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Autonomous Ultrasonic Thickness Measurement using a Steel Climbing Mobile Robot Integrated with *Martlet* Wireless Sensing

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ABSTRACT

This paper reports the recent development towards autonomous ultrasonic thickness measurement on steel bridge members through the novel integration of a magnet-wheeled steel climbing bicycle robot and a wireless ultrasonic sensing device named *Martlet*. The compact *Martlet* wireless device has been designed to attain accurate thickness measurement through the combination of high-voltage excitation, filtering/amplification of the received ultrasonic signal, and high-speed analog-to-digital conversion (~80 MHz). To achieve autonomous inspection, the *Martlet* ultrasonic device is carried by the steel climbing bicycle robot along with a dual element transducer. The developed mobile sensing system successfully obtains accurate thickness measurement in laboratory testing.

Keywords: autonomous inspection, ultrasonic thickness measurement, steel climbing robot, wireless sensing, structural health monitoring

INTRODUCTION

Non-destructive testing is one of the well-established methods for the detection of structural damage and deterioration. One major technique in non-destructive testing is the use of ultrasonic signals, which employs a transducer to generate excitation and measure response as shown in Figure 1.When no internal defect exists, an ultrasonic wave launched on one surface of a metal plate is reflected by the other surface (back wall). According to the timing of the received signal, referred to as Time of Flight (ToF), the thickness of the plate can be estimated. Note that between the transducer and the specimen, some couplant such as gel is placed to facilitate the transmission of the ultrasonic signals.

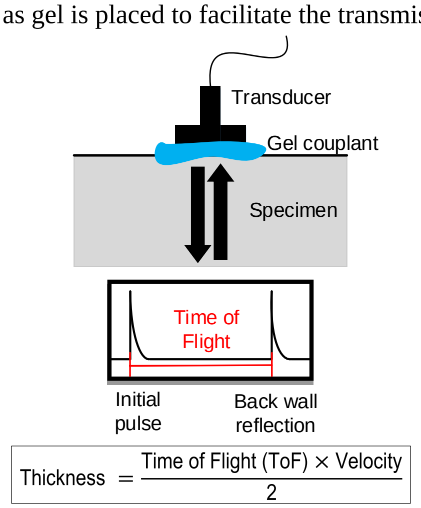

Figure 1: Ultrasonic thickness measurement using a transducer

Over the past few decades, the development of wireless sensing technologies by the structural health monitoring community has enabled continuous and reliable monitoring of the condition of civil engineering structures. As the latest generation of a low-cost compact wireless sensing device, the *Martlet* motherboard along with a wide array of extensible daughter boards forms wireless sensing network for structural health monitoring [1-3]. In particular, recent development of the compact *Martlet* ultrasonic sensing device [4] can attain accurate ultrasonic thickness measurement. Meanwhile, mobile sensing robots have been studied in recent years towards assisting bridge inspection. A recently developed magnet-wheeled steel climbing bicycle robot [5] demonstrates promising performance navigating on complex steel bridge surfaces and in tight spaces that are difficult to access. Marrying the two state-of-the-art developments [4, 5], this research produces a magnet-wheeled mobile robot capable of autonomous ultrasonic thickness measurement of steel bridge members.

