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Single-board microcontrollers applied to biaxial tests for architectural membranes

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Abstract

The last decade has been characterised by the progressive development of several biaxial testing equipment and procedures for the mechanical characterisation of coated fabrics [1]. The few standards available in this field [2] [3] led to the development of several testing machines based on different loading principles to reproduce a biaxial stress state in a fabric. The most common approach is based on the symmetrical loading of a cruciform sample by means of four actuators, one on each side [4]. However, other concepts have been successfully applied such as the "floating frame", where the upper reaction frame is mounted on spherical bearings and is free to move in the plane of the fabric [5], and the use of rigid square frame with batteries of independent servomotors on each side [6]. Two recent interlaboratory studies confirmed a fairly good correspondence in the values of stiffness obtained by the different laboratories [1] [7].

The financial cost of each type of biaxial testing machine is directly related to the size, the accuracy and the level of flexibility of the testing equipment. However, the level of complexity and the absence of off-the-shelf products has led to costs which are not affordable by small research institutions, manufacturing companies and engineering offices. This research aims to unveil the potential of the new generation of single-board microcontrollers (e.g. Arduino and Raspberry-Pi) for a reliable and affordable biaxial testing machine which can drastically reduce the current costs associated to the biaxial characterisation of coated fabrics and foils.

The paper presents the development of a data logger based on Raspberry-Pi and able to record the data measured by four load cells a and three extensometers applied to a biaxial cruciform sample obtained from ETFE foils commonly used in Architecture.

Keywords: Coated Fabrics, Biaxial tests, ETFE, Arduino, Raspberry PI

1. Introduction

The adequate level of understanding of the biaxial behavior of coated fabrics and foils is a crucial step in the design and manufacturing of tensioned membrane structures. For this reason biaxial tests are becoming more popular with the architectural industry and there is a growing interest towards developing biaxial machines able to reproduce the expected level of stress in the material and measure the corresponding strain state in the coated fabric or foil. One of the main deterrents of this technology is the high price of the laboratory equipment required. This project investigated how to develop a cost effective biaxial machine thanks to the new generation of single-board microcontrollers such as Arduino and Raspberry-Pi.

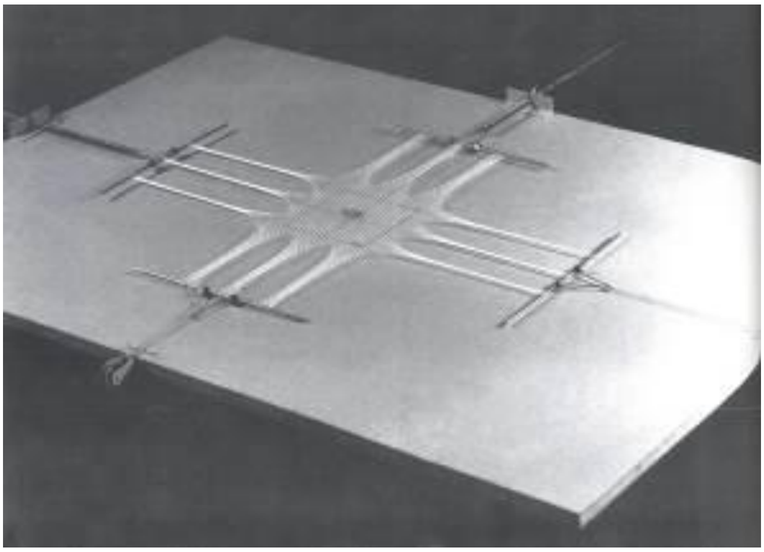

Figure 1: Loading test to determine the relation between the mesh form and the tension ratio in a hexagonal grid fabric [10]. Ingrid Müller, Claus Schuh (1985), Institute for Lightweight Structures and Conceptual Design (ILEK).

2. Biaxial tests for coated fabrics and foils

With no ISO or EN Standards concerning the biaxial stiffness and strength of coated fabrics, foils and open mesh fabrics, several approaches have been developed in order to investigate the material under tension both in warp and fill direction at the same time. The most common are the bursting test, the cylinder test and the plane biaxial test.

The plane biaxial test offers the most accurate results because of the independent force introduction in the two main direction. It is based on a slitted cross-shape specimen which is pulled in both warp and fill directions at the same time according to a stress or strain mode. The applied force and the material strain are recorded continuously during the test, with consequent identification of parameters such as the applied force and the elongation in warp and fill direction.

