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Portable Experimental Device for Determining the Mechanical Properties of Brain-Skull Interface.

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Abstract

It is important to accurately measure mechanical properties of brain and adjoining tissues like meninges to develop corresponding and realistic mathematical model of brain that can be used in computer simulation and other related fields like virtual surgeon training system and computer-integrated and robot-aided surgery. The biomaterials are very fragile and require very careful handling. We have designed a portable and robust material testing device that can be setup and used is a dissection laboratory to minimize sample transport and time between sample extraction and the experiment. This paper contains technical specification, calibration data and description of the user-interface. The hardware interfacing, signal processing and logic management is done in a portable Linux box. The compression, extension and shear for testing are performed by stepper motor driven platform. The sample displacements and forces generated are recorded by a linear variable differential transducer and a 20N loadcell. The outcome is a simple, portable and precise material testing device that can be used in wet environment where the biological sample is extracted.

Keywords: Mechanical properties, Experiment in vivo, Brain tissue

Note: The work presented in this report is a part of PhD project titled “Mechanical properties of Brain-skull Interface”.

Contents

1. Introduction

Mechanical Property of tissues and its accurate quantification is central to biomechanics. Most tissues tested are post mortem samples obtained from various sources. In most cases the sources are experimental animals raised in Animal research facilities in Universities and medical facilities. Some facilities follow strict containment protocol, making it difficult for tissue sample to be moved to other testing laboratories or facilities. Many facilities also have to run quarantine protocol due to may unforeseen complication at different times in the year. This all can lead to delay of experiments if they are being carried out in external facility. It will also add to the bulk of paperwork required apart from necessary ethics and other policy approvals. The simplest way to circumvent these issues is to have an experimental device setup in the animal research facility. The ISML bench top testing device is one such device.

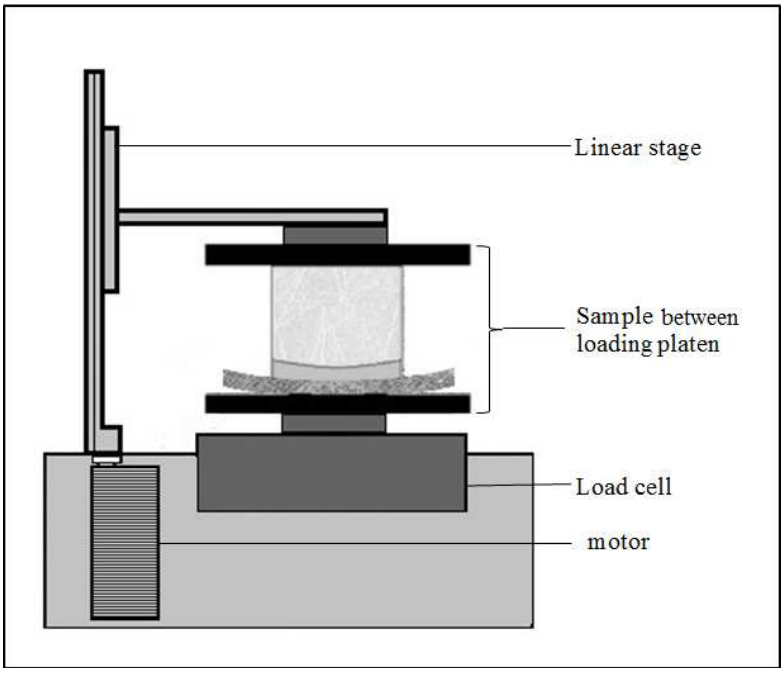


Figure 1: Schematics of testing rig

The ISML bench top tester is a portable and easy to setup device.

