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A Quadcopter with Heterogeneous Sensors for Autonomous Bridge Inspection

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Continuously monitoring a bridge’s health by sensor technologies has been widely used to maintain the operation of a roadwork while protecting public users’ safety. However, monitoring and inspecting numerous bridges in a state is a labor-intense and costly task. A recent survey (Gastineau et al. 2009) shows that among 25 sensors used in 38 companies, there is no autonomous system capable of inspecting bridges. We propose to advance the bridge monitoring technology a step further by developing a quadcopter with heterogeneous sensors, which aims to enable the autonomous bridge inspection.</td></tr>
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Mid-America Transportation Center (MATC)
Nebraska Transportation Center (NTC)
Proportional-Integral-Derivative (PID)

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Abstract

Continuously monitoring a bridge's health by sensor technologies has been widely used to maintain the operation of a roadwork while protecting public users' safety. However, monitoring and inspecting numerous bridges in a state is a labor-intense and costly task. A recent survey (Gastineau et al. 2009) shows that among 25 sensors used in 38 companies, there is no autonomous system capable of inspecting bridges. We propose to advance the bridge monitoring technology a step further by developing a quadcopter with heterogeneous sensors, which aims to enable the autonomous bridge inspection.

Chapter 1 Introduction

1.1 The Need of Autonomous Bridge Health Monitoring

Transportation infrastructure, such as bridges, are gradually aging, and as such, bridge engineers need reliable and efficient tools to assess the structural health of bridges in order to maintain the continuous operation of the road network while ensuring the safety of public users (Chang 2003, Farrar 2007, Worden 2004). This proposal intends to address the following important questions during bridge monitoring and inspection:

1. *How does a bridge engineer keep monitoring numerous bridges within a state over a long period of time? Are inspections conducted every other year often enough?*

State bridge engineers are responsible for the operation and safety of a bridge network. Due to the large number of bridges in a state, it is labor-intensive and costly to inspect every bridge manually, even every other year. A possible solution is to design autonomous systems to inspect bridges automatically and routinely to keep track of bridges' health over time.

2. *How should one collect data on regions that are difficult to access, such as the underneath of the bridge?*

There are non-destructive methods, such as Ground Penetrating Radar (GPR), which is often used to investigate the deterioration of concrete in a bridge deck. The problem lies in that traffic lanes must be closed to carry out the data collection, and the underneath bridge cannot be inspected using GPR equipment on the deck. We propose to design a mobile platform capable of being embedded with camera and GPR devices such that the appearance and internal structure of the underneath bridge can be analyzed from collected images and GRP data.

3. How does one reduce the installation and maintenance cost of sensors on bridges?

Advances in sensing technologies enable the integration of distributed sensors for continuous bridge monitoring and damage detection. The permanent sensors built into the bridge or stationary sensors installed at specific locations are costly to be repaired or replaced. Some types of sensors may be embedded into moveable platforms, like our proposed quadcopters, so the data can be collected at different locations as the quadcopter navigates through the bridge. Meanwhile, we avoid costs associated with the installation and maintenance of multiple stationary sensors on the bridge.

1.2 The Objective of this Project

The ultimate goal of this research is to develop autonomous systems capable of automatically monitoring and inspecting bridges with minimum labor involvement. We propose to build a prototype system consisting of a mobile robot (e.g. a quadcopter), a control unit, a group of sensors on the robot, a communication module, and data processing software on a ground station.

1.3 Relevance to MATC Theme and Thematic Thrust Areas

We propose to develop innovative equipment and solutions (autonomous systems) to monitor and inspect bridge health, enable efficient inspection and good repairs, and improve the sustainability of the transportation infrastructure, which is directly related to the MATC themes of providing a safe, efficient, and effective transportation infrastructure.

Chapter 2 Project Overview

2.1 Proposed Solution

As shown in figure 2.1, the autonomous system will monitor in-service bridges by following navigation paths designed by control algorithms or human operators, using sensors on the quadcopters to collect data that records the changes of a bridge over time, and transmitting the data over a wireless network back to a ground station. The data processing algorithms on the base station will process the data to assess the bridge health.

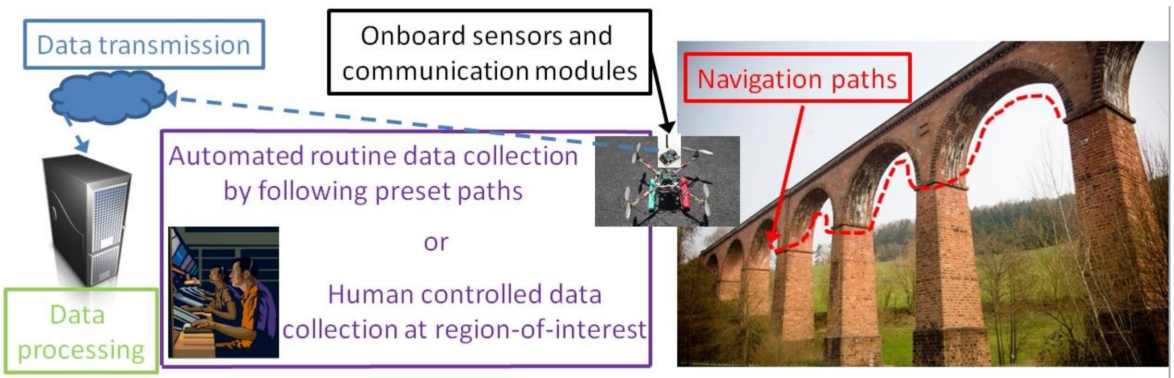

Figure 2.1 An autonomous system for bridge inspection

2.2 Project Novelty

The proposed autonomous system integrates the multidisciplinary technologies of robotics, control, sensors, communication and signal processing, which aims to:

1. relieve the cost and burden of manual bridge inspection,

2. collect complete data on a bridge including the underneath, and

3. routinely inspect a bridge over a long time with low sensor maintenance cost.

