

Fabrication of Autonomous Wheeled Mobile Robot for Industrial Applications Using Appropriate Technology

M. M. Islam, Rajib K. Saha, Abdullah A. Amin, and M. Z. Haq

Abstract—The autonomous mobile robot was designed and implemented which was capable of navigating in the industrial environments and did a job of picking objects from variable height and delivering it to another location following a predefined trajectory. In developing country like Bangladesh industrial robotics is not very prevalent yet, due to the high installation cost. The objective of this project was to develop an autonomous mobile robot for industrial application using the available resources in the local market at lower manufacturing cost. The mechanical system of the robot was comprised of locomotion, gripping and elevation system. Grippers were designed to grip objects of a predefined shape. Cartesian elevation system was designed for vertical movement of the gripper. PIC18F452 microcontroller was the brain of the control system. The prototype autonomous robot was fabricated for relatively lower load than the industry and the performance was tested in a virtual industrial environment created within the laboratory to realize the effectiveness.

Keywords—Industrial application; autonomous mobile robot; appropriate technology.

I. INTRODUCTION

USE of technology and materials available at local markets in the developing countries to design and manufacture robots has been the major challenge. Industrial prototype robot was fabricated from locally available resources and cheaper technologies that would be viable for industries in the developing country like Bangladesh. Devoid of high tech and appropriate components at local market often lead to the kind of reverse engineering. So, materials were collected from the local hardware or automobile surplus store at first then design was performed based on available resources to maintain overall fabrication cost lower.

M. M. Islam is a lecturer in the Department of Mechanical Engineering in Bangladesh University of Engineering and Technology (BUET), Bangladesh. (phone: +8801911703718; e-mail: mahub.me.buet@gmail.com).

Rajib K. Saha is a graduate student in Mechanical engineering in Bangladesh University of Engineering and Technology (BUET), Bangladesh. (phone: +8801818325295; e-mail: saha.me.buet@gmail.com).

Abdullah A. Amin is a Phd student in Mechanical engineering in university of Akron, USA. (e-mail: nirjhor18@gmail.com).

M. Z. Haq is a Professor in the Department of Mechanical Engineering in Bangladesh University of Engineering and Technology (BUET), Bangladesh. (e-mail: zahurul@me.buet.ac.bd).

* All Authors have equal contribution to the work.

The prototype autonomous robot was fabricated for relatively lower load than that of the industry to test the performance on a dummy industrial setup. The robot is capable of maneuvering through a predefined path to grip an object from variable height and to deliver it following predefined trajectory. For structured regular terrain of the industries wheeled robot is the optimal solution [1]. Differential front wheel drive system was used for ease in maneuvering and veering. The robot facilitates re-programming with the change in industrial environment.

In this paper use of locally available technologies to design and fabricate different sub-systems such as driving, gripping, elevation and microcontroller based intelligent control system of autonomous mobile robot are delineated.

II. INDUSTRIAL TEST SETUP

The robot performance was simulated and tested in a virtual industrial setup as shown in Fig. 1 where the robot could pick an object from a dummy conveyor belt; carry it following a trajectory to deliver to a delivery van. Three different paths could be chosen using switches mounted on robots. Three unloading stations were created to test the robots accuracy in different trajectories. Some obstacles were placed to test the robots accuracy to follow the predefined path.

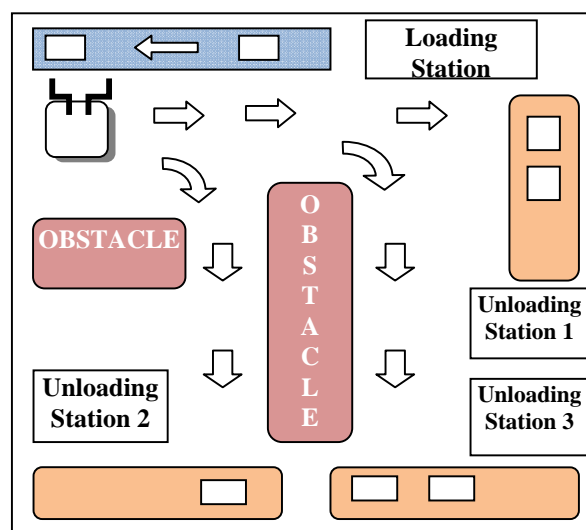


Fig. 1 Dummy industrial environment.

