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A novel method for in-situ calibration of a 2-dof force platform for tremor detection in small-sized animal models

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Abstract— **Tremor analysis in human or animal model plays a fundamental role for understanding the physiopathology of human disorders and to test new pharmacological treatments. Mechatronic systems for automatic and quantitative behavioural analysis are now of current use for Neuroscientists to improve the results of their research. Most of these devices are portable and need to be used out of engineering labs by personnel with no technical expertise and without specific equipment. The calibration of the devices, that should be performed before each experimental session, is a typical issue to be faced. This paper deals with a new calibration method that is fast, simple and doesn't need other external measurement systems. It is based on the parallel use of an accelerometer and an optical sensor. The two signals are processed and compared to obtain the final calibration curve of the device.**

I. INTRODUCTION

The study of tremor in animal or human models is fundamental for understanding the physiopatology of human disorders and the development of new therapeutic agents [5]. Different kind of mechatronic devices have been developed and many of them are commercially available [6], [7], [3], [2], [8]. Such technologic systems helped Neuroscientists to lead more objective and quantitative experiments. Furthermore also new methods and algorithms for automatic computerized detection and classification of tremor have been devised [13], [17], [18]. The trend towards the automatization and the quantification of the behavioural analysis systems is clearly evident [1]. The work presented in this paper takes place in this context. It has been conceived to be applied on a GRF detecting platform, a mechatronic device designed and developed by the same authors, whose technical description can be found in [9], [11]. In the II, calibration issues are presented and some of the solution presented in literature are shown. Section III introduces the solution proposed by the authors based on the integration of a force and an acceleration sensor. Section IV shows the development of the solution while section V illustrates the results obtained with the implementation of the technique.

II. THE CALIBRATION ISSUES

GRFs detecting platform (hereafter GRF device) can be used to detect and analyze tremor in small animal models during locomotion [11]. More generally the platform described is modular and in its final application it should be used parallely together with other dynamometric modules or even with different types of devices to perform an integrated multimodal behavioural analysis.

In any case it is fundamental to get correct force data from each one of the GRF modules, so that the whole measure process could be considered reliable. In a measurement process the reliability of data can only be guaranteed by sensors calibration.

The classical calibration process entails some temporal and spatial constraints: usually it is performed into well-equipped metrologic laboratories with very high quality instrumentation (high accuracy, high precision, etc.) and it is a time-consuming process. Furthermore the calibration process should be performed again every time environmental conditions or internal sensor parameters change.

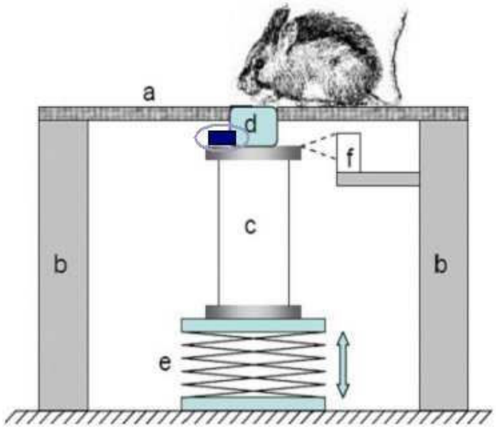

Fig. 1. Scheme of the GRF detecting device: a circular arena with wooden floor (a) was placed at a certain height from a table and sustained with lateral columns (b). At the center of the floor, a 1.5 *cm* diameter hole was drilled which would host the sensorised tile (d), i.e. a plastic cylinder glued on top of the force platform (c). By means of a manual z-axis stage (e) placed right beneath the wooden arena, the force platform was lifted up so that the plastic cylinder would fit through the hole in the center of the arena and stay right at the level of the arena. The optical sensor (f) was fixed at a height so that it faced one side of the platform.

So referring to the GRF device, according to what stated above, the optimal situation would be to perform a calibration just before starting each measurement session, but this scenario is actually impossible to be acted with the classical calibration techniques since the GRF device is intended to be used into animal facilities and, more generally, into non-engineered labs as a portable research tool by Neuroscientists who, furhtermore, most of time have no technical expertise.

