# A Magnetic Wheeled Robot For Steel Bridge Inspection

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**Abstract.** There are thousands of steel bridges with different structures and designs that have been built around the world. Although they have different structures and designs, they have in common that they need regular quality checks to avoid possible unfortunate accidents. Often, the inspection is being carried out manually, and the inspectors need to bring the testing equipment to climb the tall bridges to perform inspection. This job is dangerous and difficult. To support the inspectors, we present the design and construction of a robotic system that can assist them to perform steel bridge inspections to help minimize difficulties and dangers as well as increase productivity in the quality inspection. The robot can move on bridges with a square or circular steel structure. It is capable of carrying several types of sensors for navigation and mapping. The collected data is stored in an onboard computer and simultaneously sent to the ground station for processing in time. The robot also has the ability to mark suspicious locations to facilitate locating repairs. The results of laboratory tests in fact show the feasibility of robot design.

**Keywords:** Climbing Robot, Bridge Inspection, Magnetic Wheeled Robot.

## 1. Introduction

A bridge is built to connect two areas of land that can be divided by ditches, rivers, streams, or other foreign objects such as roads, railways, etc. The construction of bridges has made the traffic continually contributing to promoting economic and social development. However, bridges are aging, overloaded in use, but not regularly checked and maintained, which have caused extremely tragic bridge collapses. There are hundreds of bridges in the condition, which should be checked for maintenance to ensure safe use. The need for regular steel bridge inspection and maintenance is extremely necessary. However, this work is currently done manually by inspectors through visualization or using expensive and specialized equipment for analysis and evaluation. It is dangerous and difficult to bring bulky equipment to climb high to perform the inspection. Not to mention climbing for a long time, fatigue can make the inspectors' assessment no longer accurate and stable. Therefore, the use of technology including robots to assist inspectors to perform testing is perfectly suitable to reduce the dangers and difficulties as well as increase productivity, accuracy and stability for the inspection process and look up. More and more research has applied advanced robot technology to automate the bridge structure inspecting process over the past two decades. La et al.

[1-3] has developed an automated robot system that is integrated with advanced non-destructive evaluation (NDE) sensors to inspect and evaluate bridge decks. Lim et al. [4-5] has developed a robotic system to inspect the bridge deck cracks. Besides, there have been studies including checking other bridge structures. For example, Mazumdar et al. [6] proposed a robot that uses strong permanent magnet pins to move through a steel structure to inspect the steel bridge. Different types of magnetic wheeled robots have been also reported in recent developments [7-9].

The objective of this paper is to present the construction and demonstration of a mechatronic system, which is designed to support the structural steel bridge inspection. A robot designed with four permanent magnet wheels, which can adhere to steel surfaces, controlled via the wireless connection and can move freely on flat and curved steel surfaces. At the same time the robot can bring a few sensors to detect image cracks, structural mapping and mark fault location structures. With advanced mechanical design, the robot can carry heavy loads (about 10 pounds or 4.5kg) while climbing on both inclined and reverse surfaces. The collected data is stored in the minicomputer equipped on the robot and sent to the ground station for monitoring and processing in real time. In addition, magnetic field sensors, inertial measurement unit (IMU), encoder and range sensors are also integrated to help the robot map and move safely on steel surfaces. Magnetic force analysis has been conducted to determine the possible structures that robots can work with.

## 2. Overall Design

A robot design with four powerful permanent magnet wheels is proposed to be able to move flexibly on steel surfaces without consuming any energy for adhesion. The robot control system is divided into two classes: low-level and high-level controllers. The low-level controller receives commands from the high-level controller and then performs the appropriate operations such as wheel control, camera control, reading of the sensor value and transmits to the high-level processor as required. Robot system with integrated sensors is shown in Fig. 1. The high-level controller resides in an onboard computer equipped on the robot to handle complex problems like image processing, mapping and communication with ground stations. The robot is equipped with a camera to capture images of suspected locations, while helping inspectors at the ground station to observe the robot working easily. The use of 2-axis Pan-Tilt set will make the camera's vision more flexible. To orient in 3D space we use a smart 9-DOF IMU sensor and encoders to extract robot’s velocity and position. Besides, safe moving robot is an important criterion, so we use 4 IR sensors at the four corners of the robot along with intelligent algorithms to help the robot recognize it’s position in advance to move safely. An 8bit-AVR microcontroller is equipped as the control center of the low-end controller, and Intel NUC industrial computer is used as high-level controller. High-end controller using a robot operating system (ROS) to localize, navigate and collect data. To transmit data between the robot and the ground station we use a wireless LAN connection. The moderate robot works on cylindrical and square structures but at the same time ensures safety in operation. The following sections will cover the design of robots to solve these problems.

