REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
20-06-2017	Final Report	25-Apr-2016 - 24-Apr-2017

4. TITLE AND SUBTITLE
Final Report: A scanning laser doppler vibrometer for characterizing and optimizing high performance materials, actuators, and implusive systems

5a. CONTRACT NUMBER
W911NF-16-1-0282

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611103

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
68458-EG-RIP.6

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT
We have acquired a Laser Doppler Vibrometer to enable a wide array of experiments aimed at quantifying various actuators and high-speed, small-scale mechanisms. This system measures out of plane velocities of a moving surface at high sample rates and with a spatial resolution enabling capture of a reasonably large surface. We have explored the use of this system for the characterization of various actuators (e.g., piezoelectric and dielectric elastomer) as well as their constituent electroactive materials. The system provides the ability to perform high temporal resolution surface analysis, giving us the ability to understand vibration modes in a variety of materials

15. SUBJECT TERMS
dynamic analysis; transducers; microrobotics; actuation

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Robert Wood
UU	UU	UU	UU		19b. TELEPHONE NUMBER 617-384-7892

Report Title

Final Report: A scanning laser doppler vibrometer for characterizing and optimizing high performance materials, actuators, and implusive systems

ABSTRACT

We have acquired a Laser Doppler Vibrometer to enable a wide array of experiments aimed at quantifying various actuators and high-speed, small-scale mechanisms. This system measures out of plane velocities of a moving surface at high sample rates and with a spatial resolution enabling capture of a reasonably large surface. We have explored the use of this system for the characterization of various actuators (e.g., piezoelectric and dielectric elastomer) as well as their constituent electroactive materials. The system provides the ability to perform high temporal resolution surface analysis, giving us the ability to understand vibration modes in a variety of materials and devices without the need for physical contact.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u> <u>Paper</u>

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u> <u>Paper</u>

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
06/20/2017	4	Kaushik Jayaram, Benjamin Goldberg, Neel Doshi, Robert Wood. Towards rapid running at resonance using HAMR, a biologically-inspired robotic platform, Society for Integrative and Comparative Biology. 06-JAN-17, New Orleans, LA. : ,
06/20/2017	5	Neel Doshi, Benjamin Goldberg, Kaushik Jayaram, Robert Wood. Task driven optimal leg trajectories in insect-scale legged microrobots, American Physical Society March Meeting 2017. 17-MAR-17, New Orleans, LA. : ,
06/20/2017	3	Peter A. York, Robert J. Wood. A geometrically-amplified in-plane piezoelectric actuator for mesoscale robotic systems, IEEE ICRA. 30-MAY-17, Singapore. : ,

TOTAL: **3**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received   Book

TOTAL:

Received   Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Equipment acquired: Turnkey High Performance, 1 MHz Bandwidth VibraScan System
Manufacturer: Polytec
Cost: $275,000

(1) We used the vibrometer to characterize the voltage and frequency responses of 2.5 to 10-mm size flextensional piezoelectric actuators [1]. The vibrometer significantly reduced the testing time required for each device, allowing us to quickly iterate through the design space.

(2) The electromechanical coupling coefficients of piezoceramics depend on material strain, applied electric field, and temperature, and thus are not well known, particularly at high electric fields. To fill this gap, we are using the vibrometer to better characterize the coupling coefficient d33 at high fields (ongoing, unpublished).

(3) The vibrometer was used to characterize the frequency response of ultrasonic emitters used in advanced 3D printing techniques (unpublished)

(4) We have used the vibrometer to measure displacement in multilayered dielectric elastomer actuators. Specifically we are looking at out-of-plane deformation of membranes to quantify strain as a function of applied field and frequency (unpublished).

(5) We have been using the laser doppler vibrometer extensively to characterize piezoelectric actuators — i.e., we measure the tip motion and the signals from current measurement circuits. The work has been presented at two conferences [2,3] and the journal manuscript [4] is under preparation.

List of papers that have cited DURIP as support:

[1] A geometrically-amplified in-plane piezoelectric actuator for mesoscale robotic systems, P. York and R.J. Wood, IEEE ICRA, Singapore, May 2017

[2] Towards rapid running at resonance using HAMR, a biologically-inspired robotic platform, K Jayaram, B Goldberg, N Doshi, RJ Wood, INTEGRATIVE AND COMPARATIVE BIOLOGY 57, E304-E304

[3] Task driven optimal leg trajectories in insect-scale legged microrobots, N Doshi, B Goldberg, K Jayaram, R Wood, Bulletin of the American Physical Society 62

[4] Concomitant sensing and actuation for microrobots, K Jayaram, N Jafferis, N Doshi, B Goldberg & RJ Wood, (in preparation for Smart Materials and Structures, see attachment)

Technology Transfer

n/a

Concomitant sensing and actuation for microrobots

Kaushik Jayaram, Noah Jafferis, Neel Doshi, Ben Goldberg & Robert J Wood

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March 2017

Abstract. Miniaturization for microrobotic applications makes sensor fabrication hard. Here, we present a technique for estimating the velocity (magnitude and phase) of piezoelectric actuators, a popular choice for driving devices at microscale, that requires simple electronics and no additional mechanical components, critical for applications as such small scales. This approach relies on the insight that the motion of the actuators causes varying strains on the surface on the piezoelectric material, which via the direact piezoelectric effect, results in a current proportional in magnitude and in phase with the motion of the actuator. We first experimentally determined the electrical properties of the actuator in a motionless state and then used these values to estimate the piezoelectrically generated current during motion. We show that the behavior of a piezoelectric actuator can be approximated well as a parallel combination of a frequency and voltage dependent resistor and capacitor and a velocity proportional current source in the electrical domain. Using the above strategy, we were able to determine the actuator tip velocity to within 10 $\mu m s^{-1}$ in magnitude and within 10% phase over a range of voltages $(10 - 250V)$ and frequencies $(1 - 2000Hz)$ well beyond their resonant peaks. We successfully demonstrate the usefulness of this approach on two millimeter sized robots - Harvard Ambulatory Microrobot (HAMR) and RoboBee to estimate the phase of the limb and wing trajectories with respect to the drive commands as they approach resonance. In the future, we aim to use this modality to detect collisions and enable close-loop feedback for controlling appendage trajectories.

Keywords: sensing, piezo-electric, actuators, microrobots, concomitant