3. Biaxial testing rigs developed in recent years

Due to the complex woven geometry of the most common architectural coated fabrics the use of uniaxial testing methods does not allow a real understanding of the complex interaction between warp and fill. For this reason, during the 20th century several research institutes have developed a series of testing machines characterized by a progressive level of accuracy and complexity.

The first biaxial machine available in literature was developed by Haas [8] and was based on a on a symmetrical method of applying force to the sample. This is still considered one of the most common and cost effective way to to reproduce a biaxial stress state in a fabric. It is based on the assumption that the material's principal directions are perfectly aligned with the specimen arms directions. Therefore, the load is applied maintaining the double symmetry of the system: the centre of the sample remains stationary in the original position and the force (or displacement) is applied to the sample by four actuators connected to the ends of the cruciform sample which work in pairs in order to balance the force (or displacement) applied in each direction. Examples of this typology of testing rigs are currently used, among the others, by the Taiyo Kogyo Corporation [9], Base Structures Ltd [1] and the Universität Duisburg-Essen [4].

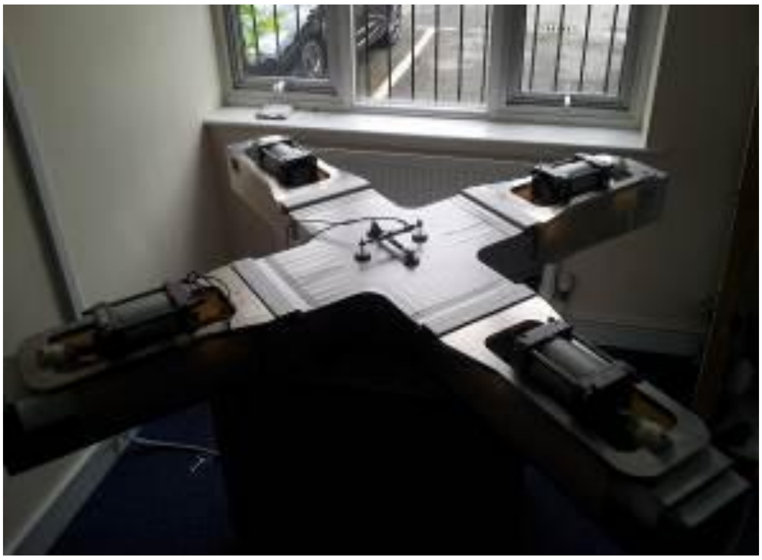

Figure 2: Biaxial Machine based on the symmetric load of a cruciform sample available at Base Structures Ltd (UK)

In the 1971 Losch [11] introduced the idea of large frame capable of housing specimens of considerable dimensions or one-to-one scale details such as junctions or anchorages. In addition, with a rigid square frame equipped with batteries of independent servomotors is possible to apply the load independently for each arm's slit in such a way that the application direction is constantly orthogonal to the other direction of the sample. At a later stage, this concept has been implemented by LaborBlum which manufactured three testing machines currently in use at DEKRA Industrial International GmbH (former Labor Blum GmbH) (D), at the Centre for Synergetic Structures at Swiss Federal Laboratories for Materials Science and Technology (EMPA) in Dübendorf (CH) and at the Taiwan Textile Research Institute (ROC). A similar concept has been adopted for the testing rig developed by the clusTEX testing laboratory, Politecnico di Milano (I).

Figure 3: The biaxial machine developed by the author for the clusTEX testing laboratory, Politecnico di Milano.

In addition, several interesting concepts have been developed in order to reduce the complexity of the testing rig (number of actuators and load cells, controlling software, costs etc.) or to allow the spontaneous alignment of the actuator with one of the two weaving directions, which are not necessarily orthogonal due to bow or skew of the fill yarns. Alex Heslop and Newcastle University [5] developed a testing machine which is the combination of two uniaxial apparatuses on the fundamental assumption that, while the reaction frame in one direction is fixed and leans on the ground, the other is mounted on spherical bearings and free to move in the plane of the fabric. The concept is also known as 'floating frame' and is currently in use at Newcastle University and Architen Landrell Associates Ltd.

