ADAPTIVE GEOMETRY TRACK DESIGN AND IMPLEMENTATION FOR AN ALL TERRAIN MOBILE ROBOT

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Abstract— **Limitation of an autonomous mobile robot for moving in ragged terrain exist. In some situations, it can not move through the required target trajectories because the type of driving system is not appropriate. To reduce this limitation, a new inventive concept of mechanism is presented in this paper. The mechanism is designed in a triangle shaped tracking wheel in which the inner construction can be manipulated depending on that particular terrain, thus this type of wheel is likely to move through all terrain. Four ball screws, which are the most important mechanism of the robot, are extruded and contracted in order to make tracking belt tight when the robot climbing up and down the stair. In tracking wheel system, 12 DC motors are used, 6 DC motors are utilized in the part of angular adjustment, 4 DC motors are applied for the extrusion and contraction and the last 2 DC motors are used for driving the tracking wheels. Each DC motor is controlled by a microcontroller (Atmel AT89C2051) and a personal computer is being used as graphic user interfaces that allows communication with all the microcontrollers via serial communication RS-485.**

Keywords—**Mobile robot**

I. INTRODUCTION

AUTONOMOUS mobile robot is an intelligent machine which is able to extract information from its environment and uses knowledge about its world to move safely in a meaningful and purposive manner, it can operate on its own without any human intervention. The primary task of a mobile robot is an environmental navigation as basis for more useful tasks. In contrast to indoor mobile robots and industrial manipulation robots, both working in relatively static and structured environment, outdoor mobile robot works in dynamic and unstructured environment, the robot must be able to perceive its surroundings through different kinds of sensors and initiate appropriate actions in that environment through actuators to achieve its designed goals.

The mobile robot has played an important role to accommodate the human needs in many ways such as: explore and navigate in hazardous areas in order to lower risk that can occur. At present, the development on the mobile robot has increased in the area of robustness and accurate control. The drive system is also one of the important parts which emphatically improve the performance of the mobile robot. This research focuses only on the difference between wheels and tracking wheels.

The advantages of most wheels are dexterous movement, lower friction between a wheel and a platform and easy control but it is very difficult to move in the rugged terrain. On the other hand, the tracking wheel is appropriate to move along both level and rough ground but the friction between the tracking wheel and the floor is somewhat higher.

The problems confronting most mobile robotic development efforts arise directly from the inherent need to interact with the physical object and entities in the environment. The platform must be able to navigate from a known position to a desired location and orientation, avoiding any contacts with fixed or moving objects while en route. There has been quite a tendency in early developmental efforts to oversimplify these issues and assumed that the natural growth of technology would provide the needed answers. While such solutions will ultimately come to past, it is important to pace the evolution of the platform with a parallel development of the needed collision avoidance and navigation technologies.

II. RELATED WORK

There are many researches and papers on various types of mobile robots, [1], [2], [3], [4], [5], [6], [7] and [8] are typical examples of researches on mobile robots. Mobile robots can be used in all kinds of applications from industries all the ways up to militaries such as iRobot PackBot (used during the wars in Iran and Afghanistan). Some of them are built as a rescue robot, to rescue people under the damaged buildings, etc. Some of them use in militaries to spy on the enemies, to survey unsafe area, to get rid of the bombs, etc. They are varied in sizes, capabilities, most of them are equipped with remote control circuit which allows user to control from a comfortable distance, only a few of them are autonomous robots. Many of them are still under development around the world.

III. PROPOSED ADAPTIVE GEOMETRY MOBILE ROBOT

The main objectives of this research are:

- To design a drive system that can adapt its own geometry in order to move through various environments such as rough platform, limited height passage or even climb up and down a stair. The maximum target velocity of robot is 5 m/s and the angular motion of each angle can vary from 95º to 150º.

- To simplify a basic platform that can be used to build a typical rescue mobile robot in the future.

