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Robotic Crawler for Structural Health Monitoring of Tanks and Furnaces

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Abstract
In Metallic (ferrous) storage tanks and furnaces weak spots are developed and this needs to carry out regular maintenance and inspections tasks. Manual inspection (such as, visual inspection) is a difficult and time consuming task. This paper aims to replace human inspectors by designing a wall crawling robot with permanent magnetic wheels. The Robotic crawler has been designed to be operated in either an autonomous mode or tele-operation mode. The robotic crawler is capable of transmit real time video and safely traverse between boundaries walls even if they are perpendicular. The on-board central control system is present in the robotic crawler which manages multiple sensors and coverage algorithms help robotic crawler to navigate autonomously to the desired location of the wall. A prototype of robotic crawler has been developed and operated in various constrains. The developed robotic crawler does have enough capacity to travel for about 40–45 min and covers approximately 300–350 m distance.

Keywords: *Permanent magnets, visual inspection, autonomous, tele-operation, Navigation, localization*

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INTRODUCTION

The evolution of robotics research in the last five decades has grown multi-fold in response to the evolution of human social needs, from the industrial robotics that released the human operator from dangerous or risky tasks to the recent explosion of field and service robotics to assist the human. The new trends in robotics research are orienting towards service robotics because of the general goal of getting robots closer to human social needs and to increase the reach of robotics in fields such as medical robotics, rehabilitation robotics, underwater robotics, field robotics, construction robotics and humanoid robotics. With the rapid modernization of the world, new types of services are being required to maintain a certain quality of life.

A new promising robotics sector is arising to serve the human being are modified to respond to the new market ensuring the safety of human operators in hazardous industrial environment, resulting in implementation of robotics for several purposes such as; navigation, maintenance, servicing, inspection etc. One of the major is, marine vessel and shore tanks inspection which is shown in Ref.[1]. As all industries are forced to follow the routine inspection that will enable higher performances according to general trend of rationalization so as to reach a higher level of standardization of procedures of safety and financial criteria. One of way to achieve this is through the incorporation of more technological means that increase the level of automation. In this field the mobile robots play a major role. The term mobile robot describes a robotic system able to carry out tasks in different places and consisting of a platform moved by locomotive elements. The choice of the locomotive system depends firstly on the environment in which the robot will operate. This can be aerial, aquatic or terrestrial. The choice of the locomotive system on earth is more complicated due to the variety of terrestrial environments. Wheels, tracks, and legs are typical terrestrial locomotive elements different types of mechanism and adhesion principle are shown in Ref.[2].

There are few autonomous robotic systems that replace the human intervention in the field of inspection. But those conventional mobile robots are normally large in size depending on the task the machine has to endure. With bigger size, comes a substantial amount of weight which then results to a significant rise on the force needed to move the robot. In these case, bigger actuators (motors) consuming more power and the locomotion or the movement of the robot generally becomes slower. Large mobile robots are normally attached to an external power source whether is pneumatic, hydraulic or electrical power source. The plan here is to surpass all these weakness or element that prevents the full efficiency of a Robotic Crawler (Wall climbing robot). Most of the research was started in the early 90's and developed first prototype which are able to climb vertical walls. Often seen wall climbing robots in the field of inspection application are REST[3], ROBUG[4], NINJA[5].

Besides the mechanical design implementation of the climbing robot, another important issue is the implementation of the navigation and localization platform. Since most of the climbing inspection robots are semiautonomous or tele-operated[6,7], results in reducing the flexibility of the inspection task. Kalra *et al*.[8] presents a climbing robot which can be operated in autonomous mode. Using a surface coverage algorithm based on the distance transform function which allow the robot to navigate itself on the tank surface.

RELATED WORK

Already many researches and approaches exist in industries for vertical and horizontal metallic wall climbing robots that use magnets and suction pads. Robots which are using magnets for their adhesions can be divided into two categories wheeled and tracked systems.

Tracked system use heavy magnets at the different section of the robot chassis. Some tracked system uses magnetic tracks for both locomotion and traction for the example Neptune[9], Tripillar[10]. The main drawback of the tracked system is that they cannot climb on uneven terrain or walls.

Some other inspection robots which use suction pads such as, DEXTOR robot[11] with two articulated arms are suitable only for the very flat, glossy and clean environment like window, dry surfaces[2]. The biggest drawback these robots have is that they are not robust against disturbance like dust. Furthermore, the robot must stay in motion since the suction pads slightly lose negative pressure because of small leakage.

Some of the robots use sliding frames mechanism with suction pads example Sky Cleaner System [12]. All these systems are mainly used for special applications like stationary operations at one building. Their payload is sufficiently high to carry inspection sensors or tools, but, they cannot be applied to perform maintenance tasks of large vertical structures due to slow navigation velocity.