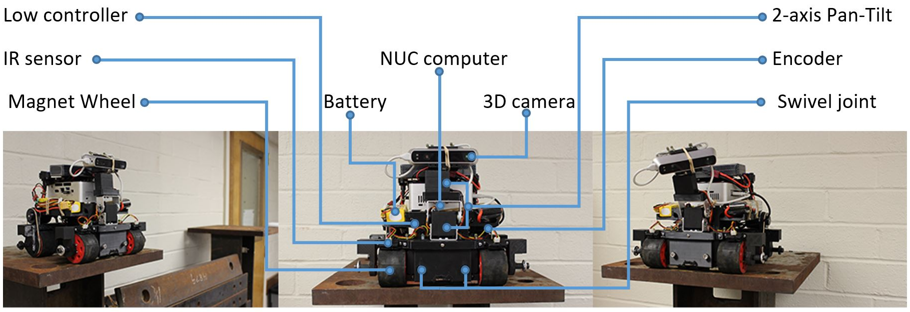


**Fig. 1.** Steel climbing robotic system with integrated sensors.

## 3. Mechanical Design

A robot design with four wheels is proposed to increase the adhesion as well as to take advantage of the robot movement flexibility. Besides the wheels and motors can automatically fold according to the contact surface to move. The robot dimension is shown in Fig. 2, the parameter of the robot is displayed in the Table I, and motor parameters are listed in the Table II.

TABLE I: Robot Parameters.

| | |
|---|---|
| **Length** | 192.70 mm |
| **Width** | 271.96 mm |
| **Height** | 183.5 mm |
| **Weight** | 3.6 kg |
| **Drive** | 4 motorized wheels |

TABLE II: Motor Parameters.

| | |
|---|---|
| **Torque** | 525 g/mm (2S Li-Po) |
| **Speed** | 0.12 sec/ 60° (2S Li-Po) |
| **Length** | 40.13 mm |
| **Width** | 20.83 mm |
| **Height** | 39.62 mm |
| **Weight** | 71 g |
| **Voltage** | 6-8.5V (2S Li-Po battery) |

Each wheel is made up of a plastic frame and 60 permanent magnets (diameter 10mm x 5mm length) surrounded, similar design to [7]. In addition to the four motor-mounted wheels, the middle part of the robot is also equipped with four small wheels with permanent magnets (12.7mm x 25.4mm x 6.35mm) to increase the ability to grip and keep the robot balanced.

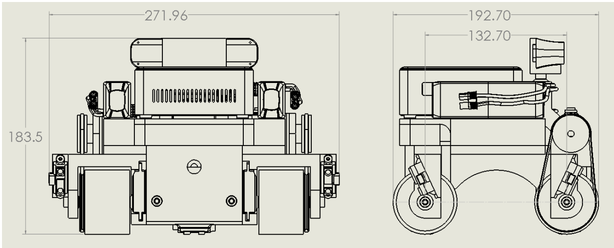


**Fig. 2.** The robot dimension.

A bridge may have many steel pipes of different diameters, hence the robot needs to be designed to be able to flexibly move on different sized cylindrical steel pipes. If a hard design is left, the robot cannot be moved on steel pipes of small size. Obviously, the magnet wheels are inaccessible, clinging to the steel surface. To avoid this issue, the robot design consists of three main parts: the middle body consists of passive wheels and magnets, the left and right wheel sections must be motor-mounted magnet wheels, and they are linked to the middle body through the swivel. The swivel joints allow the robot to flexibly change to cling to the surface of the steel cylinder that the existing designs [7, 9, 10] may not be able to perform.