III. MECHANICAL DESIGN ASPECTS

In fabrication of the prototype robot weight was always a pivotal factor. Light weight materials were chosen as weight is directly related to the required motor power and scarcity of high torque motor was a limiting factor in mechanical design. The basic mechanical systems that comprised the robot were drive systems to provide the robots mobility, the elevation system for vertical movement and the gripping system to grip the desired objects. The full view of the robot and the corresponding CAD model is shown in Fig. 2.



Fig. 2 (a) Full robot view

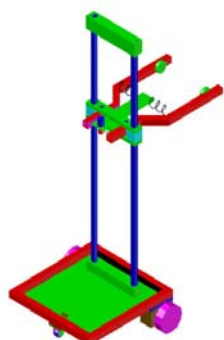


Fig. 2 (b) Robot CAD model

Technical details of the robot are summarized in the table I.

TABLE I
TECHNICAL SPECIFICATIONS

Robot weight	11 Kg (with battery)	Gripper extension range	0-250 mm
Robot height	900 mm	Graspable object size	50 -200 mm cube
Base area	800 × 500 (mm)	Power supply	DC 12V , 6A
Elevation range	100 mm (750 -850)	Motor power	40 W

A. Locomotion/Drive System

1) Driver System Construction

To construct the chassis square Aluminum channel was chosen because of its high strength to weight ratio to meet the weight constrain and also for its availability in the local market. For the accommodation of the power supply, motors and circuit boards, some portion of the chassis was covered by thin aluminum plate. Schematic of the chassis is shown in Fig. 3.

The locomotion system of the robot comprised of two DC gear motor powered wheel and one caster. Differential casters were designed and used to eliminate its initial alignment

problem which creates accuracy problem in following the predefined path. That showed remarkable improvement in performance in lower velocities, but failed in higher velocities due to the skidding problem.

Considering the loading condition of the robots the wheels were kept overhanging i.e. supported on one side through bearing to avoid the unnecessary frictional power loss associated with both side supported configuration resulting from the shaft bending. The actual motor mounting and the bearing housing is shown in Fig. 4. Wheels were fabricated from Nylon due to its light weight, excellent abrasion resistance and availability at local market. To increase the traction force rubber mat was used as tire. The dimension of the wheel was traded off between the available motor torque and stability of the structure. The larger diameter wheels required higher torque from the motor and the stability decreased due to the raise of the center of gravity of the machine.

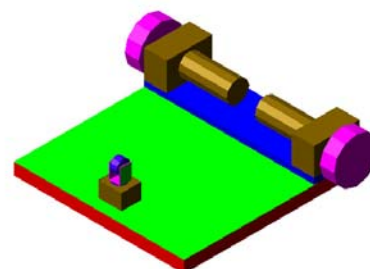


Fig. 3 Chassis schematic

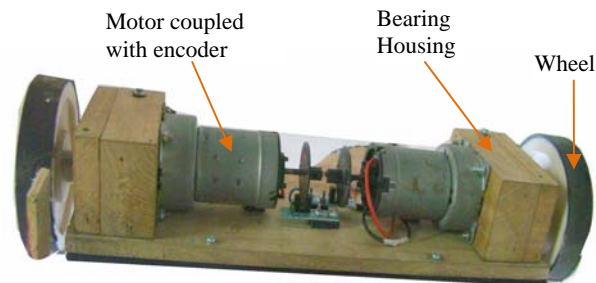


Fig. 4 Motor mounting

2) Steering Strategy

Differential action was achieved by controlling the duty cycle of individual motors connected with two drive wheels. Stepper motor operated steering was also tested in another previous project and was avoided here due to additional intricacy in the control strategy and the remarkable deviation in reaching the destination resulting from slightest inaccuracy in steering.

In the differential drive system, synchronization of two drive motors was most vital factor. The drive system using motors with similar electrical characteristics can behave erratically and follow curvilinear path when prompted for straight run if two motor axes do not coincide on a same straight line. The only source of the motors was the surplus

automobile shops and it was fortuitous to find identical motors. Motor was mounted with the highest possible accuracy that was obtainable through available facilities. Encoders mounted on each drive motors ensured feedback control and an intelligent program strategy was developed to make the drive system independent of these parameters and that finally exhibited well predictive behavior.

