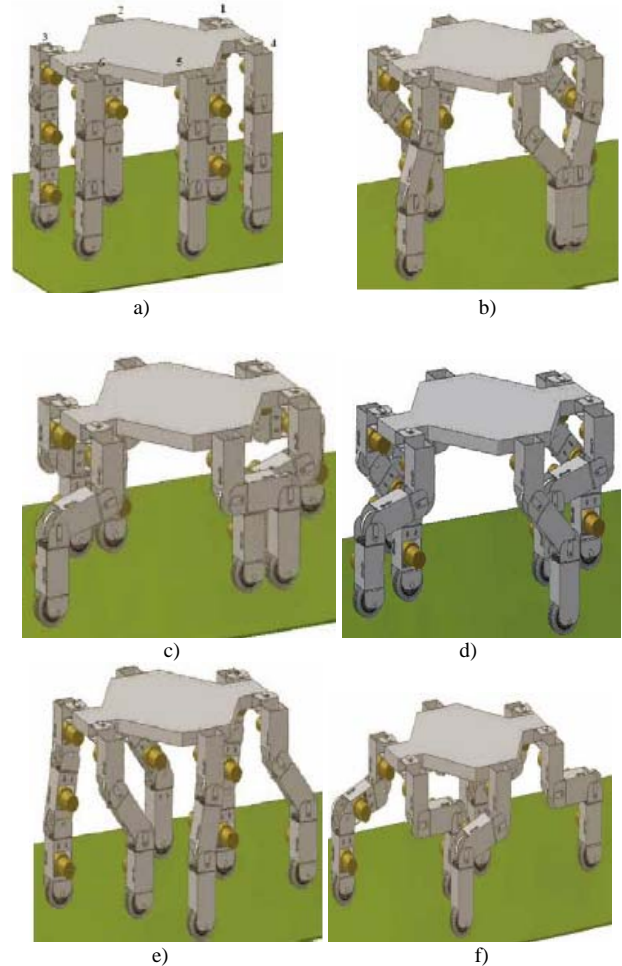


Fig. 7. Phases for a one step double tripod forward walking motion of a hexapod robot according to the Grafcet diagram in Fig.7: a) initial configuration; b) 3 legs move forward; c) 3 legs reach the maximum forward configuration and the other 3 start moving backward; d) 3 legs are in the maximum forward configuration and the other 3 reach the maximum backward configuration; e) 3 legs keep the maximum backward configuration and the other 3 move backward. f) final configuration.

This scheme of operation of one leg has been shown in Fig 4 and Fig 6 as suitable flowcharts for a flexible programming. In Fig 6, M_1 refers to the status of the motor R_2 in the first module of the leg and it can be indicated as + for the counterclockwise motion and as - for the clockwise direction. Motor M_2 refers to the status of motor R_3 in the second module of the leg. A timer T is also provided for timing purposes. The signals t, b, and c can be given from switches. When signal b is 1, the leg moves fully forward, when signal c is 1, leg moves fully backward and t represents the timer status. When t is 0, the timer is off and when t is 1, the timer is on. The signals b and c cannot be simultaneously 1, because the leg cannot move in both the directions at once. The variable q represents the internal position.

A series of such elementary movements can be used for performing forward walking using tripod gait by synchronizing the leg operation. In this case, the legs 1-3-5 and 2-4-6 move simultaneously. It must be noted that, in order to ensure that the robot remains stable, at least three of the legs of the robot must be in contact with the ground at a time. Thus first, the legs 1-3-5 are activated and are lifted in the forward direction (Fig. 7(b)). The legs 1-3-5 then move to forward extreme position and the legs 2-4-6 start moving in the backward direction (Fig. 7(c)). After this, the legs 2-4-6 are further brought to the backward extreme position (Fig. 7(d)). This constitutes the start of one step of the hexapod. Now, the legs, 1-3-5 are again activated and brought backward (Figure 7(e)). Then the legs 2-4-6 are brought forward (Fig 7(f)). This signifies the end of the step.