## 4. Circuit and Software Design

The robot needs to be small and compact to be easy to move without being entangled. Therefore, the control system also needs to be designed to be compact, but it must meet the operating capacity of the robot. The low-level controller is designed in detail as shown in Fig. 3. The center of the low-level control circuit was using Atmega2560 at speed up to 16Mhz. Equipped with up to 54 digital pins and 16 analog pins for increased connectivity with more peripherals.

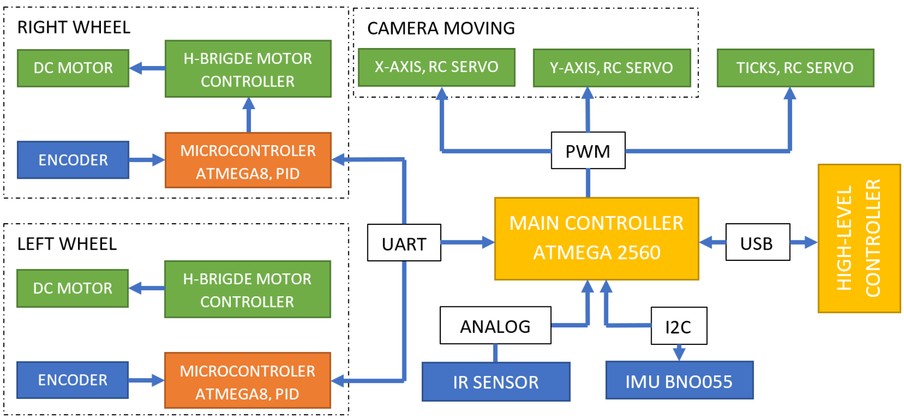


**Fig. 3.** The low-level control diagram.

Besides, equipped with four UART communication ports, one SPI, one I2C also allows connection with many existing modules such as IMU, GPS, ..., etc. An intelligent 9-axis Absolute Orientation Sensor is also integrated into the circuit to help orient the robot when operating more accurately. A MEMS accelerometer, magnetometer, and gyroscope are combined together and processed by a high-speed ARM Cortex-M0 based processor to digest all the sensor data, abstract the sensor fusion and real-time requirements away, and spit out data, so we can use in quaternions, Euler angles or vectors. Based on feedback from the encoders connected with the wheels, we designed a PID motor controller to synchronize left, right wheels speed. The gravity of the robot will cause the wheels spinning, hence we applied the PID position controller to keep the robot stationary. If the value from the encoder is changed when the robot is in a stop state, this means that the robot is moving under the action of gravity. At this time, the PID position controller will calculate to give signal to control the spinning wheels in the opposite direction with a sufficient force to keep the robot not move. We used ROS to build and develop a control software system for this robot. We have created ROS topics to control robot movement, camera movement or read the value of IR sensor, IMU, encoders, 3D structure camera.

## 5. Experimental Result

Both indoor and outdoor experiments have been carried out to confirm the effectiveness of the robot. Indoor tests are in the laboratory environment on small steel bars that are attached to each other while outdoor testing conducted on the bridge connecting the two buildings on the University of Nevada, Reno campus. The ability to move and hold position is evaluated in both experiments. We used 3 of the 3S1P 11.1V 2200 milliampere-hours (mAh) battery to power the robot for one hour of the test. A laptop that can connect to a wireless LAN is used as a ground station to observe robot activity and sensor's data. The robot shows the ability to adhere to flat steel surfaces, move flexibly, and its ability to hold a good position by PID position controller with many different poses as shown in Fig. 4. The maximum velocity of the robot is approximately 30 centimeters/second. In outdoor experiments, we also conducted experiments to demonstrate self-tuning ability to adhere to curved steel surfaces, move flexibly as well as its ability to hold a good position by PID position controller. Fig. 5 shows the robot changing its body shape to cling in order to adhere to curved steel surfaces. Fig. 6 shows positions of the robot moving on the bridge as well as its ability to hold the position on the curved steel surface.

