A SELF-TRANSFORMING CATEPILLAR ROBOT DESIGN FOR EFFECTIVE NAVIGATION IN A CLUTTERD ENVIORENMENT

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ABSTRACT

A mobile robot navigating an indoor space should overcome various static and dynamic obstacles in its path as well as operate through different man-made structures. The self-transforming robot design presented in this work was motivated through the need to autonomously adjust to requirements and limitations in the surroundings in an indoor space, for efficient navigation. The caterpillar design can be transformed to several poses, according to height or width restrictions, while maintaining full mobility. The transformations and mobility were tested in an indoor-like environment cluttered with obstacles.

Key Words: Mobile robot, Indoor navigation, Self-transform

1. INTRODUCTION

Self-transforming robots are autonomous kinematic machines, able to deliberately change their shape by re-arranging their parts in order to achieve a specific task. These mobile self-transforming robot are used in many fields such as, military, space explorers, hospitality, Medical, etc [1,2],. Self-transforming robots has been used as space explorers [3] robots dedicated for bin picking [4], and in industrial environments performing labor intensive tasks [5] .

This paper focuses on the design of a self - transforming robot. It concentrates on the primary development of concepts for a robotic caterpillar that can explore or operate in small areas where the human are not able to reach and expand limbs. The concept of Self-Transforming Explorers has been used in various robots in reaching unreachable places in industries, space and other rough places. In this project our primary objective is of mechanisms to self- transform.

A Self-Transforming Caterpillar is a hybrid system composed of a combination of conventional system components and elements such as, actuators, sensors and power networks.

The proposed design can change its pose and orientation with six transformations. One key objective was to design a robot can self- transform in a stable manner, while maintain full mobility. It can navigate any smooth or terrain surfaces. It can also be used to climb stairs and climb over small obstacles. This robot can transform itself to move across narrow places (between two obstacles) and also it can adjust itself to crawl under furniture. Pushing light objects from one place to another is another capability of this product. The rest of this paper presents the core-concept, design, operation, and system architecture of the self-transforming caterpillar.

2. BACKGROUND

It has been demonstrated through research into modular robot [3], that a large number of unique system configurations can be realized with a small inventory of parts, as shown in Figure 1. The result is that a highly capable robotic system can be achieved composed of simple elements.

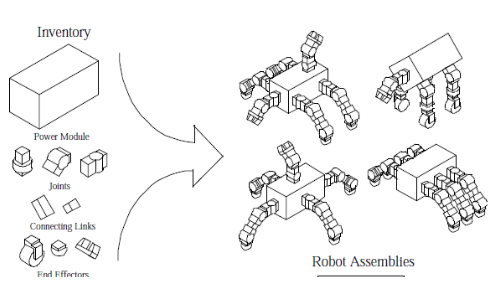


Figure 1: A Modular Design Approach to Robotics [3]

Using basic analysis, simulations and laboratory experiments, the STC concept is studied and determined its potential and its fundamental limitations. An essential objective of the work has been to identify some of the key enabling applications that will be required for the successful implementation of self-transforming robot concept.

3. PROPOSED DESIGN

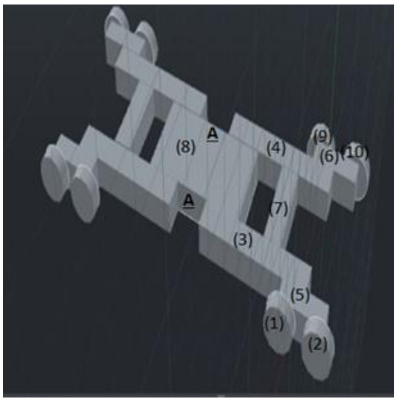


Figure 2: 3D vive of the proposed self-transforming caterpillar

The self-transforming robot is symmetrical about the A-A axis as shown in figure 02. (1),(2),(9),(10) are the wheels which are independently connected to four dc motors (5),(6). The chassis (8) is lifted by the high-torque dc motor (7).

The caterpillar was designed in such a way that by moving the arms it can transform into different positions. There are six joints, two of them are independent (the two grey strips are the high toque motors) and the other four are at the edges of the robot with four other high toque motors. The torque needed for robot's mobility is supplied by 6 geared DC motors each of rpm 180. Chassis is lifted by the use of its wheels connected at each DC motor.