MARTLET WIRELESS ULTRASONIC SENSING DEVICE

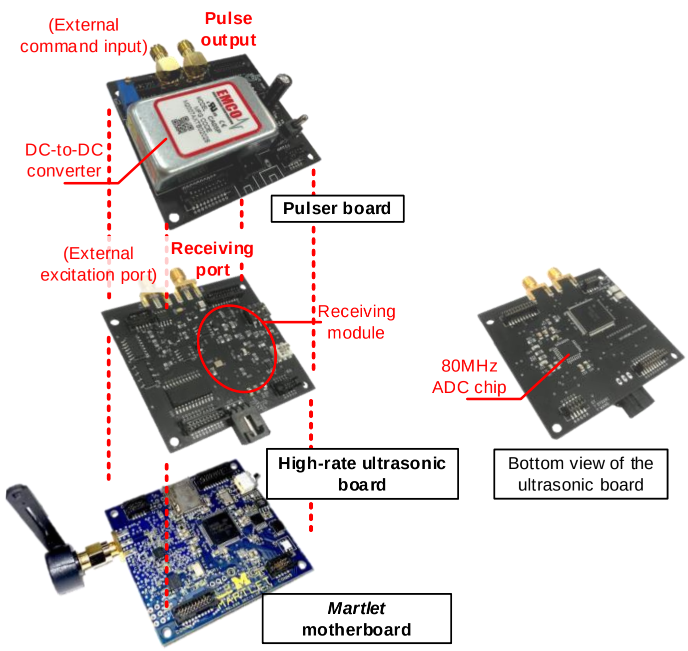

Figure 2: *Martlet* wireless ultrasonic sensing device

The exploded view in Figure 2 summarizes the recently developed *Martlet* wireless ultrasonic sensing device [4], including the *Martlet* motherboard, the high-rate ultrasonic board, and the pulser board. The planar dimension of each board is 2.5 in by 2.35 in. The functional diagram of these two boards is shown in Figure 3. The pulser board generates a high-voltage (up to 200V), short-pulse excitation signal to the transducer. The high-rate ultrasonic board is capable of filtering/amplification of the received ultrasonic signal and high-speed analog-to-digital conversion (up to 80 MHz). The sampled data is transferred to the *Martlet* motherboard through the serial-peripheral-interface protocol (SPI). In the end, the *Martlet* motherboard wirelessly sends the data to a base station connected to a PC.

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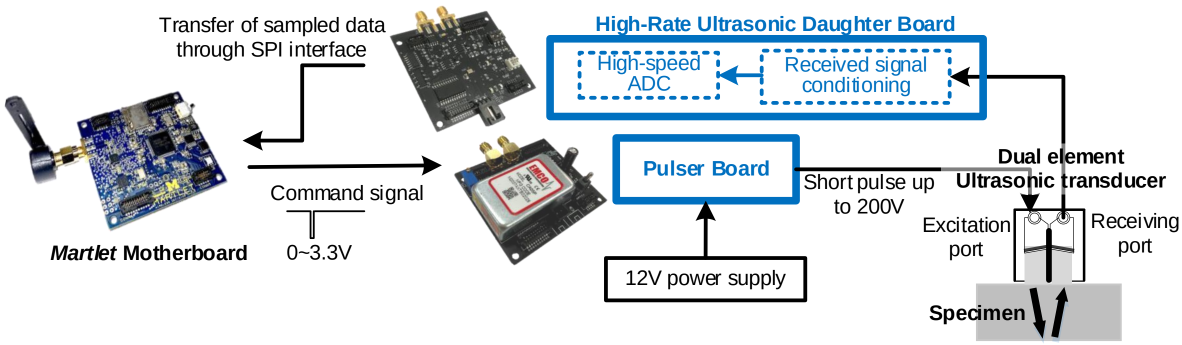
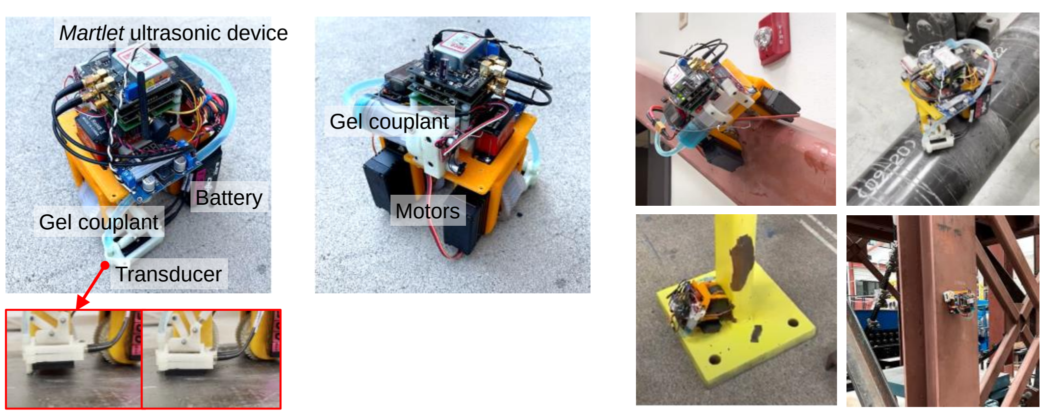