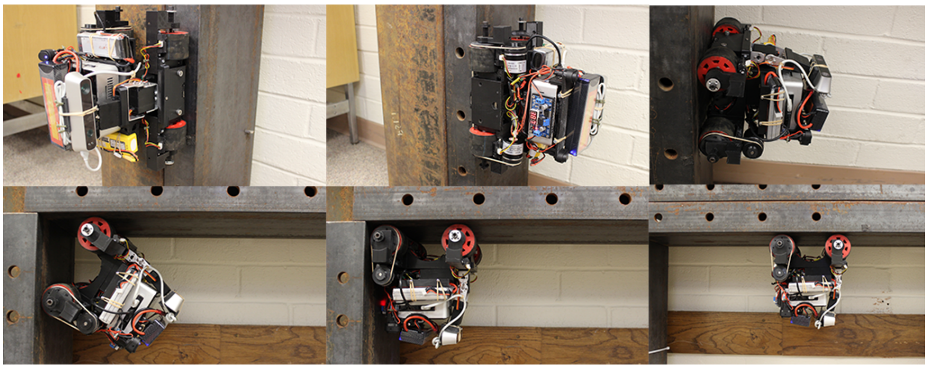

**Fig. 4.** Robot moving on flat steel surface and transiting from one surface to the other.

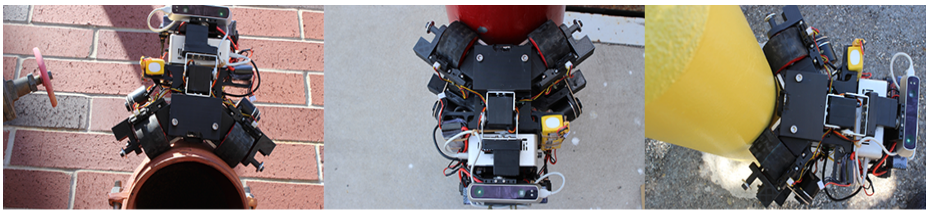

**Fig. 5.** Robot itself changes to cling to the cylindrical steel structure.

## 5. Conclusion and Future Work

This work describes the design and implementation of steel climbing robot capable of moving on many steel surfaces on different structures. The results also show that the robot move more safely when equipped with infrared sensors and encoders, which help the robot keep a good position when needed. In addition, IMU and 3D cameras are also equipped on the robot for later localization. With its climbing capability, the proposed robot can assist the inspectors in steel bridge or steel structure inspection. In the future, we also plan to upgrade the robot so that it can carry non-destructive sensors such as eddy current sensor to inspect defects inside steel structures.

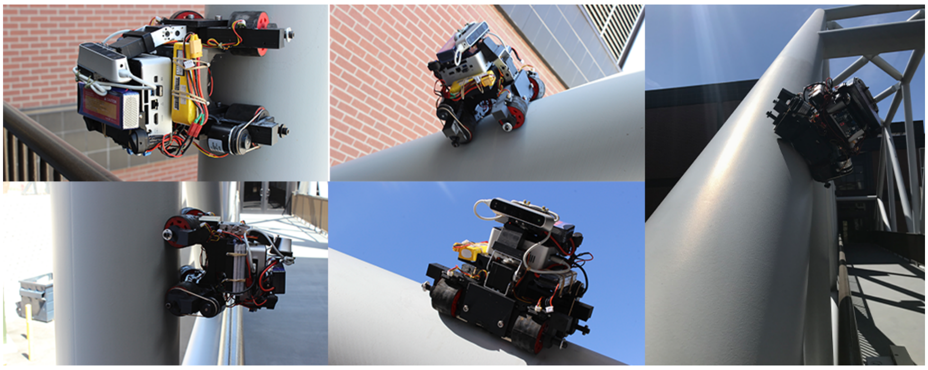

**Fig. 6.** Robot moving on a steel bridge at the University of Nevada's campus.

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