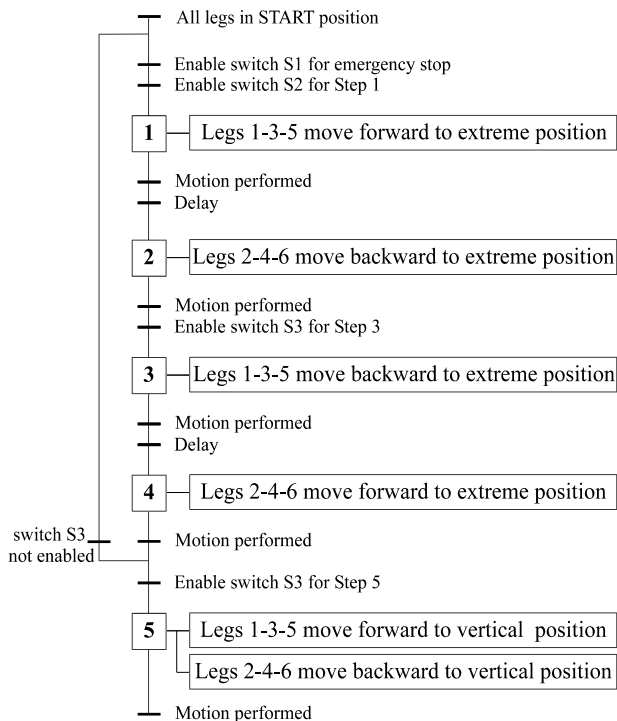


Fig. 8. Descriptive Grafcet for forward walking operation of the hexapod.

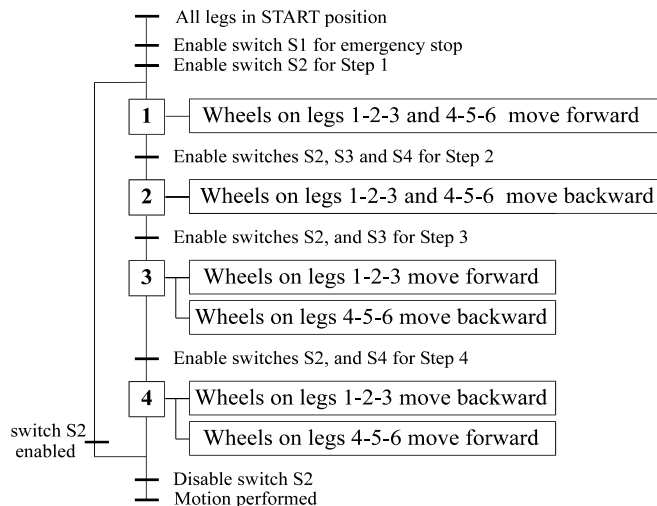


Fig. 9. Descriptive Grafcet for wheel operation of the hexapod robot; forward, backward and turning operations are achieved by selecting a proper combination of latching switches S3 and S4.

