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A Robotic System for Soft Tissue Characterization

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Abstract

A miniature robotic system has been designed and fabricated to perform in vivo mechanical characterization of soft tissues. The tissue tester employs a stepper motor controlled using microstepping techniques to prevent irregular rotation of motor shaft at lower rates, and a load cell to measure the reaction force of tissue under test. At the end of tests session, data could be post elaborated on a PC with a specific software that reconstructs the force-displacement curves of tested tissues. A position and rate feedback control is actuated by motor control using a digital encoder to minimize errors during evaluation of viscoelastic phenomena typical of biological tissues. Calibration tests have been done showing that the force-displacement curves of the miniature robotic indenter are consistent with that obtained using an ordinary universal testing machine.

1. Introduction

Soft tissue is a composite of many structures and unfortunately its mechanical response cannot be correctly described by in vitro behavior of its constituents [1]. These structures have a common problem related to their high nonlinearity, viscoelasticity and good response to creep, stress-relaxation, histeresis and preconditioning.

A lot of smart systems have been built to enable compressive in vivo indentation of the bulk soft tissue. First examples of mechanical indenter, consisting of a simple beam arrangement for compressive loading tissues, did not support rate-controlled excursions of indentation tip, so important in viscoelastics phenomena evaluation [2,3]. Also plunger-like tissue testers, using a load cell to measure indentation force and indentation. Unfortunately acquired data was affected by a LVDT for displacement, do not support rate-controlled indentation rate [4]. Mak's et al. system, a cylindrical indenter with a load cell drove by a stepper motor, was controlled by a laptop computer supporting rate-controlled gravitational variations, enabling only horizontal measurement and also indenter excursion was only 5 mm [5]. Torres-Moreno's indenter had a larger excursion but only 6.4N of indentation's force [6]. Pathak's et al. system exceed the limits of the previous systems (30 mm. of indenter excursion and 44 N of indentation force), but allows tip excursions controlled by position and not by load [7]. Furthermore systems performing a rate-controlled indentation need a PC to be controlled. Other examples of indentation systems use pen-size hand-held probe composed of an ultrasound transducer and a load cell [8]. The advantage is the short size of probe, against the disadvantage of a manual indentation that prevents the evaluation of viscoelastic phenomena.

This paper presents a novel robotic system (indenter) developed by the researchers of the INAIL RTR Centre for in vivo soft tissue characterization of its viscoelastic properties.

2. Materials and methods

The main technical specifications for designing the indentation system have been the following: 1) indenter excursion up to 35 mm; 2) indentation force up to 50 N; 3) indentation rate up to 300 mm/s; 4) precise position and indentation rate control; 5) load-controlled and position-controlled tests; 6) negligible delay between loading and unloading; 7) replaceable indenter tip; 8) total mass less than 1 kg; 9) length less than 200 mm; 10) hardware safety features to prevent accident during clinical trials; 11) totally stand alone during tests; 12) portable testing system.

The indentation system is composed of two parts, as shown in Figure 1: a mechanical tissue tester and a control box.

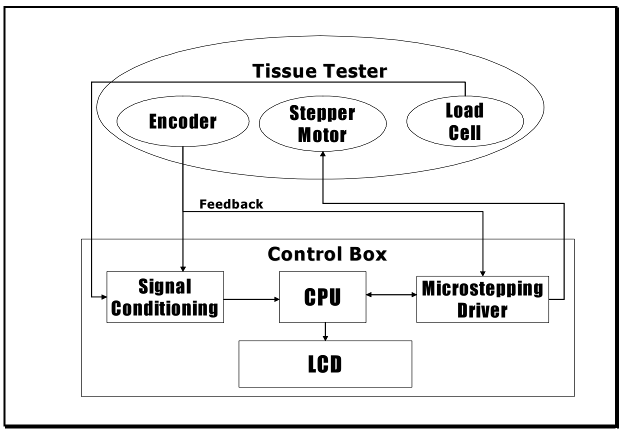

Figure 1: Block diagram of the indentation system.

2.1. The mechanical tissue tester

A Teflon [1] piston, constrained to run upon three cylindrical rectified brass guides moves an indentation Delrin[2] tip against testing tissue surface (see Figure 2). A stainless steel miniature button type precision load cell, with an operating range from 0 to 110 N, (Model L1650, Futek, Irvine, USA) is mounted between piston and tip for measuring reaction force resulting from tissue indentation. The axial movement of the piston is actuated by a 200 step per revolution bipolar stepper motor (Model HY200-1713-0150-AX04, Mae, Offanengo (CR), Italy) that put into rotation a 0.3 mm pitch tangential screw. A Delrin internal thread is bond to the piston by three screws.

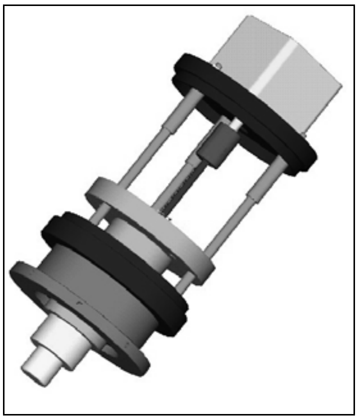

Figure 2: General assembly of the Tissue Tester.