B. Gripping System

To grip objects of a predefined shape without distortion and deformation grippers are designed. Grippers of general purpose are capable of gripping objects of irregular shapes. Tactile sensors were incorporated to ensure the perception of gripping. With the increased application of autonomous mobile robots, general purpose robotic grippers with the ability to grasp and identify objects of different shapes appear as of greater importance. Autonomous robots of those are to be used in industrial application require the sense of touch to make sure the gripping of a predefined shape. Tactile sensors were used at different positions along with timing control of actuator in the range of microseconds with the aid of microcontroller to ensure the perception of gripping.

String Pulley Gripper

While designing and fabricating the grippers the availability of suitable materials at local markets were the main concern. Instead of using ready-made components all the parts were fabricated from Aluminum square channel, Aluminum thick plate and spring collected from local hardware store and DC gear motors from used-photocopy machines.

Gripper jaws were pivoted on the slider sandwich structure supported by bearings. Based on the available motor torque and the required stiffness of the spring, distance from the pivot point of the jaws and to the spring attachment point was calculated. The gripper-elevation assembly and the CAD model are shown in Fig. 5.

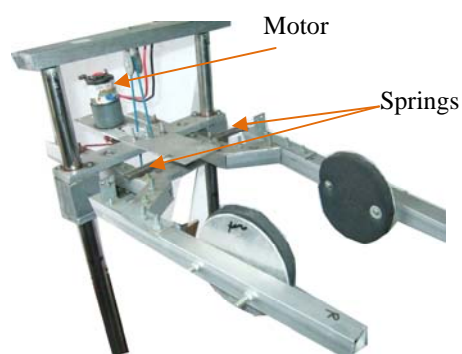


Fig. 5 (a) Gripper view

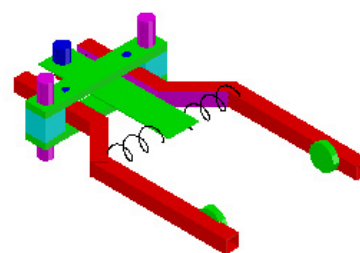


Fig. 5 (b) Schematic of gripper

The gripping force were provided by the spring set in between the neutral plane and the actuating jaws where as the motor set backward of neutral plane draws and elongates the springs by drawing the string on a pulley which is attached with the jaws at rear end. The gripper opened by the pulling force created by the motor but gripped the object by the spring force. The pulley diameter was also optimized based on available motor torque. The main drawback with string pulley was the unreliable elasticity of the string used which causes intricacy in the gripper actuation only with timing control. Another problem arises if proper time control is not provided for the gripper to set close the string wounds in the pulley in reverse direction and causes the gripper to open again. The timing control of the motor was used to control the gripper actuation which assisted by tactile sensors set at different position of the gripper jaws to send interrupt signal to the microcontroller. Tactile sensors were used as limit switches to circumscribe the gripper jaw positions within reasonable range, thus providing smooth operation, preventing motor stalling and over winding in pulleys which would result in string failure. This type of gripping system requires motors with high torque or consideration in the operation time if weight is a major concern because motor with high power density is not much available.

C. Elevation System

In industrial application objects need to collect and unload to/from variable heights. The purpose of elevation system in robots is to provide vertical movement. Lower manufacturing cost and limitation in the resources as well as available limited machining facilities were always taken into account which directed towards simplified system design. Elevation system is shown in Fig. 6 (a).

A sandwiched structure of two rigid Aluminum bar was used as a slider and was mounted on two circular guide ways of stainless steel, provided for the movement of the slider system. Circular guides were drilled on the rigid bar with a clearance of around 0.25 mm. Slider sandwich and guideways schematic is shown in Fig. 6 (b).