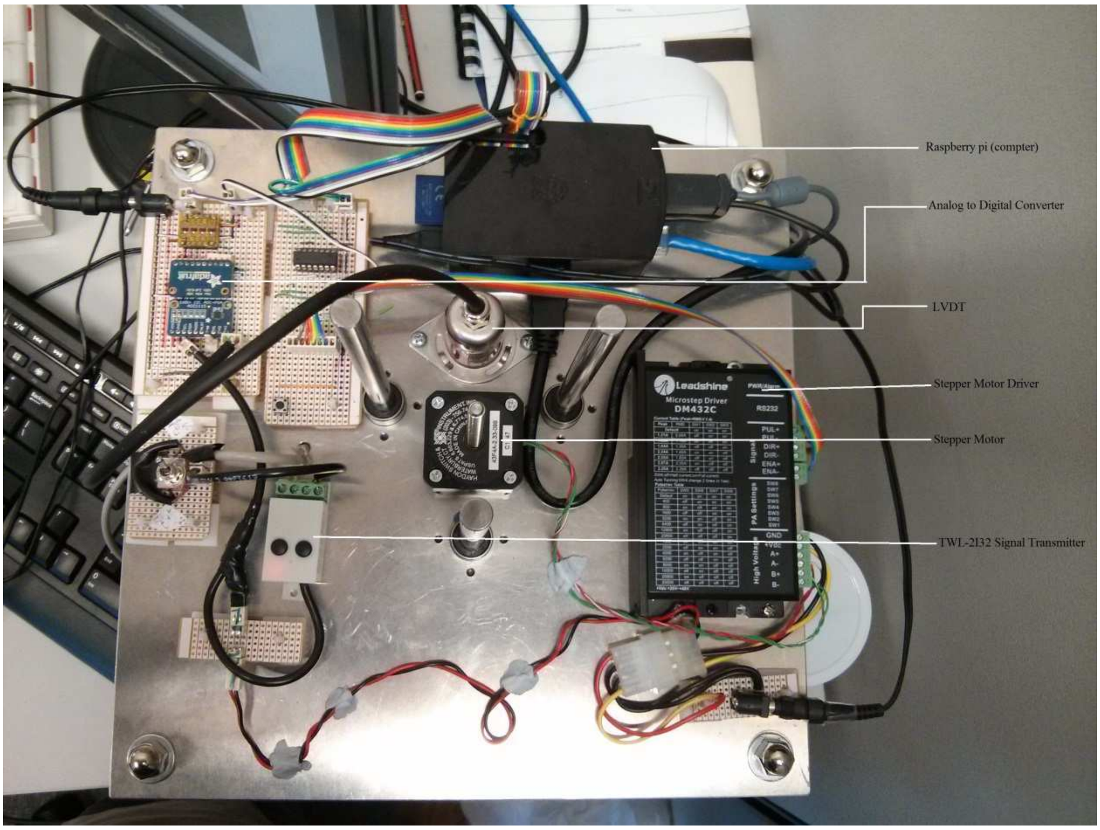
The model is designed to sit on a level table or workbench in either vertical or horizontal position. The system is designed to perform tensile, compressive and shear tests on soft biological tissues. It is a complete system that manages data logging, hardware interfacing, user interface and signal management all by itself. Schematic of the test rig is shown in figure 1.

2. Hardware Components

The main components of the device are shown in Figure 2 and are listed in table 1. They are described in following sections according to functionality performed. All the electronics components are mounted on top of the tester frame to avoid water spillage.

Table 1: Hardware and electronic components in the device

Components	**Function**
Raspberry pi Linux box	On board computer, UI and Signal processer
Arduino Uno board	Platform motion controller
Texas Instrument ADS1115	16 bit Analog to digital converter
Burster 8523 Loadcell	Force sensor
MTS Temposonics CS H2 LVDT	Linear displacement sensor
Ametek linear actuator 43F4A-2.33-099	Platform Actuation.
DM432 Anti-Resonance Stepper Motor Drive	
Monitor	Input and control components.
Wireless Keyboard	
Wireless Mouse	
Power Adapters for various component	Power supply
Various cables	Connectivity
Switches and logic level shifters	Signal flow and communication between components