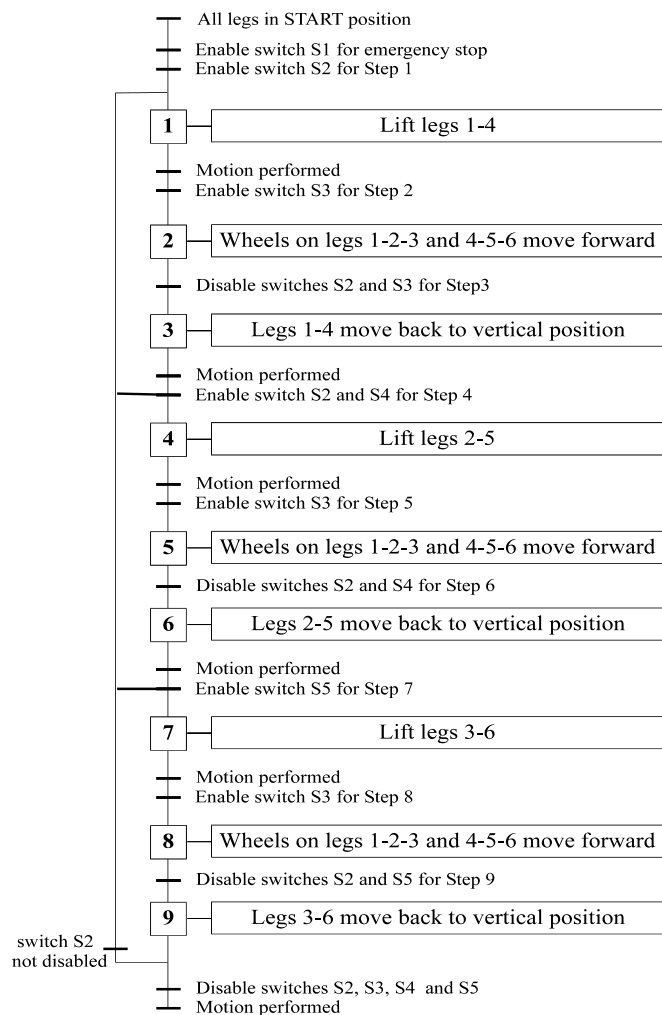


Fig.10. Descriptive Grafcet for obstacle avoidance operation.

At this point of time, the legs are straightened back to its default position (Fig 7(a)). A descriptive Grafcet for forward movement of the hexapod has been shown in Fig. 8.

Wheel motion of the hexapod robot can be used for its locomotion in flat surfaces. When all the wheels of the robot move in forward direction, the robot will move forward and when all of them move in backward direction, the robot moves back. Differential turning of the wheels can be used to turn the robot in right or left direction. The GRAFCET logic for this operation has been presented in the Fig. 9. The robot can be made to turn in right direction, if the wheels of legs 1-2-3 are moved forward and wheels of legs 4-5-6 are moved backward. Similarly, the robot can be turned left, by moving the wheels of legs 1-2-3 in backward direction and the wheels of legs 4-5-6 in forward direction.

A strategy for avoiding obstacles has also been studied. First of all, the two front legs 1-4 of the hexapod are lifted simultaneously and the robot is moved forward using the wheels. Legs 1-4 are then brought to the ground and the middle legs 2-5 are lifted from the ground. The robot again moves forward using wheels. Finally, legs 2-5 are brought to ground and legs 3-6 are lifted. The robot moves forward again using wheels and the legs 3-6 are brought to vertical position. The Grafcet logic for obstacle avoidance has been shown in Fig 10.

Summarizing, the programming strategy consists in building suitable programming routines for each different gait mode or walking situation after a suitable analysis of the walking and its action sequence, similarly to what has been presented here in this paper for the basic walking operation for an hexapod gait

5 Laboratory Tests

In order to test the working of the robotic leg, the operation of one leg of the hexapod was tested first. In this test, the leg moves from one limit position to another. Activation of switch S2, moves the leg towards left and activation of the switch S3, moves the leg towards right, according to the GRAFCET in Fig 4 and Fig 6. The images from the actual tests have been presented in the Fig 11.

Experimental tests have been carried out to verify the feasibility and efficiency of the programmed walking modes by just looking at the motion capability of the joints, legs, and hexapod at the whole with no other sensors that could have complicated the PLC operation up to not permitting it.

Then, experimental tests have been conducted on the whole prototype to verify the operation of the Hexapod. For conducting the tests, the prototype has been fixed on a platform, such that none of the legs have any of interference from any external object. The sequential pictures from the experimental test have been presented in Fig 12.

Experimental tests have also been conducted on the prototype to test the wheeled operation of the hexapod. The hexapod has been placed on flat surface and moved using the wheels. The hexapod has also been turned in the left and

right directions, using differential motion of its wheels. The sequence of pictures from the test has been presented in Fig. 13.

Experimental test have been useful to verify a successful use of a commercial PLC with a fairly simple PLC programming. Indeed, the reported test have shown the successful operation of the built prototype in few different basic motion modes as based on a PLC programming only.