From a functional viewpoint (fig.II), the GRF device is

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composed by a mechanical part, used as a transducer of force into displacement and an optical electronic stage which converts the displacement into an electric signal.

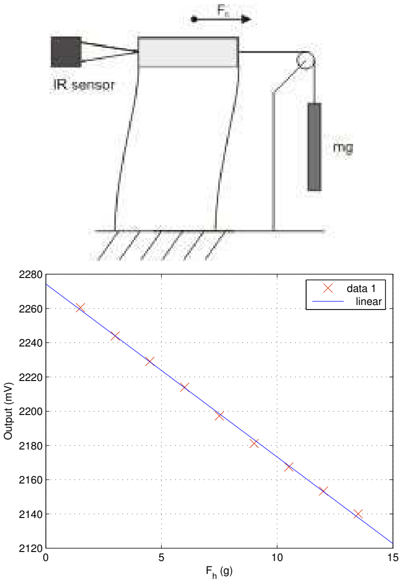

Fig. 2. In the top figure a scheme of the setup used for calibration is shown: small weights are hanged to the wire in order to generate an horizontal known force; in the bottom plot, the results of calibration (Voltage vs Force) is presented. A negative lineare curve is highlighted

In [9] it has been demonstrated with a static calibration that the mechanical structure has a linear response in the range of interest of the forces as shown in fig.II. Furthermore the mechanism could be considered robust and stable enough not to need a calibration every measurement sessions, since the environmental parameters (light, temperature, pressure, temperature, ecc) don't affect the mechanical characteristic of the device. What is much more affected by these parameters is the electronic stage and in particular the optical sensor.

Infact it has a highly non-linear response shown in fig.II and the working point of the sensor depends mostly on the intensity and the frequency spectrum of light present in the environment where the experiment is performed. The GRF device is used under the hypothesis of small displacements of the sensing element, so that once detected the working point, the non-linear response curve of the sensor is linearized around it (see fig.II). As the working point shifts on the sensor curve (due to the environmental parameters variation), the slope of the red line changes as well. That is the main reason why the calibration of the optical stage is so crucial.

This paper proposes a new technique that allows a fast calibration without any particular high quality device and that, although it was conceived for the GRF detecting module, it can be easily applied to other devices.

A. *The static and dynamic calibration*

In [15] and [19] optical sensors are used to get the displacement of a moving object along time, thus detecting some tremor characteristics of the object itself. In both cases

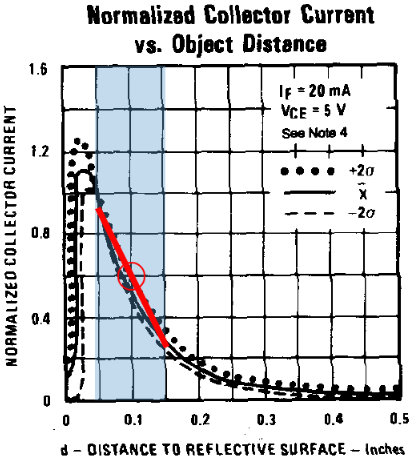

Fig. 3. Non-linear characteristic of the optical sensor. The blue area is the working interval of the device. The red circle is the working (rest) point, the red line is the linearization of the curve around the rest point

before starting a new experimental session, the authors perform a *static* calibration: known displacements are provided to the sensor thanks to the use of a micrometric screw; then for each displacement the output of the sensor is collected; finally joining the data collected it is possible to get the calibration curve which correlates the input displacements to the output voltage.

Such calibration method is time consuming, requires an accurate mechanical instrument (i.e. micrometric screw) as well as a suitable environment; it provides the static output of the sensor, but nothing on the dynamic response.

Also in [9] a static calibration has been performed on the GRF device by using the micrometric screw to impose a displacement to the mechanical structure of the sensor whose stiffness was known, thus simulating an input force.

But in literature it is possible to find also examples of dynamic calibration of force platform as in [14], [16], [20]. In these cases a variable force generated through the use of mechanical oscillators (i.e. pendulum, eccentric rotating mass, vibrator) stresses the platform devices and then the system response is collected. Finally the calibration curve is derived from the correlation between the a-priori known input and the observed output.