In this research, a triangle shaped caterpillar wheel is being used as a triangular base of the robot. Each internal angles of the triangle wheel can be adjusted by changing the rotation and linear displacement of the appropriate ball screw(s). This concept allows the robot to move along the level, rugged ground and climbed up and down a stair as well. The communication software (via serial communication RS-485) will also be developed for user to manually control the robot in various situations.

IV. PHASE I (HARDWARE DESIGN)

The hardware design phase has been divided into 2 portions, the mechanical design and the control hardware design respectively. The robot resides on two triangular shaped like bases, the user can adjust the configuration of this triangular base to avoid the obstacle(s), move on smooth surface and climb the stair. Fig.1. shows the typical robot model for the calculation. Fig.2. shows the respective mathematical equations.

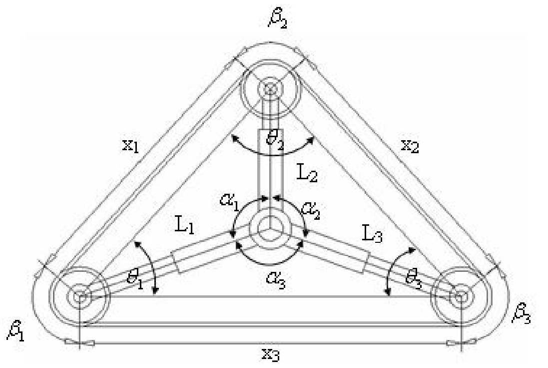


Fig.1. Typical robot model for the calculation.

The calculation starts with equation (1) where M is the circumference of the above caterpillar tractor wheel belt and r is the radius of the wheel.

$$X_1 + X_2 + X_3 + 2\pi r = M \quad \text{……………..(1)}$$

The input values of the system are $\alpha_1, \alpha_2, \alpha_3, r$ and M therefore the results are the angles, the distances and the radius of the wheel denoted as θ_1, θ_2, θ_3, L_1, L_2, L_3, X_1, X_2, and X_3, respectively. First, the angles between link L_1, L_2 and L_3 are calculated as in equation (2), they are as follow:

$$\alpha_1 + \frac{\theta_1}{2} + \frac{\theta_2}{2} = 180, \ \alpha_2 + \frac{\theta_2}{2} + \frac{\theta_3}{2} = 180$$
$$\alpha_3 + \frac{\theta_1}{2} + \frac{\theta_3}{2} = 180 \quad \text{..........(2)}$$

$$X_1 = \frac{P}{\left(1 + \frac{(C_2 + C_1C_3)}{(1 - C_3^2)} + \frac{(1 - C_2^2)}{(C_1 + C_3C_2)}\right)}$$

$$X_2 = X_1 \frac{(C_2 + C_1C_3)}{(1 - C_3^2)}, \quad X_3 = X_1 \frac{(1 - C_2^2)}{(C_1 + C_3C_2)} \ \ldots(3)$$

$$L_1 = X_1 \frac{\sin(\frac{\theta_2}{2})}{\sin(\alpha_1)}, L_2 = X_2 \frac{\sin(\frac{\theta_3}{2})}{\sin(\alpha_2)}, L_3 = X_3 \frac{\sin(\frac{\theta_1}{2})}{\sin(\alpha_3)} \ \text{..(4)}$$

where $P = M - 2\pi r$, $C_1 = \cos\theta_1$, $C_2 = \cos\theta_2$ and $C_3 = \cos\theta_3$

Fig.2. Respective mathematical equations.

The above equations (1), (2), (3) and (4) are respective mathematical equations regarding to the proposed mobile robot.