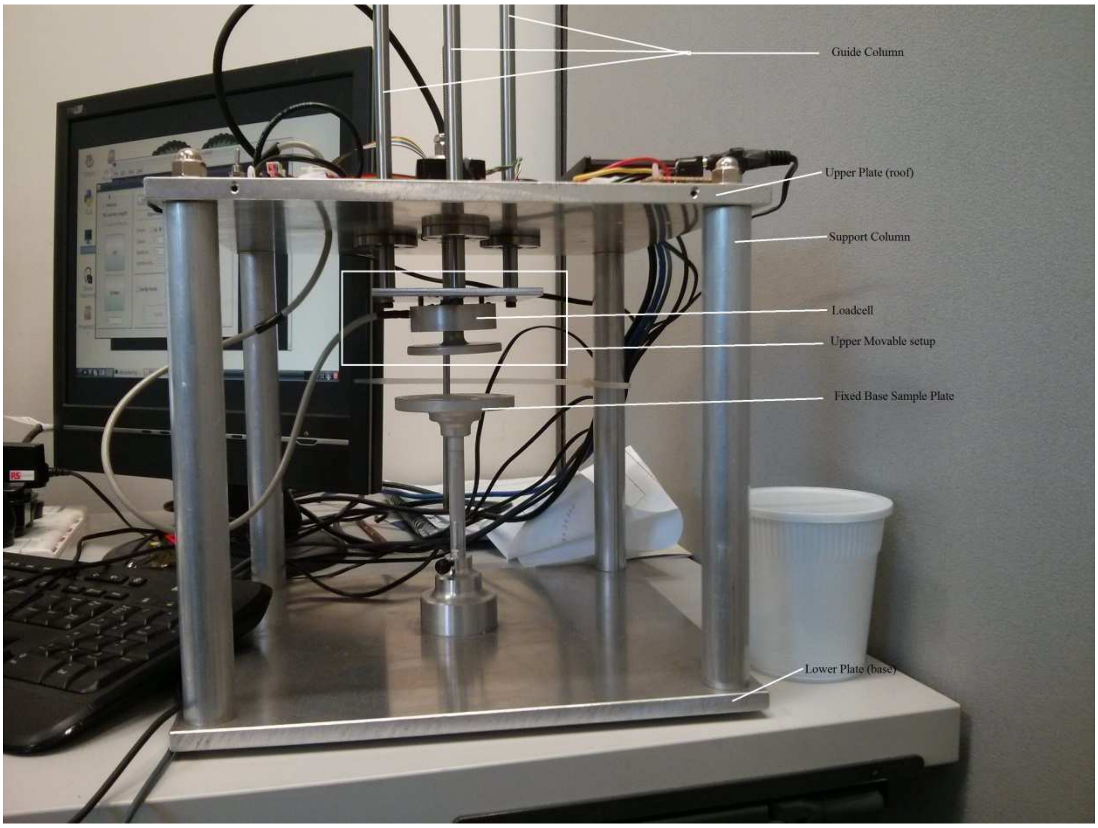


Figure 2: Device components

2.1. Data, logic and signal processing

The major data, logic, signal management for the tester is done by a Raspberry Pi (http://au.element14.com/, order code 2191863), the on-board computer which is mounted on the tester frame. It is a Linux box with a 700MHz ARM 11 processor. The system runs on a Raspbian distribution of Linux. The software managing the device collects test data including force, displacement and time and logs it at the end of every test is stored in a coma-separated value (CSV) file that every spreadsheet application can read and edit. The data then can be transported to other more powerful computer for further analysis. The software also provides full control of test machine's hardware parameters. It also manages the UI for the device.

The setup also has a arduino uno development board to handle stepper motor. To precisely control the stepper motor the arduino board generates square wave/drive pulse as instructed by the raspberry pi during the testing.

ADS1115 analog to digital converter (ADC) (Texas instrument, product code ADS1115) has a precision of 16 bit at a maximum sampling rate of 860Hz. It communicates with raspberry pi using I^2C protocol. It requires a two way logic level shifter to communicate with the raspberry pi due to difference in operating voltages.

2.2. Sensors

The device has two sensors, one to measure displacement of sensor to record strain and second to measure force to quantify stress build-up. The sensors are both analog sensor and require ADC to communicate with the on-board computer. They have two dedicated ADC to efficiently convert and transfer the recorded values.

The displacement is measured by MTS Temposonics CS core sensor in H2 housing. Coupled with the ADC it can measure displacement with precision of 5.57 micron. It can measure displacement of up to 148mm.

The force is measured by Burster 8523 20N Loadcell. The loadcell is only run on half the loading capacity, 10 N. In the current setup it can read data with a precision of 0.0012N in both extension and compression. Due to data transmitter issues the through zero operation (transition from compression then relaxation to extension or extension then relaxation to compression) is not permitted.

Both the sensors were delivered with calibration certificate that stated absolute values of variation and repeatability.