The three main drivers in the development of a biaxial testing ring are the size of the sample which needs to be tested, the level of accuracy which has to be achieved and the number of actuators with the corresponding controlling software. The dimension of the sample has direct implications on the size and strength of the structural frame and on the size of the actuators. The price of the actuators, especially for electromechanical actuators, is directly related to the power required which depends by the maximum expected force and speed. The overall accuracy of the testing machine is directly linked to the accuracy and quality of the sensors and the electronic components employed. Finally, the number of actuators employed has direct impact on the numbers of components (sensors, motors, ball runner blocks, linear guides, cables, connectors, input/output electronic channels. Due to the reduced market for this equipment there is no standard and each testing rig is the result of a unique project developed by the supplier according to the requirements of the client. A cost analysis carried out for the development of the biaxial testing machine at clusTEX testing laboratory highlighted that the commercial value for the equipment (testing machine + controlling software) can be estimated equal to: 60k€ for a “floating frame” concept (central area 50cmx50cm), 150 k€ for a “symmetric loading” concept (70cmx70cm), and 320k€ for a “square frame with batteries of independent servomotors” concept (70cmx70cm). The main part of the costs is related to the selling margins, the engineering costs and the development of the controlling software. When the equipment and the software is developed internally by the research centre/university the costs can be reduced considerably (40-50%).

Figure 4: The biaxial machine based on the floating frame concept available at Architen Landrell Associates Limited.

4. Single-board microcontrollers

The new generation of single-board microcontrollers, such as Arduino and Raspberry-Pi, open extraordinary possibilities for the easy prototyping and development of projects based on the interaction with the surrounding environment using sensors and actuators. The interest toward these devices has grown considerably in the last few years due to a combination of their purpose, capabilities, and usefulness.

Arduino and Raspberry-Pi can both be considered barebones computers developed with the intention of providing low-cost computers and free software to students. The printed circuit board is extremely compact (the size of a credit card) and houses the input and output connectors as well as the computer hardware itself. They are one of the most significant pieces of technology to foster computer science education due to the intrinsic affordability. In addition, thanks to the “open hardware” approach adopted by the developers, there is a wide web community which develops exchanges and sells thousands of products, components and software at a very effective cost.

The cost of a Raspberry-Pi is around 40€ and can be easily connected to sensors and actuators with a price which varies between few euros and less than one thousand euros.

Figure 5: A Raspberry-Pi single-board microcontroller combined with a low cost LCD screen.

5. Development of a cost effective biaxial testing rig based on Raspberry PI

The project between Maco Technology srl, University of Nottingham and Holscot Fluoroplastics Ltd aimed to investigate the potential of a Raspberry-Pi micro-controller in the development of cost effective test equipment for the investigation of the mechanical performance of architectural coated fabrics and foils.

The testing device is composed by a data logger, able to record several channels simultaneously, and a metal rig 130cmx130cm able to test a cruciform sample 90cmx90cm with a central area of 30cmx30cm and arms 30cm long. Each side of the ETFE sample, which is previously folded over a cylindrical bar which prevents any slippage, is held by an aluminum keder rail 50cm wide. The load is applied manually through a threaded bar, however, the next development of the biaxial machine aims to include actuators directly controlled by the Raspberry-Pi micro-controller.

The force is measured by means of up to four S type load cells (Phidget CZL301) designed for a maximum force of 5kN. The elongation of the material is measured through up to three linear potentiometers (Alps RSA0N11S9002) with a maximum stroke of 100 mm. The data of force and elongation are recorded simultaneously and are then used to develop the stress-strain response curves (or surfaces) used for the investigation of the mechanical performance of the material. In addition, the data logger has four channels for the measure of temperature and humidity and two sensors for the measure of pressure (0-5 Psi).