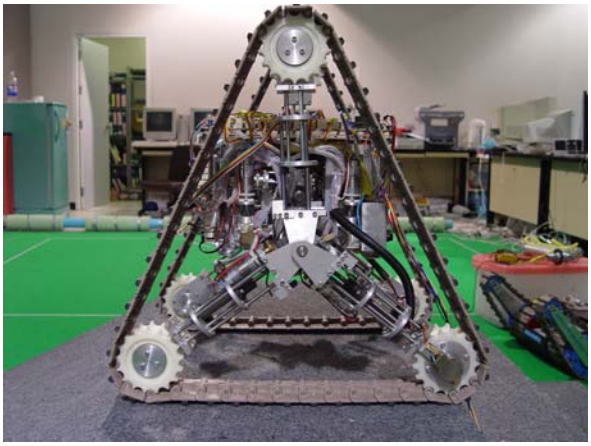


Fig. 3 and Fig. 4 show typical side view and a typical view from different angle of the proposed triangular based robot respectively.

Fig.3. Typical side view of the proposed robot

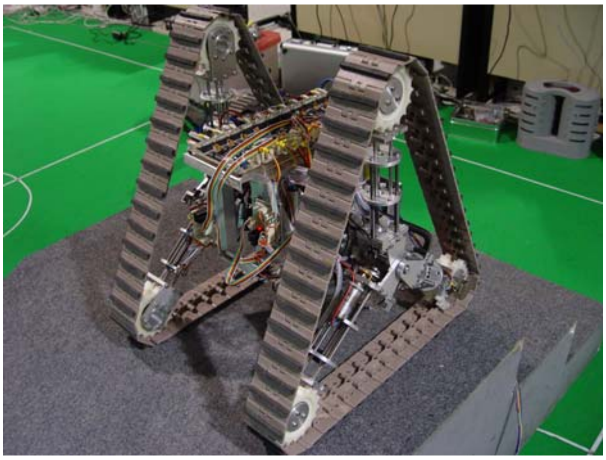


Fig.4. Type view of the proposed robot

For the control hardware, a concept of distributed control has been utilized, 12 of Atmel AT89C2051s are connected together to form a typical RS-485 serial network. This network is then connected to a RS-485<->RS-232 converter to allow the above serial network to connect to a notebook which acts as console system for the triangular based robot. Fig. 5. shows typical control structure of the proposed robot.

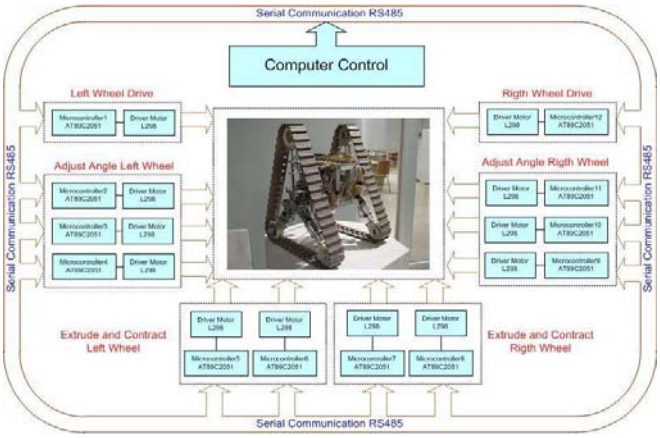


Fig.5. Typical control structure of the proposed robot.

The serial communication RS-485 system are utilized to communicate between the computer and each microcontroller (AT89C2051) and the timing of serial communication for transferring data is 104 μs/byte. The microcontroller receives commands from PC, processes all the necessary calculations and sends the signal to the respective full bridge single chip driver motor (L298) in order to control the respective DC motor. The encoder with the resolution of 200 pulses /revolution is applied to provide the feedback counts back to the microcontroller to control the positioning of DC motor. The optical sensor was installed to prevent the damage and limit the movement of the hardware for safety.

In the implementation part, the angle of each link can be adjusted between 95º and 150º. The ball screws are applied to regulate the linear displacement from 0 mm. to 100 mm, for making tracking wheel tight in the situation that the robot moves through high tilt. The tracking wheel is able to move along the rugged terrain, climb up/down stair in which each step is 15×25 cm. (height × width) and its maximum slope is approximately 30º.