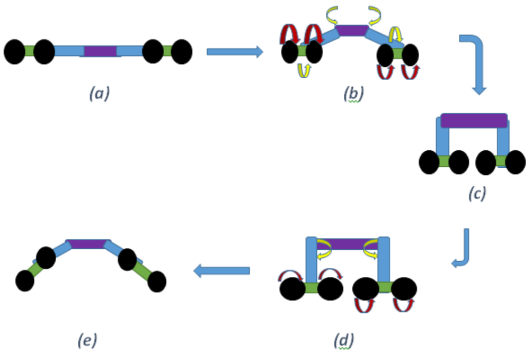


Figure 3: Transformation sequence of the caterpillar

Figure 3 illustrate the caterpillar transforming itself in a sequence. In order to bring the robot to a completely horizontal pose (Figure 3 (a)) 9v power is given to a high torque motors to turn the arm, then the arms with the wheels are used to overcome the friction so that it will help the high torque motors to transform easily. The power needed to turn the Wheel is supplied by geared DC motors.

This is considered as the idle position for the robot. The robot can move through a gap of 6cm ~ 10cm while maintaining this pose.

Figure 3 (b) and (c) illustrate the caterpillar operating at different heights. High torque motors in the chassis are powered to bring the arms vertical position. Therefore the black and white strips which is used as an encoder, measures the angle of rotation needed to turn it into a vertical position. The arrows in the above figure show the direction of the rotation of the arms and wheels.

The force analysis determines if the high toque motor is capable of providing the required torque, determined by considering its static equilibrium in its current position. This evaluation method is consistent with the fact that the high toque motor is going to move at slow speeds: a quasi-static approximation is appropriate.

Moreover, under this hypothesis, if the different evaluation positions of the high toque motor are closely distributed in space and time, the torque distribution on the wheels that verifies the high toque motor's balance can be approximated as the actual commanded torques and can be used to calculate power consumption.

The center of mass affects the load distribution on the wheels and the stability of the vehicle. It is therefore critical to compute its location. From this, the input force to the system was deduced.

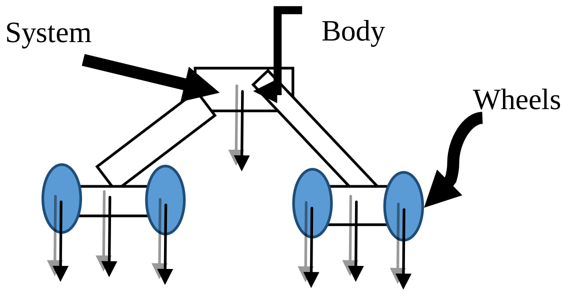


Figure 4: The mass distribution of the caterpillar

The input forces can be expressed as a wrench that will be located at the center of the body. This input wrench vector is composed of six components computed in (**x**", **y**", **z**"): $[\ Fxi, Fyi, Fzi, Mxi, Myi, Mzi\ ]^T$. The quantities *Fxi*, *Fyi* and *Fzi* are the components of the sum of all the externally applied forces in **x**", **y**" and **z**" respectively. Mxi, Myi and Mzi are the components respectively in **x**", **y**" and **z**" of the moment created by the sum of the externally applied forces on the center of the body. These external forces can be arbitrary forces or moments along the direction of motion of the system. Forces resulting from the manipulator's interaction with its environment can be represented as well.

The Center of mass in the initial position is balance with the final position so it can tilt around 45 degrees from the horizontal position.

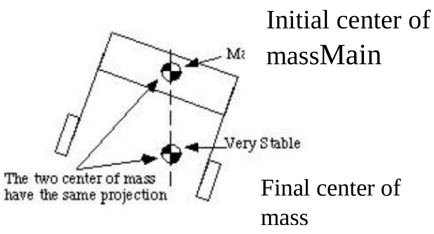


Figure 5: Center of Mass of the robot.