A particular union joint with dovetail grooves has been realized to enable off-line recovery between motor shaft and tangent screw with an high axial stiffness (see Figure 3). In particular, dovetail grooves allow to reverse rotation without the disassembly of joint. The central plate is made of Teflon to minimize sliding friction.

Figure 3: Particular of Union Joint.

For the same reason three little Teflon ferrules have been mounted between at the interface piston-guides.

[1] Teflon is a registered trademark of DuPont
[2] Delrin is a registered trademark of DuPont

A light-weight aluminum case houses all the components mentioned above, giving to the system the high stiffness that a test instrumentation needs.

2.2. The control box

The indentation robotic system should perform rate-controlled, load-controlled and position-controlled tests to enable creep and stress relaxation characterizations. To perform in vivo tests without the need of a portable PC during acquisition time, an intelligent Motion Control for the tissue tester has been developed. A little plastic box (16x16x4 mm) houses two cheap microcontrollers made by Microchip (PIC 16f877). The operator, using four buttons placed at the top of the box (see Figure 4), selects test parameters (test type, possible number of cycles, indentation rate, load or position limit, and acquisition frequency) surfing a simple menu. The selections made are displayed on a 2x16 lines LCD. The differential signal from load cell, amplified by a instrumentation amplifier (1000 x) and cleaned up by a fifth-order low-pass anti-aliasing filter (cut off frequency of 100 Hz), is digitized by the on board 10 bit ADC of CPU I. The information about load and displacement are recorded into a 2 Mbit FIFO (First In First Out) with one variable acquisition frequency from the operator. With a 50 Hz acquisition frequency the system allow recording of about 20 minutes of tests information.
Special mention should be made of the motor driver (Model IM483IE, IMS, Marlborough, United Kingdom), that uses a microstepping control of stepper motion. This allow to reduce the characteristic tripping behavior at low rates of stepper motors. The encoder feedback allow to minimize error position and indentation rate.
A specific software made using LABVIEW[3] has been made for post-elaboration of acquired data.

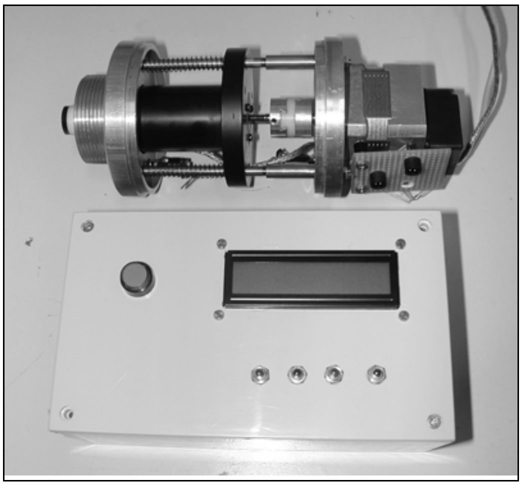

Figure 4: Prototype of the mechanical tissue tester and the control box.

[3] LABVIEW is a registered trademark of National Instruments, Austin

2.3. System calibration and characterization

Even if the load cell has been previously calibrated by manufacturer it was necessary to recalibrate the entire system to find the relationship between sensor output signal and axial force on the indentation tip. A 4464 Instron[4] testing machine (Model 4464, 1 kN load cell, Instron Corporation, MA, USA) has been used to load the indentation system. A special tip of the same dimension of the indenter one was realized to facilitate the alignment of the two sensors. System calibration has consisted of reading the same force value from both sensors.

After the load cell calibration, the performance of the developed indentation system has been compared to that of an Instron universal testing machine (see Figures 5 and 6). Test material was silicone usually used by dental technician, previously strained and set into a cylindrical box. Cyclic loading up to 50 N of indentation force was performed at three different rates.

Figure 5: Picture of the Silicone Sample Tested using the Instron testing Machine

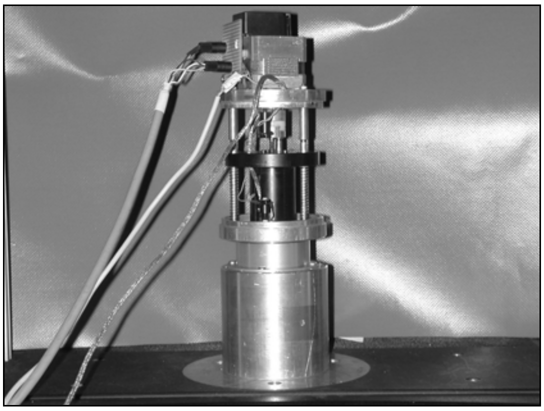

Figure 6: Picture of the Silicone Sample Tested using the Robotic Indenter

[4] Instron is a registered trademark of Instron Corporation, MA

3. Results

The linearity error of indenter load cell calculated on best fit straight line method and with an excitation voltage of 5 V was –0.553 % Full Scale at 50 N.