Figure 3: Functional diagram of *Martlet* wireless ultrasonic sensing device

INTEGRATION WITH STEEL CLIMBING MOBILE ROBOT

The *Martlet* ultrasonic device is integrated with a magnet-wheeled bicycle mobile robot [5] as shown in Figure 4(a). The bicycle-like robot has two magnetic wheels controlled by two independent steering actuators. For ultrasonic thickness measurement, the robot additionally carries a 2.25 MHz dual element transducer and gel couplant. Gel couplant is stored in a tank and dispensed using a syringe mechanism with a pump. To attain measurement on vertical surfaces, we select a high viscosity gel. A mounting/retrieving mechanism of the transducer is designed to ensure the reliable contact between the transducer and the steel surface. Climbing capability of the mobile robot is verified on different types of steel surfaces as shown in Figure 4(b).



(a) Gel pumping & transducer mounting (b) Climbing on various steel structures

Figure 4: Steel climbing robot integrated with the *Martlet* wireless ultrasonic device

To validate the performance of the developed mobile sensing system, laboratory testing is conducted on a hollow steel tube with the nominal thickness of 0.465 in at the Earthquake Engineering Laboratory, University of Nevada, Reno. Figure 5 shows sample ultrasonic waveforms obtained wirelessly by the mobile robot carrying the *Martlet* device. The received signals contain a sequence of echoes that correspond to the reflection of the transducer's response against the excitation signal. The time interval between the neighboring echoes is the ToF. To accurately extract the ToF, the autocorrelation function of the received signal is calculated. The first peak in the autocorrelation function corresponds to the ToF, which is 3.987 μs. With the nominal velocity of 0.2339 in/μs [6], the thickness of the specimen is obtained as 0.466 inch, nearly equal to the nominal thickness of 0.465-inch. This experiment validates the robot's successful operation of ultrasonic thickness measurement and its accuracy.

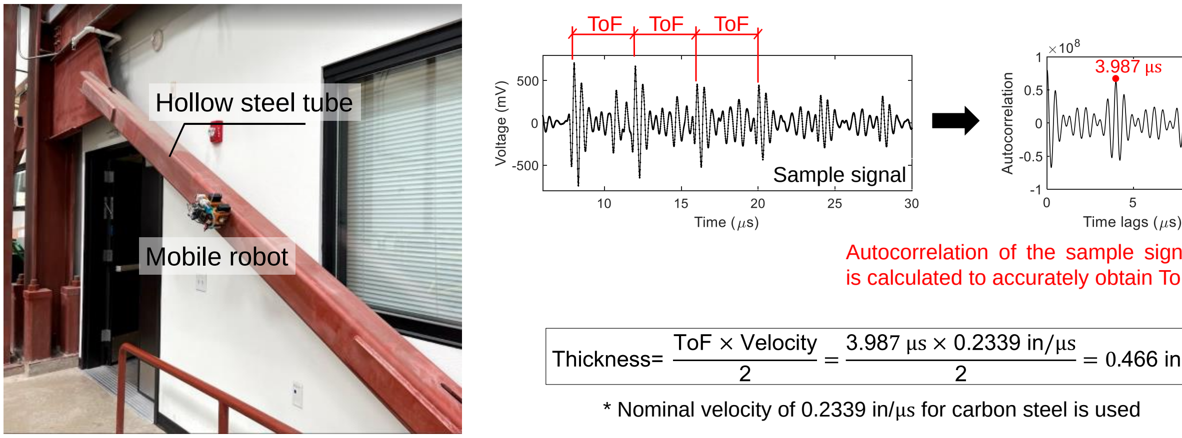


Figure 5: Ultrasonic thickness measurement on a hollow steel tube with 0.465-inch nominal thickness

SUMMARY

This study reports the novel integration of a magnet-wheeled steel climbing bicycle robot and a *Martlet* ultrasonic device, towards the autonomous ultrasonic inspection of steel bridge members. The developed mobile sensing system successfully obtained accurate thickness measurement in laboratory testing. To further validate the performance of the developed system, field testing on steel bridges will be conducted in the future.

ACKNOWLEDGEMENT

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