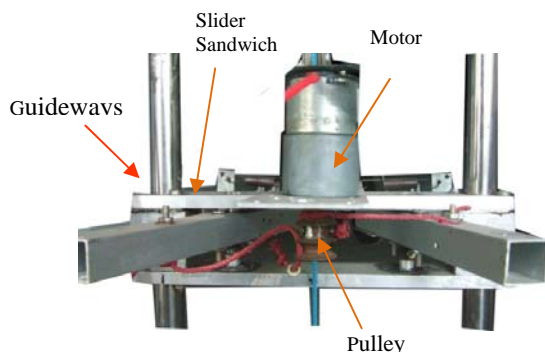


Fig. 6 (a) Elevation system



Fig. 6 (b) Slider sandwich and guideways schematic

Previously in another project four rod pulley sliding system was implemented where four rollers rolled over four circular rods producing the sliding motion. The system used circular stainless steel guideways and for each of the guideways two nylon made pulleys were used to roll over it with less friction. Vertical distance between these two pulleys was optimized by calculating the moment generated by the gripper system attached to the slider. Power window motor collected from surplus automobile shop and string pulley system was used to move the slider vertically. But the rollers needed to be realigned or the contact force between the roller and the circular rods were needed to be calibrated periodically. Two guideways sliding system largely reduced the difficulties of higher weight and space of four guideways system.

Wear due to protracted use enlarges the clearance provided consequently slider jerks on movement, increases required motor power and sometimes even often stalls the motor.

IV. CONTROL SYSTEM

For the control system PIC18F452 microcontroller was used as a main processing unit. All the circuitry other than microcontroller programmer was collected from local market. Printed Circuit Boards (PCBs) were made in the laboratory to reduce the cost. Detail layout of circuit board is shown in Fig. 8.

Close loop control system was employed for driving motors and open loop system for gripper and elevation system. Close loop control system is shown in Fig. 7. For feedback control system encoders were mounted on drive motor to count the number of rotation as feedback to the microcontroller. Similar encoders were used by Mariolino et al. to count the rotation of their automated vehicle drive wheels [2]. IR sensors were used to convert encoder rotation into a sequence of digital pulses. IR sensor mounting is shown in Fig. 9. The encoder was

capable to track 1/780 parts of wheel rotation. Identical motors were chosen for this purpose but the motors possessed different characteristics on its CW and CCW rotation. As in the differential drive system both motor rotate in the opposite direction in case of straight movement so energizing motor with same power causes motors to travel slightly different path. To resolve the problem a function was used in the microcontroller program which continuously counted the rotation of each motor and calculated the difference in rotation count on every 10 milliseconds and the motor which lagged, the duty cycle for the motor was increased to keep the vehicle straight. For left/right turning pulse width duty cycle of one motor was altered thus the vehicle changed its direction. As the robot was tested for some defined path so values of the duty cycle were set to take the necessary turning. To avoid hard collision the robot would retard while being near the destination.

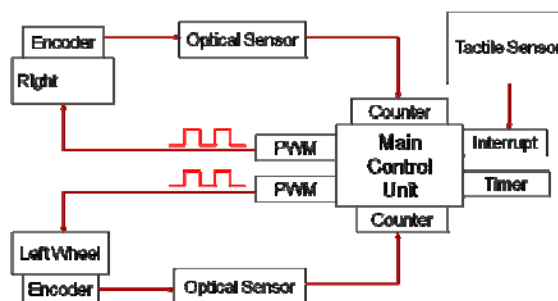


Fig. 7 Close loop control of drive motor

H-bridge circuit with electronic braking was used for motor controller. Motor controller and microcontroller circuit board is shown in Fig. 10. When the power of the DC motor turned off due to inertia it continues to move some more paths so precision movement controlling was difficult. Regenerative electronic braking was used to stop the vehicle instantly with millimeter accuracy. In the regenerative braking system both terminal of the motor was short circuited and motor act as a generator producing current in reverse direction of what was supplied to the motor causes the motor to stop momentarily.