Therefore, the three questions in chapter 1.1 are going to be addressed in this project.

Chapter 3 Accomplished Project Tasks

3.1 Assemble the Quadcopter

We built a quadcopter as our mobile platform that can freely move around a bridge and collect data without closing traffic lanes. The radio-controlled quadcopter has four propellers to lift it into the sky, as shown in Figure 3.1. It is loaded with an assortment of sensors to help it maneuver and hover.

Figure 3.1 The quadcopter for bridge inspection

3.2 Embed Sensors and Signal Transmission Modules on the Quadcopter

We embedded sensors and data transmission modules in the quadcopter to collect data and transmit data and commands between the quadcopter and ground station. Sensor data, including live videos, are transmitted back to the ground station by our signal transmission module for data processing or human piloted navigation. On this one-year project, our goal is to build the proof-of-concept system with GPS, an accelerator, a gyroscope, and video camera sensors. In the future, we plan to collaborate with civil engineers and radar scientists to incorporate more sensors on the quadcopter, such as the heavier GPR module.

3.3 Develop Stabilization Algorithms

An indoor flight test lab measuring 16ft x 16 ft x 8ft was built during this project to develop and test the quadcopter stabilization algorithms, as shown in figure 3.2

Figure 3.2 Indoor flight test lab.

The collected sensor data must be registered to real coordinates so we know where the data is collected. It would be difficult to map the collected data to their corresponding locations on the bridge if the quadcopter vibrates too much during its flight. We developed prototype PID control algorithms on the quadcopter to stabilize it. Figure 3.3 shows a stabilization example where the quadcopter can fly back to its original position after an external disturbance, such as being pushed away by a human or a gust of wind.

Figure 3.3 Stabilize a multicopter after an external disturbance. The multicopter is capable of staying in the air for the inspection task.

3.4 Develop Navigation Algorithms

We proposed several navigation algorithms for the quadcopter. First, the navigation paths can be pre-programmed with specified GPS locations. Secondly, a human operator can control the quadcopter to collect data by watching the real-time videos. Thirdly, we propose a two-stage algorithm for automated navigation. During the training stage, the human operator steers the quadcopter remotely by watching living videos transmitted back. During the routine inspection, the quadcopter will automatically follow the previous paths steered by human operators.

3.5 Analyze Sensor Data Collected from the Quadcopter

On this prototype system, we used image data as a case study on bridge health inspection. To demonstrate the capability of real-time data processing, we developed a pedestrian detection system based on the quadcopter (fig. 3.4). We are currently developing techniques to mosaic subimages captured at different bridge locations into large images that overlook the global condition of a bridge and analyze the images to detect and locate cracks on the bridge.

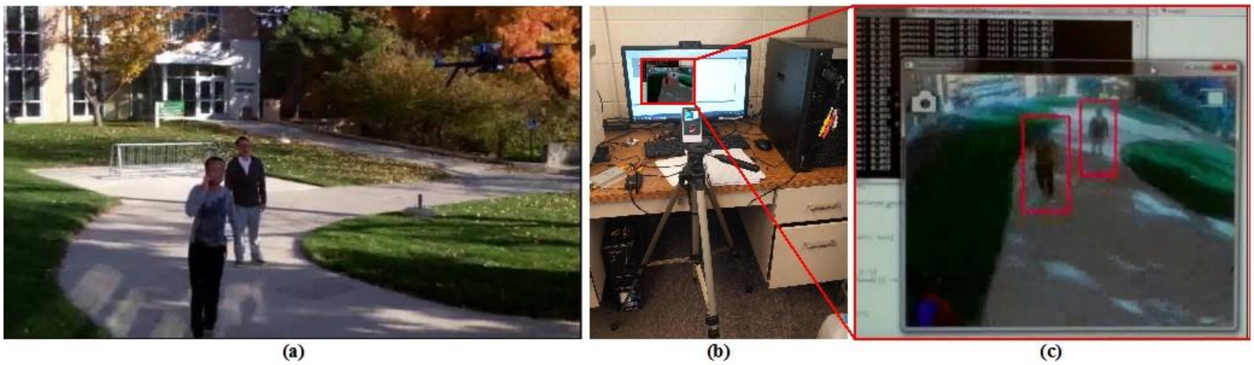

Figure 3.4 Test of real-time sensor (visual) data processing. A quadcopter flying outdoor to detect pedestrians (a); video stream captured by the quadcopter transmitted back to the ground station for processing (b); Zoom-in details of the real time processing on the monitor (c).

Chapter 4 Conclusion

This project developed a quadcopter testbed with heterogeneous sensors for the purpose of autonomously inspecting and monitoring bridges. The prototype system will serve as a basis for the PI to use as he collaborates with bridge health experts and sensor scientists to design innovative technologies on the autonomous inspection and monitoring of bridges by robots.

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