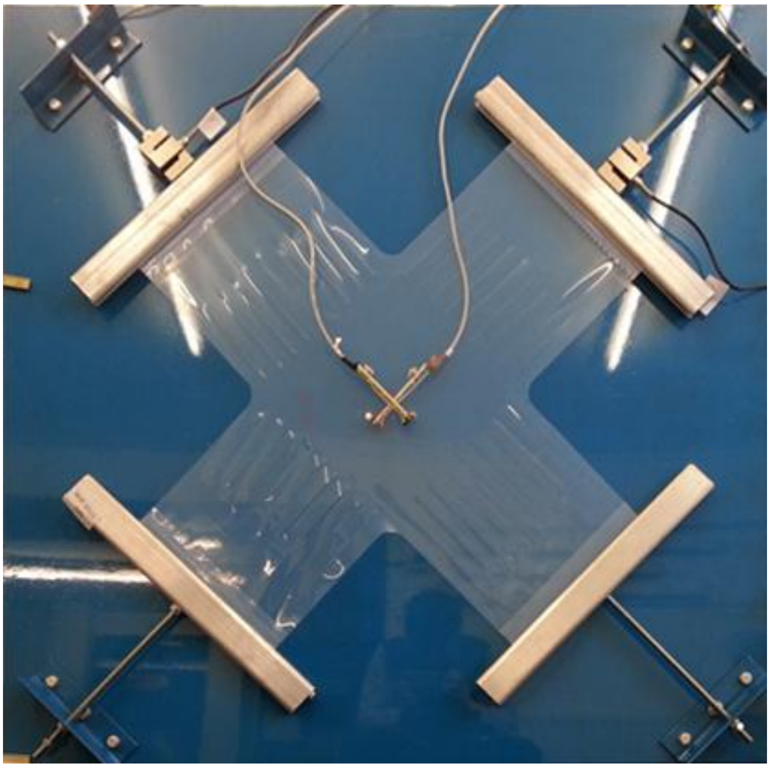

Figure 6: The cost effective biaxial machine developed by Maco Technology srl, University of Nottingham and Holscot Fluoroplastics Ltd.

Figure 7: The Raspberry-Pi single-board microcontroller combined with a low cost touchscreen.

The extremely reduced cost of the sensors (650€), combined to the price of the printed circuit board, the electronic components, the LCD, the wiring and the connectors (1290€) makes this testing machine extremely cost effective with the addition al advantage that the open-source hardware can be implemented and modified according to the requirements. Considered an overall price of the steel frame equal to 500€, the final price of the equipment can be estimated around 2500€.

6. Results

The equipment has been tested by carrying out a biaxial test with an ETFE foil (250µm). The results, shown in the biaxial stress-strain curve represented in fig. 8, demonstrate a good correlation with the data available in literature [12] where it is clearly visible a yield point. The smoothness of the curve is affected by the loading profile which, due to the absence of computerized actuators, is applied manually by means of a threaded bar. Therefore, the load profile is characterized by several steps and a certain shift between the load applied in the machine and transverse direction (with the consequent alteration of the stress-strain curve). It is realistic to assume that this inaccuracies can be solved applying a set of actuators controlled by the Raspberry-Pi microcontroller.

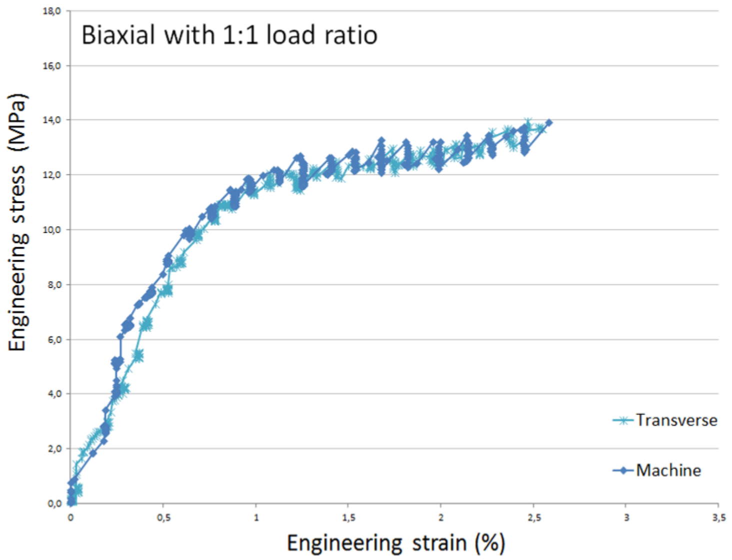

Figure 8: Biaxial stress-strain behavior measured on the cruciform specimen by means of the biaxial machine based on the Raspberry-Pi microcontroller.

7. Conclusions

This paper investigated the potential of a Raspberry-Pi micro-controller applied to a biaxial testing rig for architectural fabrics and foils. The main types of biaxial testing rigs currently in use are here described together with an estimation of the manufacturing costs which are finally compared with the cost effective solutions available thanks to a wide range of open-source hardware compatible with Raspberry-Pi

Acknowledgement

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