V. Phase II (Software Design)

Once the hardware configuration has been individually tested and done, the software design can then proceed. There are 2 supporting programs for the proposed robot, the first program is written in assembly language, this program is for each of the AT89C2051 microcontroller. Since the objective is to control each individual motor in the same manner, only one assembly program is being developed. Each AT89C2051 can be identified by its own unique ID which is embedded in each AT89C2051 and each of them can be identified through communication protocol from the notebook PC via RS-485.

The second program is being developed with C++Builder version 6 from Borland Software Corporation. This program resides on notebook PC and acts as system console program. It receives input from user, make some calculations and map the result of the calculation into a series of command protocol messages. These command protocol messages are then sent down as serial data on RS-485 platform to each individual AT89C2051s. Only the AT89C2051 which has identical ID will act upon the received command protocol message.

To control the triangular based robot, the user can use the above system consol program. The system consol program allows 6 basic activities on the robot, they are: Angle Calculation, Robot movement, Adjustable, Climb Up, Climb Down and Extrusion. Fig.6 is a typical System Console screen on a notebook PC.

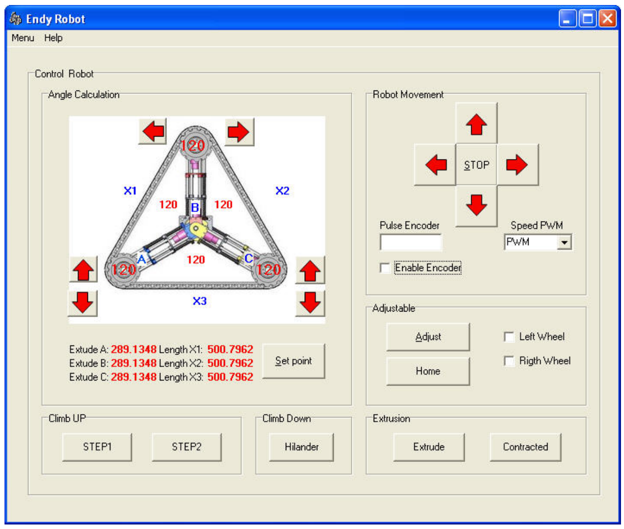


Fig.6. Typical System Console screen on a notebook PC

The following are description of each activities on the System Console screen, they are:

1. Angle Calculation: there are 6 directional arrow buttons. Each pair of the arrow button allows angular control on each axis. With these arrow buttons, the shape/size of the robot can be adjusted accordingly.
2. Robot Movement: there are 4 arrow buttons, 1 stop button, 2 entries of pulse encoder and speed PWM selection and an enable/disable encoder checker. The first 4 arrows allow the robot to move in the direction of each arrow button accordingly. The stop button stops the robot. The 2 entries control the speed and movement of the robot. The enable/disable encoder checker allows the user to enable or disable the encoder on continuous move.
3. Adjustable: there are 2 (Adjust and Home) buttons and 2 (Left and Right Wheel) checkers. The Adjust button works in pair with the Left Wheel and Right Wheel checkers, they allow the user to adjust the corresponding wheel to the predefined position. For the Home button, this allows the user to move the all the axes back to their respective home positions.
4. Climb Up: there 2 Step buttons for manual control to allow the robot to climb the stair, the Step1 button allows the robot to proceed with the climbing, one the front wheels can climb up on step, the Step2 button allows the robot to ship its own weight and proceed with the second move to cover the rest of the above steps. The robot must execute these 2 moves repeatedly for each step to climb the whole stair.
5. Climb Down: Climbing down is a lot easier, the robot can ship its own weight to the front end of the robot and move down the stair in one continuous move.
6. Extrusion: there are 2 buttons in this case, the Extrusion button allows the axes to expand, the Contracted button allows the axes to retract.

Fig.7 and Fig.8 are example of typical move command flowchart1 and flowchart2 for the Robot Movement activities on the system console screen.