Table 1: List of Components used in the prototype

Component	Count	Power supply
Yellow DC motors	08	6 V
High Torque Motors	06	12 V
Wheels (Diameters 7cm)	08	12 V
Motor Drivers	02	12 V
IR Sensor circuits	04	5 V
Arduino MEGA	01	12 V

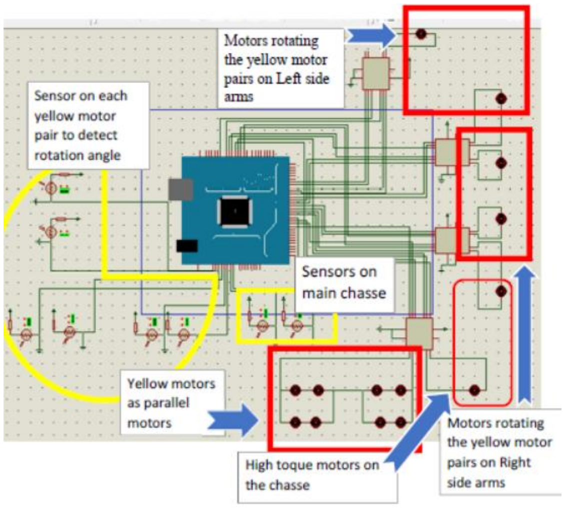
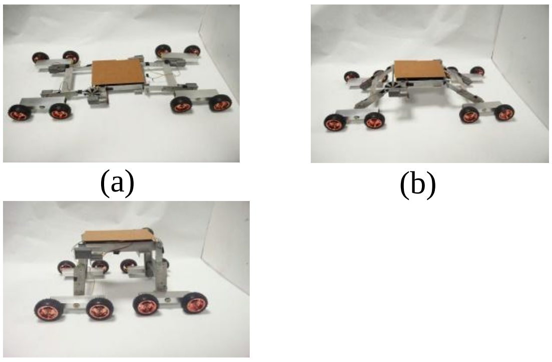


Figure 06: System block diagram of the robot. The System controls 14 motors via pulse with modulation using 4 motor drivers.

Figure 6 illustrates the key components and system architecture of the caterpillar while the specifications for the developed prototype are given in Table 1.

4. RESULTS

A major challenge in developing the prototype was to obtain the required angular motion to provide the transformation necessary to shift the original shape of robot to the most effective pose such that it can easily navigate through a particular location. This robot is able to change its shape based on its task and this allows it to be used for various purposes, as given in Figure 7.



(c)

Figure7: Transformation poses of the real product (a) – (c)

5. CONCLUSION

The aim of this work was to develop a self-transforming caterpillar, a machine capable of carrying out operations in hazardous environment and unchartered areas where human intervention is minimal. In order to achieve the objective of operating autonomously in environments where direct human intervention is not feasible, this robot can self-transform. In this paper, a successful design of the self-transforming caterpillar with features such as changing height autonomously is presented. As future works, using a camera attached to the robot so that it can provide a live feed and scan the area, and use GPS to self-navigate to achieve a given task.

6. REFERENCES

[1] L. Xuan, Z. Minglu, and L. Wei, *"Function-based modular robot system,"* International Conference on Mechatronics and Automation, Changchun, pp. 3190-3195, 2009.

[2] K. Kotay, D. Rus, M. Vona, and C. McGray, "*The Self-Reconfiguring Robotic Molecule*," in proceedings of the IEEE Conference on Robotics and Automation, Leuven, Belgium, pp. 424-31, 1998.

[3] S. Dubowsky, "*Phase Study of Self-Transforming Robotic Planetary Explorers,"* Field and Space Laboratory Department of Mechanical Engineering Massachusetts Institute of Technology

[4] M. Nieuwenhuisen, D. Droeschel, D. Holz, J¨org St¨uckler, A. Berner, J. Li, R. Klein, and S. Behnke, "*Mobile Bin Picking with an Anthropomorphic Service Robot", in* proceedings of the IEEE Conference on Robotics and Automation (ICRA), Karlsruhe, Germany, May 2013.

[5] Ackerman Warehouse Forum, "*Robots in warehouse",* vol. 23, no. 5, April 2008.

[6] H. Zhang, J. Gonzalez-Gomez, Z. Me, S. Cheng, and J. Zhang, *"Development of a low-cost flexible modular robot GZ-I,"* IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Xian, pp. 223-228, 2008.

[7] W. Wu *et al*., "Task-oriented inverse kinematics of modular reconfigurable robots" *IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, Wollongong, NSW, pp. 1187-1192, 2013.