III. THE PROPOSED SOLUTION: IN-SITU DYNAMIC CALIBRATION

In all the techniques described above either static or dynamic, the calibration curve was obtained because the input force signal was known. But this implies the use of devices enabling the researcher to exert desired (or at least known) variable forces to the platforms.

The method proposed in this paper, instead, uses a different approach: the dynamic input force signal applied to the platform isn't required to be known. The input signal could even be imposed manually by the researcher without any particular care about it.

The basic idea is the addition of a further sensor (i.e. an accelerometer) to the GRF device; in this way the input signal is double detected both by the optical stage and by the accelerometer itself.

It should be noted that the two sensors can detect signals of different nature, i.e. the linear *displacement* and the *acceleration* of the mechanical structure. Anyway since those two physical dimensions are correlated one to the other and, after some mathematical elaboration, it is possible to get the same measure from the two inputs, thus allowing a comparison between them. Finally, using the electronic circuit for self-calibration built-in the accelerometer sensor, a reference signal useful to calibrate the device is extracted.

In practical terms, the goal of the calibration process is to obtain the characteristics of the curve (assumed linear[1]) which correlates the input (i.e. displacement) and the output (i.e. voltage) of the device. The offset can be simply calculated by observing the working point of the device. What is really needed is the gain (i.e. slope) of the line.

Here the steps used by the authors to get it follow: the acceleration signal is acquired, filtered and integrated twice in order to obtain the position data which is taken as a reference vector to be compared to the output optical sensor signal for the final calibration. Unfortunately this way presents some technical problems mostly related to the difficulty to extract displacement data from acceleration ones.

In particular the numerical integration of an acceleration signal presents a well-known problem because of the drift affecting the accelerometers; such an error even grows linearly if the signal is integrated along the time. In formulas:

$$v(t) = \int (a(t) + \varepsilon)\ dt = \int a(t)\ dt\ +\ \varepsilon\ t \qquad (1)$$

$$d(t) = \int v(t)\ dt = \iint a(t)\ dt^2 +\ 1/2\ \varepsilon\ t^2 \qquad (2)$$

where a, v and d are respectively the acceleration, the velocity and the displacement signal, while ε is the drift error (assumed constant). The presence of ε is the main issue limiting the use of this method: to get a realiable calibration, it must be as small as possible.

To overcome these problems, an alternative way has been adopted. The GRF device is stressed with an impulse-like input (i.e. small shock). Fig.III illustrates how signals from accelerometer and optical sensor are processed. System response is a damped sinusoid at his natural frequency (transfer function, fig.III). In order to minimize the noise, both the acquired optical and acceleration signals are processed with a narrow passband (a second order Butterworth) filter whose bandwidth is centered just on the resonance peak of the system ($w_0 = 134\ Hz$); infact around that frequency the SNR (Signal-to-Noise Ratio) is maximum. The phase shift imposed by filter to the signals doesn't affect the applicability of the method, since both the input signals undergo the same shift. Then a double integration of the acceleration around w_0 (indicated also in the functional block in fig.III) is performed according the following formula:

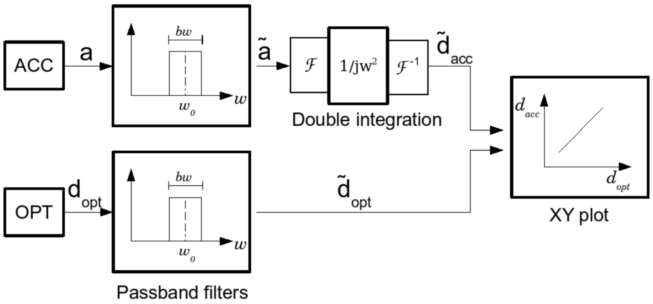

Fig. 4. Functional block diagram of the signals elaboration.

$$A(w) = \mathscr{F}(a(t)) \qquad (3)$$

$$d_{acc}(t) = \mathscr{F}^{-1}\left(\frac{A(w)}{(-w)^2}\right) \qquad (4)$$

around the interval $w_0 - \delta_w < w < w_0 + \delta_w$, where $\mathscr{F}$ is the Fourier transform while $\mathscr{F}^{-1}$ is the relative anti-transform, w_0 is the resonance frequency of the system, δ_w is a the range of frequency of the passband filter(for this application $\delta_w = 10\ Hz$). Finally the so obtained displacement data $d(t)$ are plotted versus the signal collected by the optical sensor. The cloud of points is then fitted with a linear regression giving the desired value of the gain.