2.3. Platform motion for testing

Of the two platforms lower one is fixed and upper one has single degree of freedom. The platform is suspended on three cylindrical linear bearings to maintain surface of the platform parallel to the roof of the device and hence the base and base specimen resting platform. The moving platform is connected to a stepper motor’s (Ametek linear actuator 43F4A-2.33-099) screw shaft that has a step precision of 0.00793 mm. It is a 1.8° (200 steps per revolution) stepper motor capable of producing 200N of force at platform speed 5 mm/sec. The motor is driven by DM432 Anti-Resonance Stepper Motor Drive (Leadshine Techonolgy Co. ltd) that can micro-step the stepper motor to 128, that will give 25600 steps per revolution of the stepper motor used. The stepper motor driver if fed by Arduino pulse. The driver can also be enabled or disabled by the on-board computer.

3. Software

All the software for the device is written in Java programming language. The on-board computer runs java version 1.6 standard edition and the software is written to comply with the standard. The software handles UI, signal control and data logging. The software interfaces with all the low level components like ADC, Arduino and input/output pins and gives handle to various hardware parameter.

User control of test parameters is facilitated by a graphic user interface shown in figure 3.The UI has three panels, namely manual adjustment panel in the left, experiment panel in the centre and status panel on the right. The manual panel provides control to manually adjust platform to load and setup specimen for experiment. The experiment panel gives us access to system properties, experiment setting of direction, speed and distance for the upper platform to travel. The status panel is created to show system messages on status of the device and the experiment.

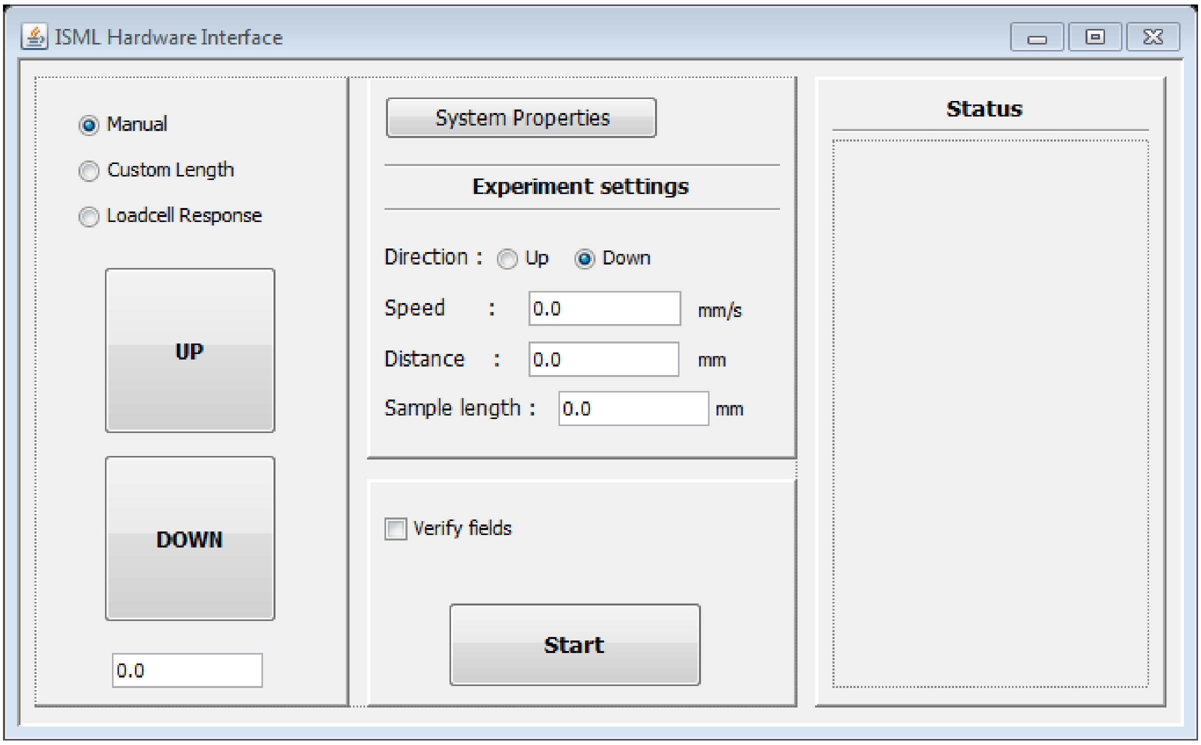


Figure 3: Screen shot of graphical user interface

System properties button leads to a properties setup dialogue where we can enter and change hardware parameters. Some of the parameters that can be changed are I2C addresses of

ADCs, load and displacement maximum threshold, addresses of pins used for stepper motor driver and Arduino control and Arduino's physical address.

