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Work in Progress: An Economical and Open-source Mechanical Testing Device for Biomaterials in an Undergraduate Biomechanics Laboratory Course

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Commercially available mechanical testing devices for mechanical characterization of biomaterials can cost tens of thousands of dollars. Open-source mechanical test frames have been designed to improve on that price point, but are still relatively expensive at $4,000 [1]. Various custom made mechanical testers exist, however their fabrication is not formally documented or detailed. In order to accommodate laboratory courses with several students, access to multiple devices can enhance the student experience by allowing the students to have the most hands-on time with the equipment. This can be prohibitively expensive, however. To address this problem, custom made devices using open-source hardware and software systems can be built with materials costing a fraction of the commercially available devices. This paper provides an introduction to our work to build an economical mechanical tester to be used in biomedical engineering teaching labs.

Device Fabrication and Design

The Arduino open-source platform has been acclaimed for its versatility, low cost, and ease of use. These microcontrollers have now been used in a broad range of engineering research and education applications. We previously reported the fabrication of a proof of concept Arduino-based mechanical tester for a total cost of less than $100 [2]. This simple device was inexpensive but limited to tension testing of soft elastic samples due to the design of the tester. With this previous version, the extension force is applied by the user (students) by pulling downward on a rope. The major drawback is that repetition of exact forces is impossible to duplicate. In addition, the original strain sensor, an ultrasonic sensor, had relatively low resolution, and was only useful for measurement of relatively large strains.

Here, we describe the creation of upgraded mechanical test frames capable of both uniaxial tension and compression tests for biomaterials. These new mechanical test frames cost less than $300 each (see the bill of materials in Table 1). The mechanical test frame consists of an Arduino microcontroller, wooden frame, a linear actuator driven by a stepper motor, and several 3D printed parts (Figure 1). Each linear actuator has a stroke of 10” in order to accommodate a broad range of samples including elastic ones. Different load cells and sample clamps can easily be installed to switch between tension and compression testing.

Sample clamps can easily be designed and 3D printed for a variety of different samples. Currently we have 3D printed clamps for tensile testing (Figure 1) and platens for compression of soft materials. One fundamental learning opportunity for the students is for them to realize that the hardest challenge of biomechanical testing is about optimizing the grip of the sample mount. Since one of the most common failures of mechanical testing is the sample slipping out of the clamp or breaking at the clamp. Our 3D printed sample grips perform as well, and sometimes better than the commercial grips we have available for the Instron machine. The ease of designing and fabricating multiple 3D printed grips could provide additional opportunities for students to try and compare multiple sample mounting techniques.