Taking into consideration all the drawbacks of the many approaches currently being used for the purpose of inspection of the less accessible spots in metallic tanks and furnaces in industries. Our design features a feasible solution in order to overcome all these barriers by using a light weight system which can be operated tele-operated by the surveyor or in an autonomous mode, with the use of magnetic wheels and compact size the robot can easily tread on narrow, uneven and unclean surfaces, taking sharp turns and transitions upto 90 degrees. We are using wireless camera with position encoders with IMU sensor for visual inspection and localisation to accurately locate the defected spots making it easier to detect corrosion, welding joints defects and surface cracks associated with the tanks and furnaces. For the proper inspection system locomotion speed is one of the main criterions as during the inspection task the robot as to cover the several tenths of square meters, therefore, magnetic wheeled system is carried out in this approach for designing the robotic crawler.

SYSTEM DESIGN

In this section we describe the hardware design of the robotic crawler. The system was designed to be light weighted, it comprises of the two wheels integrated with the 34 disc shape neodymium permanent magnets each. The robotic crawler is controlled using differential steering approach which allows the system to make turns easily on inspected surfaces. The system also had tail mechanism integrated with the small disc counter sunk type neodymium permanent magnets which provide the system stability on the surface.

The metallic walls of the oil tanks are uneven in nature and many other protruded surfaces are present which as to inspected for this purpose the while moving crawler as to traverse on the concave and convex surfaces. For satisfying the requirement the mechanical design optimization [13] for robotic crawler has been done. The crawler has a constant speed while scanning for defects and this speed can be modified by operator as per the requirements.

The robotic crawler weighs approximately 1.3 kg and have and ability to carry 2 kg more payload while climbing vertically. It is a high power magnetic wheeled design robot with the capability to travel over any weld obstacle and provide the option to angular transition between the surfaces which are even perpendicular to each other. It is driven by two 12V DC motors with a high output torque which can overcome the magnetic adhesion provided by the wheels while it is moving.

The Figure 1 shows the conceptual design of the robotic crawler and the Figure 2 shows the mechanical design of the robotic crawler. Table 1 summarizes the technical specification of the robotic crawler.

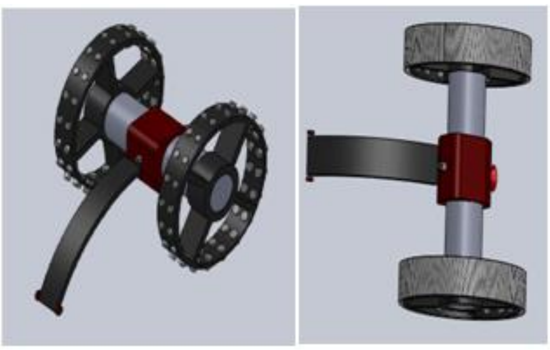

Fig. 1: *Conceptual Design for the Robotic Crawler.*

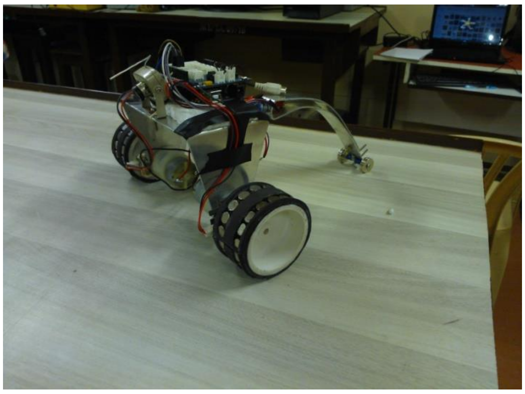

Fig. 2: *Mechanical Design for the Robotic Crawler.*

Table 1: *Technical Specification of the Robotic Crawler.*

Dimensions (l×w×h)	250 × 210 × 170 mm
Sensors	Position encoders, IMU sensor, wireless video camera
Control	915 MHz radio frequency module and personal computer
Battery	11.1V–800 mAh **-** lithium polymer
Wheels	2×34 disc neodymium magnets and 2 disc counter sunk magnets
Weight	1300 g
Actuation	2× 12 V DC gear motor

SYSTEM ARCHITECTURE

The robotic crawler consists of various software and hardware components as shown in Figure 3. This robotic crawler can be tele-operated by the human inspector using 915 MHz radio frequency module and computer interface. The robotic crawler can be equipped with many other components for the inspection of tanks and furnaces. Currently the robotic crawler has integrated with the wireless camera transmitting the real time video to a ground control station using 2.4 GHz transmission.

To provide the localization for the robotic crawler while the inspection tasks is going on, the robotic crawler is integrated with the position encoders sensors in the wheels to calculate the distance travelled by the crawler and inertial measuring unit sensors is also integrated in the system for providing the heading angle. Data from both the sensors unit has been taken and feed to the on-board controller continuously to compute the exact location of the crawler on the inspection surface.