4. Calibration

The sensors we have used, LVDT and Loadcell both come with factory testing and calibration. We performed physical calibration of both the sensors after integration in the system. The LVDT is calibrated using fixed known displacement and recording subsequent values. The loadcell is calibrated using deadweight. Figure 4 shows the calibration data for both the device.

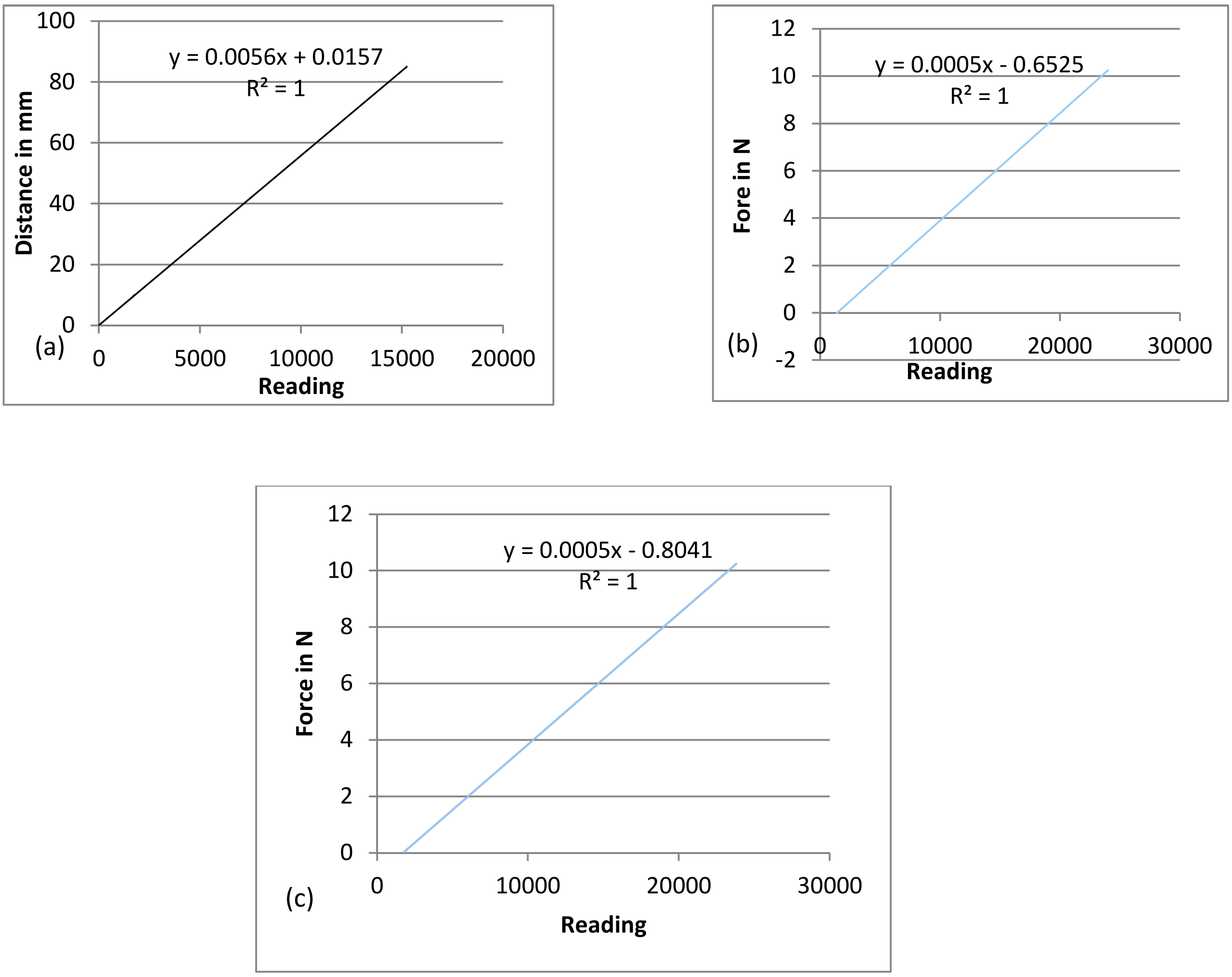


Figure 4: Calibration data for (a)LVDT, (b)loadcell in compression and (c)loadcell in extension

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