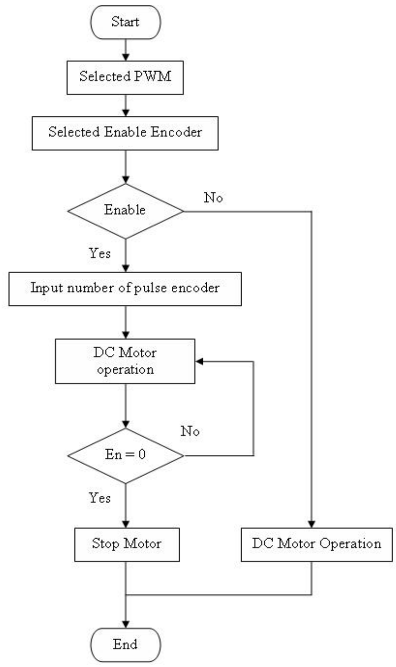


Fig.7. Typical move command flowchart1.

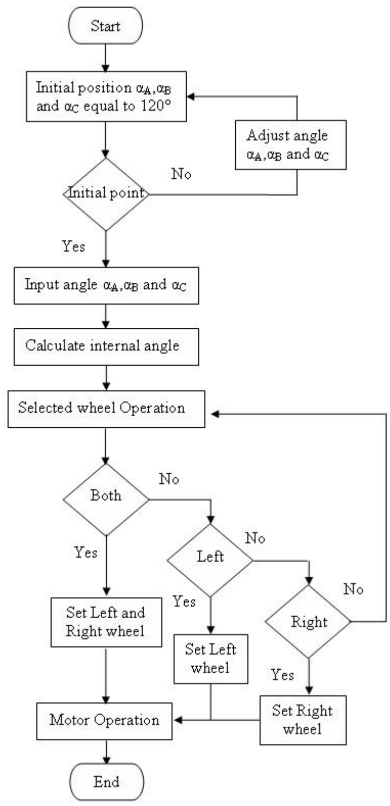


Fig.8. Typical move command flowchart2.

VI. TEST METHODOLOGY AND RESULTS

A. Functional Test

Various tests were done regularly during the design and development phases of the triangular based robot. Each individual motor was tested one at a time to make sure that each piece of the robot was working properly before they can be assembled together. After that, each individual feature such as: run forward, run backward, rotate left, rotate right all of them on smooth surface were then tested. Additional function tests included the following: extrusion, contraction, weight ship, climbing up and down stair, etc. The above tests were done to make sure that the robot can perform up to the specification that the research were set out to do.

The following are 5 typical tests on the robot, they are move in straight line, angle increment, angular adjustment, angle limitation and ball screw movement. The tests are in Figure 9, 10, 11 and 12. The results of the above tests, they are summarized respectively in Table 1.0, 2.0, 3.0, 4.0 and 5.0.

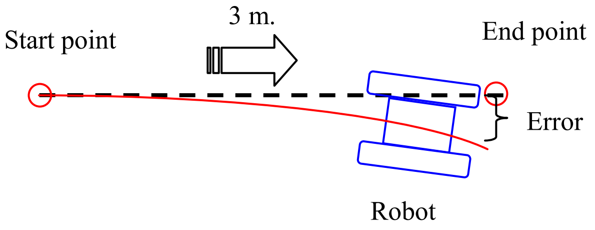
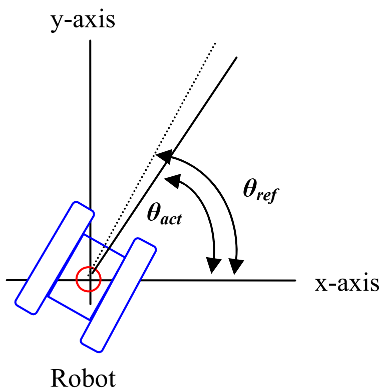


Fig. 9 Typical straight line move

Table 1.0 Typical errors when move in straight line at an increment of 35 centimeters each.