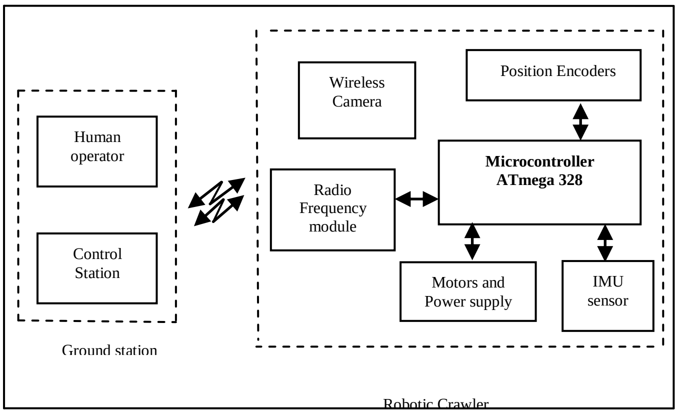

Fig. 3: *An Overview of the System Architecture for the Inspection of Tanks and Furnaces.*

Full Surface Covering Methodology

In this section we describe the algorithms for covering surface of the tanks and furnaces when the robotic crawler is made to work in autonomous mode. In this section we describe approach of the robotic crawler for full surface inspection autonomously.

Full Surface Covering Algorithm

In this algorithm we describe the methodology for the full surface inspection of tanks and furnaces without human intervention or autonomously. Just the operator has to provide the tanks dimension parameters which the robot going to inspect.

With the use of the position encoders placed on the shaft of the motors, the crawlers speed and diameter of the wheel the on-board controller will calculate the travelling distance of the crawler and by the help of the inertial measuring units sensor on-board controller compare the required turning angle and heading angle to make turning of the crawler at the edge of the wall.

Let the height and width of the surface which as to be inspected as' h' and 'b', respectively. Full surface covering algorithms is shown in Figure 4.

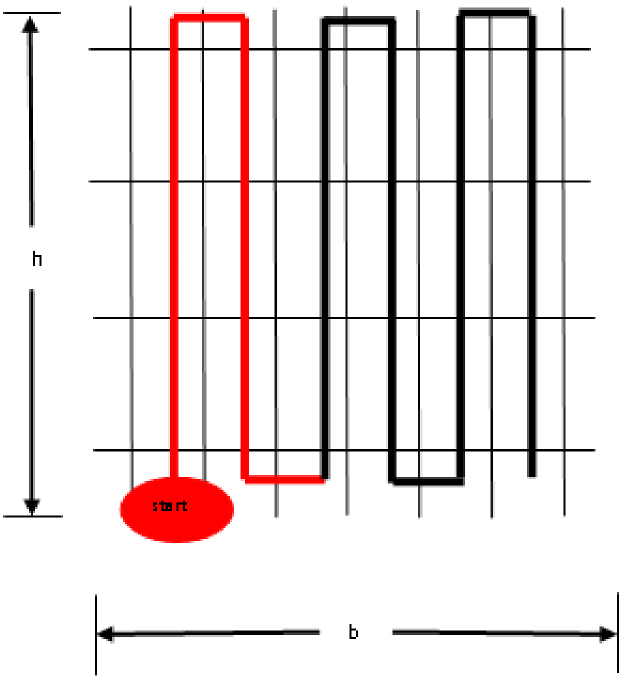

Fig. 4: *Full Surface Covering Algorithm for Robotic Crawler in Autonomous Mode.*

EXPERIMENTAL RESULTS

A prototype for the robotic crawler has been developed and tested different types of the surfaces. The purpose of these tests was to check and evaluate that how the robotic crawler would stick to the surface of the tank, the evaluation of the speed of the robotic crawler, turning effect, slipping etc. The robotic crawler is tested on the vertical as well as horizontal wall.

Tests are also made to check the effect of transition on the crawler while moving from one wall to another and also to see how the magnets of the wheels responds to the surface effected by the corrosion, peeling, thick or thin coating of paints.

In Figure 5, testing of the robotic crawler on the painted rectangular wall is shown.

Fig. 5: *Testing of Robotic Crawler on the Metallic Surface.*

CONCLUSION AND FUTURE WORK

This paper presented a tele-operated and autonomous robotic crawler for the inspection of the storage tanks and furnaces. The mechanical design of the robotic crawler was discussed briefly in this paper. Our work demonstrates the visual inspection of the tanks and furnaces of the industries. The algorithm is designed and discussed briefly for the full coverage of the surface which is to be inspected autonomously. The prototype for the robotic crawler is tested in flat surface walls.

In the future work the robotic crawler should be tested in tanks and furnaces with the cylindrical, spherical surface walls.

The robotic crawler should be added with more sensorial units to calculate more accurately the location of the crawler on the wall once the defect has been detected.

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