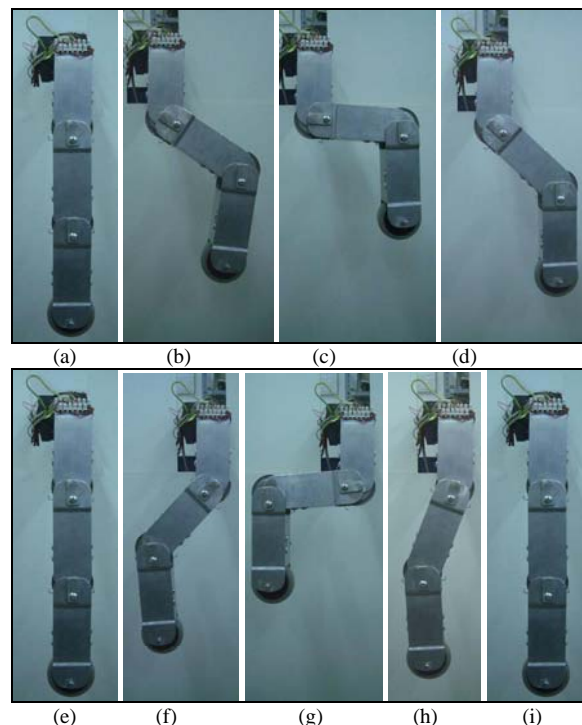


Fig.11. Sequence of images showing a forward and backward motion test for one leg according to the Grafcet of Figs.6 and 7: a) initial straight leg configuration; b) intermediate forward configuration; c) maximum forward configuration; d) intermediate forward configuration; e) intermediate straight leg configuration; f) intermediate backward configuration; g) maximum backward configuration; h) intermediate backward configuration; i) final straight leg configuration

6 Conclusions

The operation strategies for Cassino Hexapod have been proposed and implemented successfully as based on a commercial PLC unit with on-off logic. A first prototype has been built and preliminary tests have been performed successfully with satisfactory results regarding its motion capability and easiness of motion programming and operation, [22]. There are certain issues such as existence of backlash in the joints, which remain an open problem [25], and further work can be carried in this area. A goal of the project is to use a low-cost commercial PLC to control the hexapod operating with different gait modes. Satisfactory

results are reported in the paper as related to basic experiences.