Distance (cm)	**Output (cm)**	**Error (cm)**
0	0	0
35	34	0
70	73	0.5
105	103	1.5
140	138	2.4
175	172	3.5
210	206	4.2
245	241	5.6
280	276	6.5
315	309	7.8



$$Error = \theta_{act} - \theta_{ref}$$

where: θ_{ref} is the desired angle and θ_{act} is the measured angle

Fig. 10 Typical test on angle increment

Table 2.0 Typical errors in tracking wheel movement of 45 degrees increment.

Input Degree θ_{ref}	**Output Degree θ_{act}**	**Error (degree)**
45	54	9
90	100	10
135	143	8
180	191	11
225	234	9
270	280	10
315	324	9
360	370	10

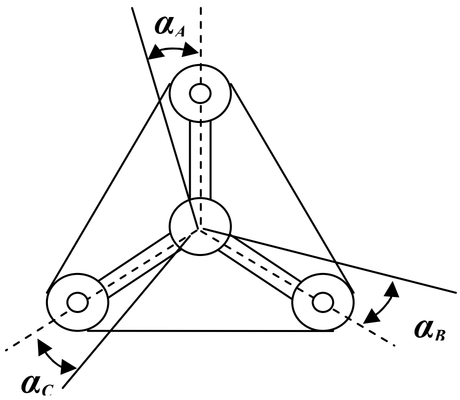


Fig. 11 Typical test on angular adjustment

Table 3.0 Typical errors in the error of adjustment angular.

Case	**Desire (degree)**			**Actual (degree)**			**Error (degree)**		
	α_A	α_B	α_C	α_A	α_B	α_C	α_A	α_B	α_C
1	120	120	120	122	118	123	2	2	3
2	105	105	150	109	103	146	4	3	4
3	145	95	120	148	97	125	3	2	5
4	95	145	120	100	148	126	5	3	5

Table 4.0 Typical motion parameter specification for angle limitation on each link.

Parameter		**Min.**	**Typ.**	**Max.**	**Unit**
Adjustable Angle	Angle α_A	95	120	150	degree
	Angle α_B	95	120	150	degree
	Angle α_C	95	120	150	degree

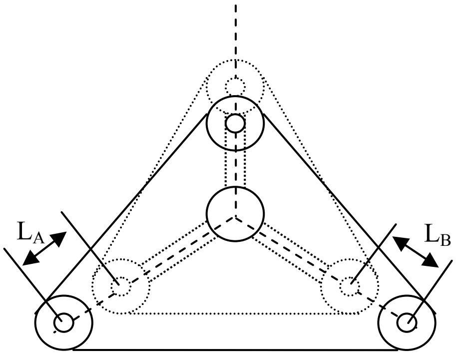


Fig. 12 Typical test on ball screw movement

Table 5.0 Typical result values of the ball screw movement.

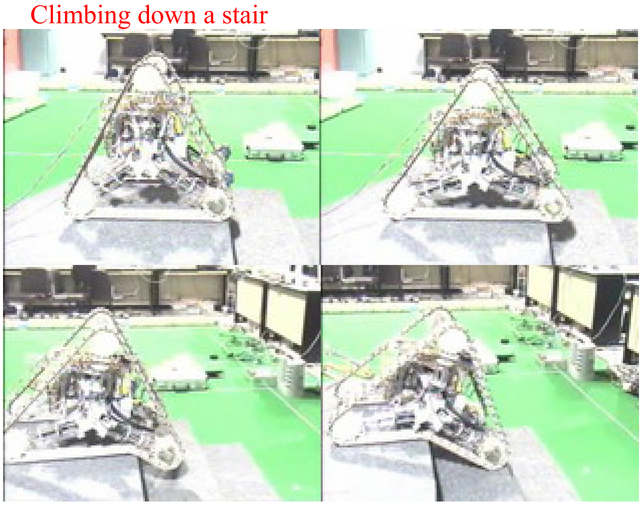
Parameter	**Reference Position(mm)**		**Actual(mm)**	
	Max.	**Min.**	**Max.**	**Min.**
L_A	70	-40	60	-30
L_B	70	-40	60	-30