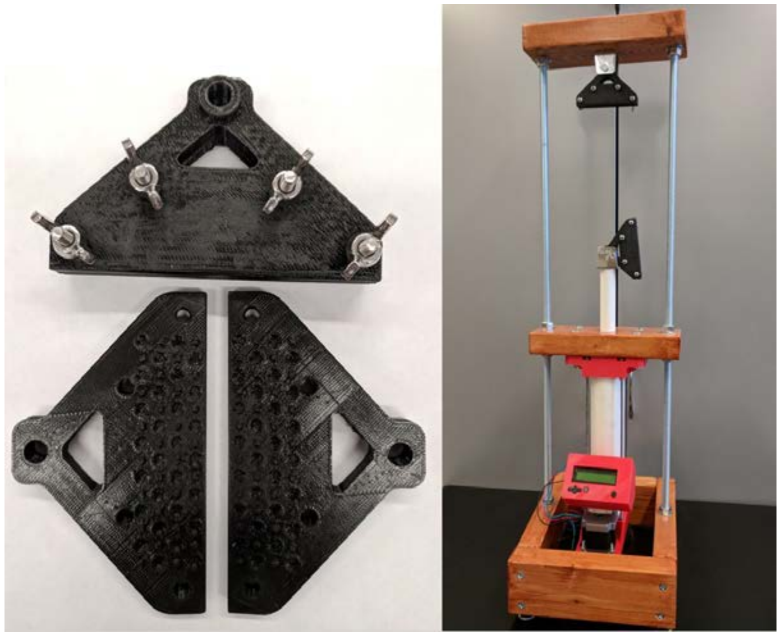

Figure 1: (Left) close up of 3D printed clamp for uniaxial tensile testing. Clamps are connected via clevis pin and have interlocking features to grip samples. (Right) Overall mechanical test frame consisting of LCD panel for control, stepper motor with linear actuator, in a wooden frame.

This device can be directly controlled via a set of buttons (a 4-button D-Pad cluster, a select button, and a reset button) with real time values displayed on an LCD screen. Otherwise, the Arduino microcontroller can be connected to a computer through a USB port for data acquisition and analysis. The devices are currently being programmed to allow fine tuning of the control and user-interface. The goal is to create a student-friendly device so users can focus on mechanical testing rather than programming and software.

Table 1: Bill of materials for each mechanical test frame.

Item	**Cost**
Electronic components	$150
Support frame	$50
PLA filament	$30
Miscellaneous hardware	$50
Total	**$280**

Device Implementation in BME Labs

Several mechanical test frames have been fabricated. They will be validated by direct comparison with a commercially available mechanical testing system (Instron 5443). These new mechanical testers will be implemented in a Junior-level biomechanics course in Fall 2018. Students will familiarize themselves with common procedures used to conduct uniaxial tensile tests. They will determine common stress-strain parameters and material characteristics which can be obtained from uniaxial tension tests, including: Young's modulus, tensile strength, failure stress, hysteresis, and anisotropy. Students will also quantitatively assess the mechanical properties of a various materials such as self-adhesive wrap, chicken skin and tendons via uniaxial tensile testing.

In the Fall of 2017, students were limited by the availability of a single Instron mechanical tester, each student only got 1-2 hours of direct contact and use of the equipment during the semester. With the addition of 4 custom-made mechanical test frames, we expect each student to get around 6 hours of direct contact with the mechanical test equipment.

Device Evaluation & Educational Value

We will report the outcomes of the implementation of this device in a Junior-level biomechanics course. The results of a survey administered to n=~24 students will be used to assess the effectiveness of using the Arduino device relative to the commercial Instron device to accomplish mechanical testing and achieve student learning outcomes. The survey asks questions regarding the ease of use of the custom device, a self-report on the learning outcomes of the lab related to testing of viscoelastic biomaterials, and general interest and awareness of the open-source maker movement.

In addition to the self-report, we will assess the student lab reports to get a quantitative measure of whether the students achieved the learning outcomes of the lab. Learning objectives associated with these labs are: 1) determine common stress-strain features, which can be obtained from uniaxial tension tests, including: tensile strength, failure stress, regions of strain hardening, and regions of necking, 2) quantitatively assess the anisotropic properties of a material via uniaxial tensile testing, 3) experimentally demonstrate the time-dependent nature of a biomaterial's mechanical response, and 4) quantitatively assess the viscoelastic properties, such as creep and relaxation, of a soft biomaterial via uniaxial tensile testing.

In addition to the mechanical testing experiments for the laboratory course, we plan to let the students use these devices to complete projects and self-designed experiments related to biomechanics at the end of the semester. We hope to explore the use of these devices to help inspire the maker movement. Possibilities include, allowing students to improve the design for additional capabilities in a bioinstrumentation course or design project.

References:

[1] J. R. Amend and H. Lipson, "Freeloader: An Open Source Universal Testing Machine for High-Throughput Experimentation."

[2] J. H. Arrizabalaga, A. D. Simmons, and M. U. Nollert, "Fabrication of an Economical Arduino-Based Uniaxial Tensile Tester," *J. Chem. Educ.*, vol. 94, no. 4, pp. 530–533, Apr. 2017.