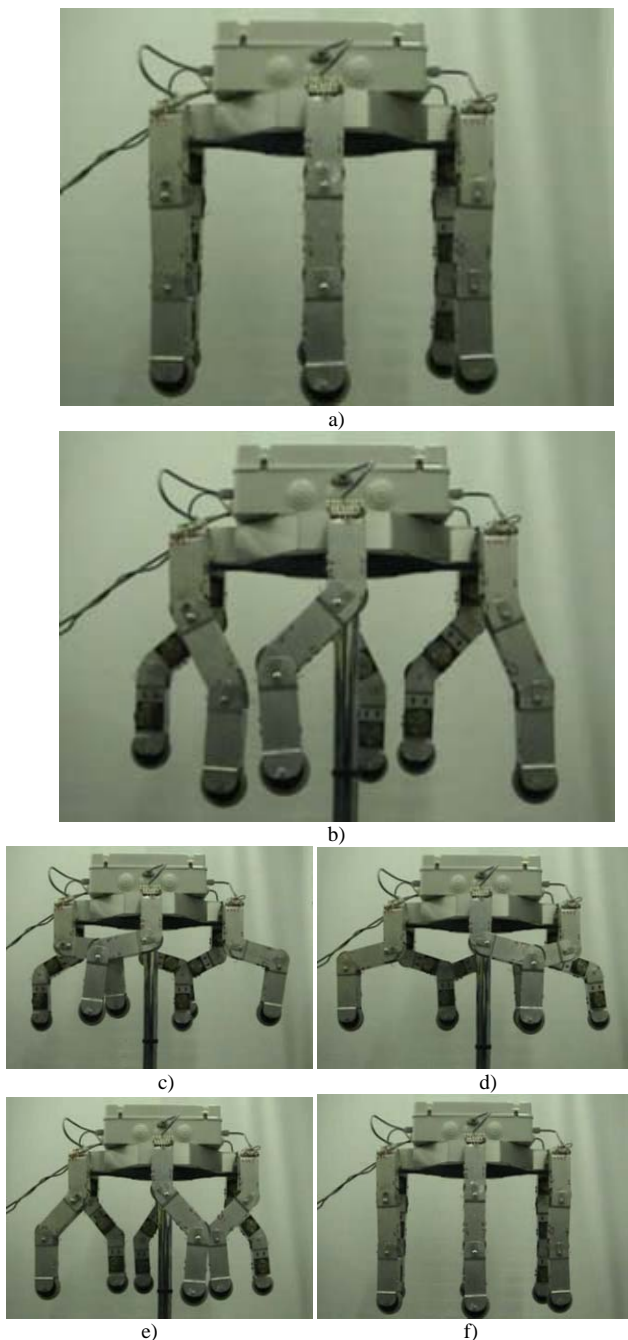


Fig.12. Sequence of images showing a forward walking test of Cassino hexapod on a fixed base: a) initial straight leg configurations; b) 1-3-5 legs in intermediate forward configuration and 2-4-6 legs in intermediate backward configuration; c) 1-3-5 legs in forward configuration and 2-4-6 legs in backward configuration; d) 2-4-6 legs in forward configuration and 1-3-5 legs in backward configuration; e) 2-4-6 legs in intermediate forward configuration and 1-3-5 legs in intermediate backward configuration; f) final straight leg configurations.

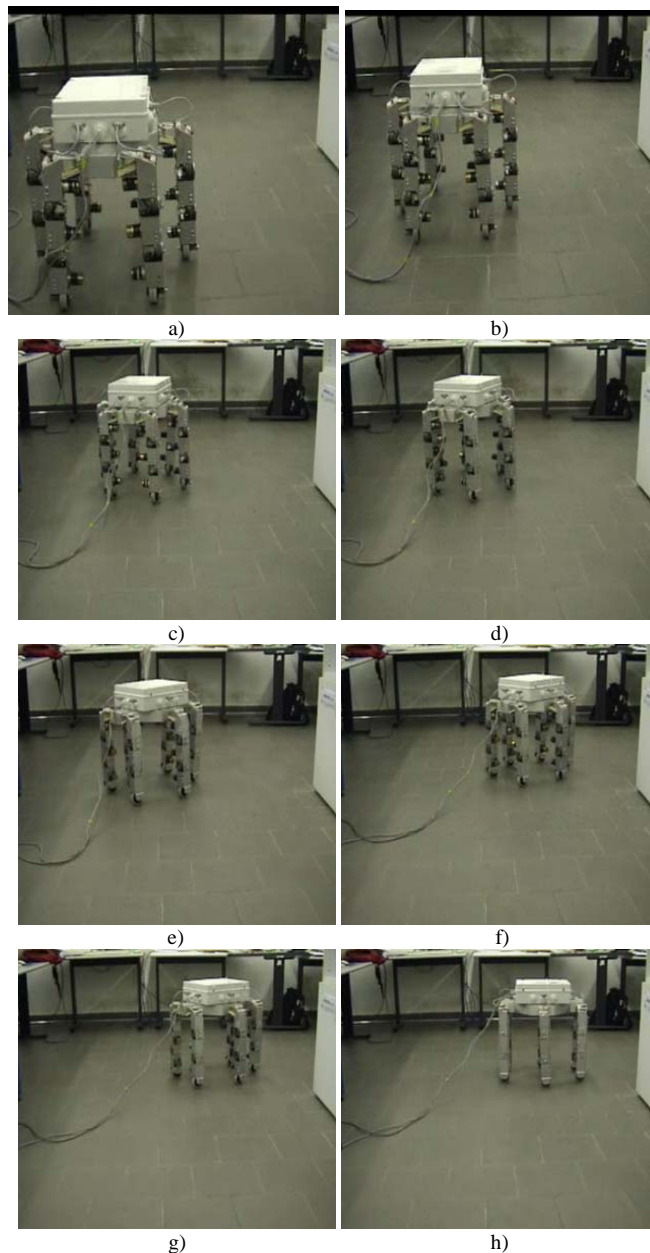


Fig.13. Sequence of images showing a wheel operation test of Cassino hexapod: a) initial position; b) forward motion intermediate position; c) initial turning position (15 deg.); d) second turning position (30 deg.); e) third turning position (45 deg.); f) fourth turning position with forward motion (60 deg.); g) fifth turning position (75 deg.); h) final position (90 deg.).

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