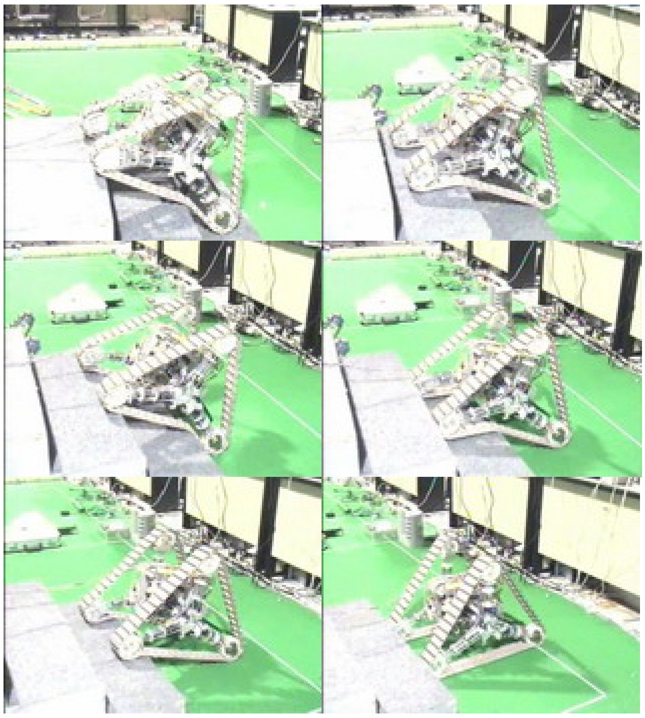
B. Performance Test

Various performance tests were done to find the limitation of the triangular based robot in all areas, after the tests the robot still can hold its own ground in the performance tests. There are some observations such as: the speed of the robot is a little bit slow which is the same for the rest of the activities on the robot. There are some effects due to backlash in the worm gear section. The structure of the robot needs to be strengthened to allow the robot to support additional weight of the upper body of the triangular based robot in the future.

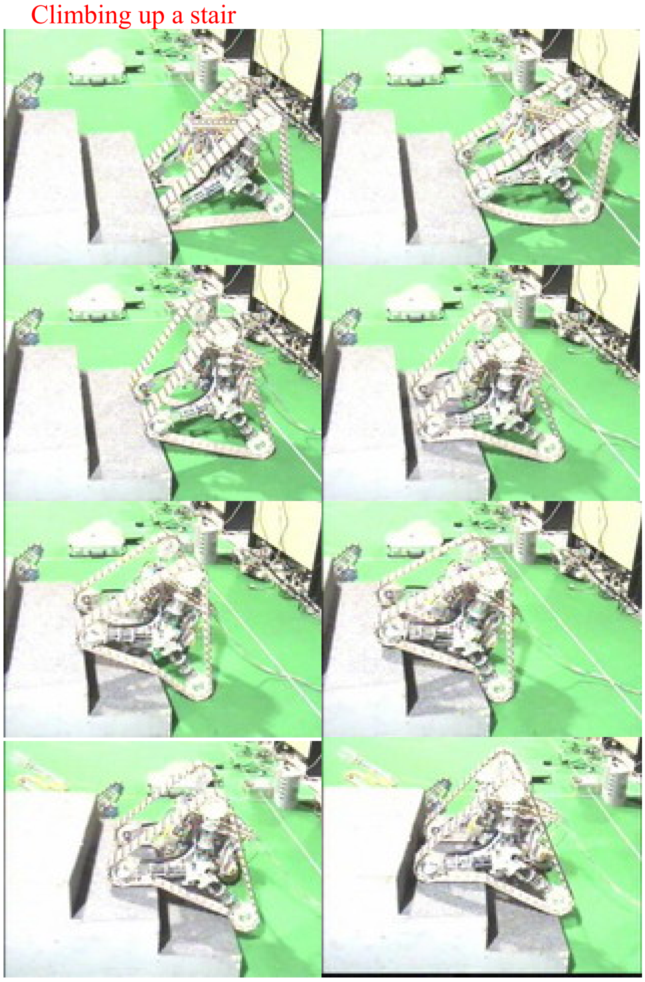
Fig 13 is typical tests on climbing down and up the stair by the robot.