IMS motion control provide autonomously to check positioning error and indentation rate accuracy using the encoder feedback. In particular it is possible to set the maximum difference between the calculated position and the effective one before automatic correction is executed (default value is 100 step). At the same time also position maintenance is performed, so as "gear shifting" detection where requested torque is highest.

In Table1 a summary of indentation system behaviors is reported.

Max Indentation Force	**50 N**
Max Excursion tip	**35 mm**
Max Indentation Rate	**300 mm/min**
Mass	**720 g**
Length	**185 mm**

Table 1: summary of the indentation system main characteristics.

Cyclic loading up to 50 N of indentation force was performed at three different rates. The results are shown in Figures 7, 8 and 9.

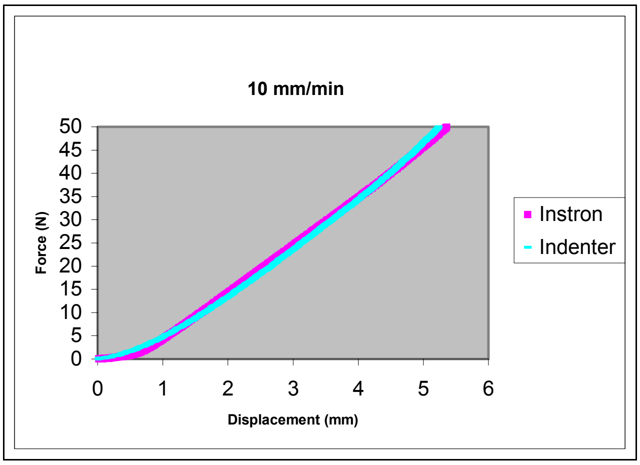

Figure 7: Cyclic loading at 10 mm/min.

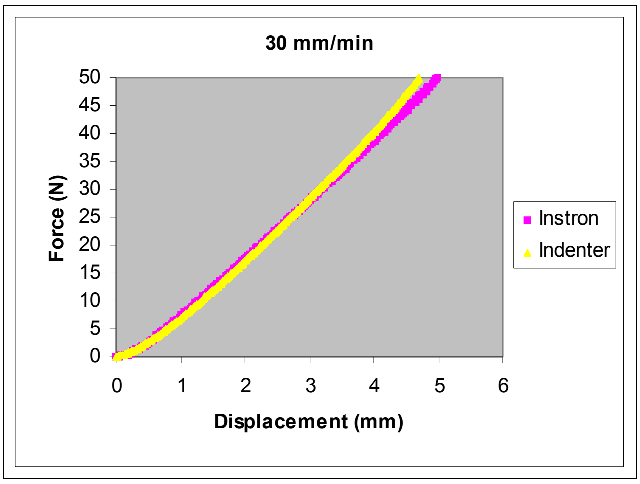

Figure 8: Cyclic loading at 30 mm/min.

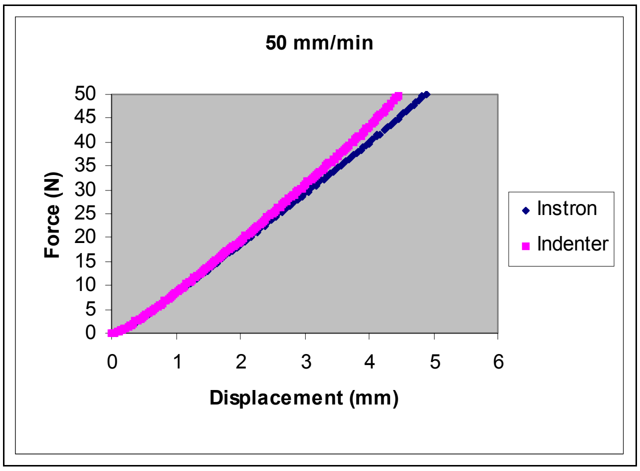

Figure 9: Cyclic loading at 10 mm/min.

The maximum indentation rate of 300 mm/min, that allows a complete excursion tip in about 7 seconds, can be appropriate to detect biological tissue response, and to minimize errors caused by inertia of the system.

Tests made at different indentation rate demonstrate the quality of acquired data, when compared to those obtained with an ordinary Instron testing machine especially at lower indentation rates. A little difference at higher rates and loads should be imputed to the difficulty from motion control to quickly correct motor shaft rate, slowed down from resistive load and inertia of the system.

4. Conclusions

An innovative robotic indenter has been developed to perform rate-controlled stand alone tests for soft tissue characterization. The system may be employed in the prosthetic field, where the palpation of patients to evaluate stability of soft tissue in common clinical practice is totally empirical and based on technician's ability and experience to understand the morphology and to unload critical areas preventing tissues trauma. The device may also be employed to perform tests in different clinical applications, as for example in plantar tissue of diabetic patients. Finally, the innovative control box and the limited dimensions of the presented system enable its employment in all the fields where the easy measurements of the viscoelastic characteristics of soft materials are needed.

Acknowledgements

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