Microcontroller Board

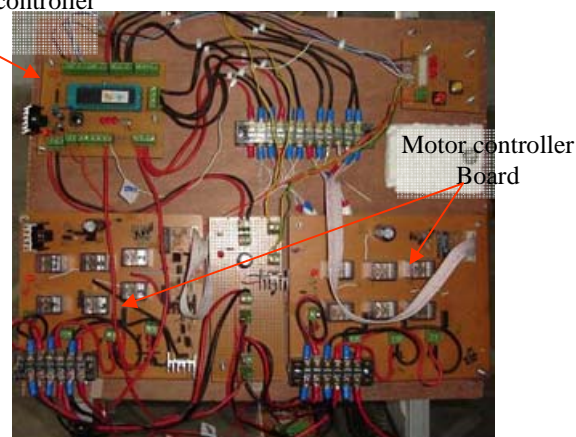


Fig. 8 Layout of full control circuitry

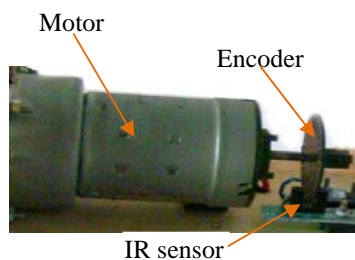


Fig. 9 Encoder and IR sensor

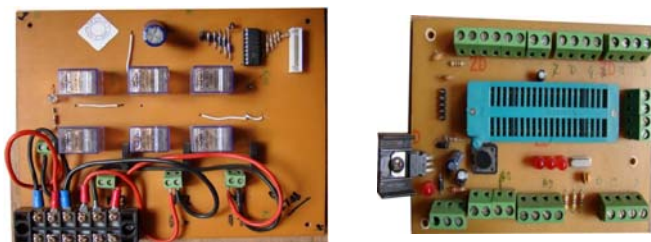


Fig. 10 (a) Motor controller circuit board (b) Microcontroller board

Tactile sensors were used for robot safety and to track destination reached. In the gripper and slider tactile sensors were acted as limit switch to avoid possible motor stall. Gripper mounted sensors limit the maximum opening of the gripper as well as to track the desired gripping object and in slider it was connected on both end of the guideways support to circumscribe the movement. At the front end of the base this sensor used to ensure destination reached.

The microcontroller was reprogrammable to facilitate necessary alteration for disparate environment. Microcontroller in-built Timers were used to count the time for each operation. Internal interrupt features of the microcontroller were used for timer overflow and external hardware Interrupt was for each tactile sensor. These sensors were operated to yield the program an interrupt signal.

V.CONCLUSION

Robots manufactured in this project can be characterized by appropriate use of available engineering resources. Industrial process automation and product quality enhancement in Bangladesh is now expected for the countries overall development as it is trying to develop industrially. Automation is generally associated with high cost technologies. The main approach of this project was to fabricate autonomous machines which could perform sophisticated tasks, using local engineering resources maintaining a low budget. Very basic and sometimes primitive engineering methodologies and tools were chosen without compromising efficiencies and this was found to work well. Overall cost was considered as a vital point so components were searched and collected in the local market, and then according to their availability optimized design was chosen to meet the requirement of task completion. This added several constraints while selecting suitable material and proper design.

Modification of the robots to meet versatile industrial needs is possible without incorporating high cost. Different features like path follower, ultrasonic sensors, and proximity sensors can be easily incorporated in these robots if implemented for industries.

Image processing and high tech laser system was avoided for sake of lower manufacturing cost. Overall the design and fabrication of the robots is good example of utilizing appropriate technology in the perspective of developing country like Bangladesh.

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M. M. Islam is a lecturer in the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. He received his B.Sc. in Mechanical Engineering from the same university in 2009. He is currently pursuing his M.Sc degree in the same university. During his undergraduate studies he was involve with robot fabrication for an international competition, Robocon. He has taken part in the Robocon 2008 held in India as the Team Leader of Bangladesh team.



Rajib K. Saha received his B.Sc. in Mechanical Engineering from Bangladesh University of Engineering and Technology, Dhaka, Bangladesh in 2009. He is currently doing computational work on micro channel flow towards his M.Sc. in the same university. During his undergraduate studies he was involved with robot fabrication for an international competition, Robocon. He has taken part in Robocon 2008 held in India as the pit crew of Bangladesh team.



Abdullah-Al-Amin received his B.S. degree in Mechanical Engineering from Bangladesh University of Engineering and Technology (BUET) in 2009. At his undergraduate level he has participated in the ABU Robocon 2008 on behalf of Bangladesh University of Engineering and technology.



M. Z. Haq is a Professor in the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh. He received his Ph.D. in Mechanical Engineering from The University of Leeds, UK in 1998. He is a Fellow of IEB since 2007. His research interests include thermo-fluid dynamics, combustion, mechatronics, robotics and industrial control systems.