Climbing down a stair





Climbing up a stair



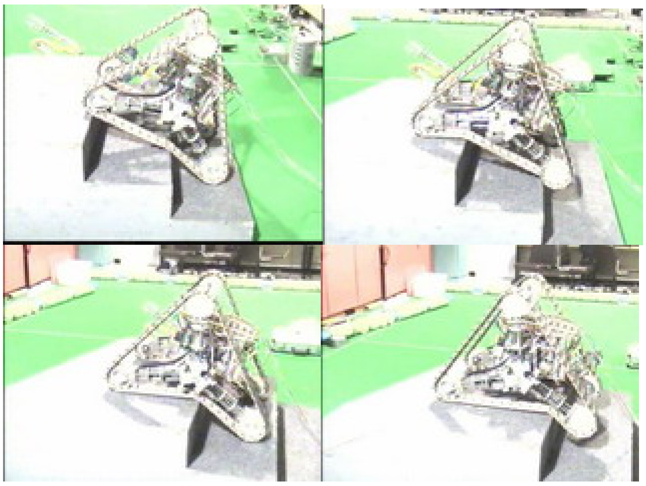


Fig. 13 Typical move down and up the stair

VII. Discussion

More researches need to be done in this area and future improvements are recommended to improve the performance of this type of robots, they are as follow:

1) Increase the speed of the robot to make them move faster for the real-life applications.
2) Minimize any possible backlash in worm gear design.
3) Strengthen the current structure to support more weight.
4) Use PID control instead of current PI control.
5) A smaller computer such as PC104 is recommended due to space limitation on the robot and provide the stereo vision capabilities which is necessary in the future.
6) Additional hardware is required to enhanced the accuracy of the angular adjustment on the robot.
7) Additional sensors such as: ultrasonic sensors to make obstacle avoidance more realistic, some types of electronic compass or gyro-meter or GPS to allow the robot to maintain it's position and heading.
8) New supporting software or modification of related software will be done accordingly.

VIII. Conclusion

This paper presents a new design concept on adaptive geometry mobile robot which was Phase I of a joint effort between AIT and SPU. This joint effort has been continued in Phase II for approximately a year at AIT to build the upper portion of this adaptive mobile robot. Once the upper portion is done, the final Phase III will integrate both portions together to form the complete robot. Fig. 14 and Fig. 15 are Typical Phase III full robot in Non-expanded mode and Typical Phase III full robot in Expanded mode respectively.

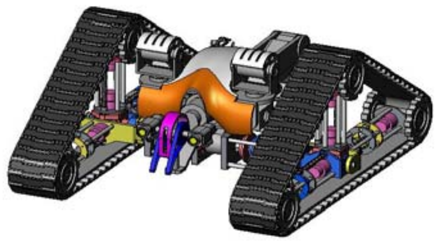


Fig. 14. Typical Phase III full robot in Non-expanded mode.

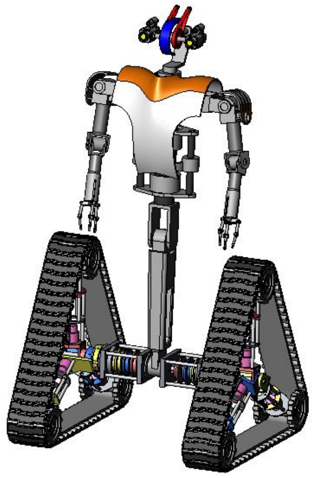


Fig. 15. Typical Phase III full robot in Expanded mode.

Additional hardware and the major portion of artificial intelligent software will be developed in the final Phase III to make a complete autonomous robot in the very near future.

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