An approximation of this method consists in performing the same mathematical operations on a single point, rather then an interval. So for example considering the value of the acceleration signal at the resonance and dividing it twice by its frequency value, it is possible to get a good estimate of the amplitude of the displacement signal.

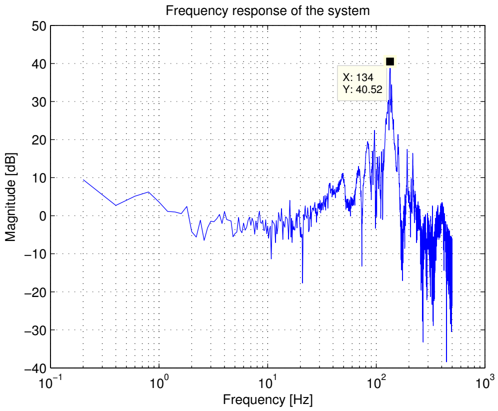

Fig. 5. Response in frequency domain of the system to the impulse-like shock input. In the plot it's clearly visible the resonance peak

IV. DEVELOPMENT OF THE SOLUTION

Before adding the accelerometer to the GRF device, some aspects should be kept in consideration.

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[1] The reasons why the calibration curve can be considered linear are described above; in particular under the hypothesis of small deflections both the stages composing the GRF device (i.e. the mechanical structure and the optical sensor) can be considered linear

The mechanical structure (i.e. the force transducer) of the GRF device is made of two parallel small aluminum tiles blocked by four stainless steel pillars; every time a force normal to the pillars is applied to the top of the parallelepiped, a displacement is caused. The weight of the upper tile and the stiffness of the pillars are the two parameters that characterize the dynamics of the system. In particular it would be desirable to have a structure as light and stiff as possible to have a wide bandwidth response, even though this is at the expense of the resolution and the robustness of the device.

Another aspect to be considered is the accelerometer's axes alignment to the ones of the GRF device in order to get a coherent measure of the acceleration. Infact a rotation between the two reference systems would finally result into an uncorrect calibration (fig.IV). Anyway the rotation entails a the multiplication of factor $\cos\alpha$ among the two signals: for $\alpha < 5^\circ$, the resulting error would be less than 0.4%.

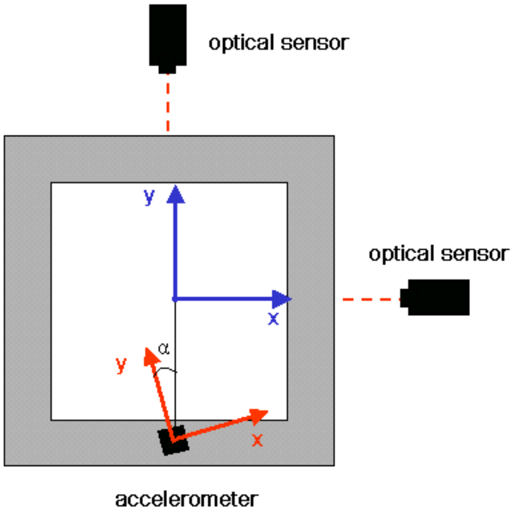

Fig. 6. Top view (scheme) of the platform tile. The two optical sensors give the orientation to the first reference system, while the second one is determined by how the accelerometer is glued on the tile. The angle α is the relative rotation between the two systems

The acceleration sensor used is a two-axis Analog Device iMEMs® ADXL203. Its total weight is less than $1g$. Once the accelerometer has been glued to the upper tile, the resonance frequency of the platform changed and in particular decreased form $149Hz$ to $134Hz$ which anyway is widely over the bandwidth required for the specific application ($30Hz$) and no significant error due to the alignment was revealed.

V. TEST AND RESULTS

The above described algorithm has been implemented with Matlab R2006a. Here a series of plots regarding the calibration process follow. In the figure V the plot of the two signal (acceleration and optical) versus time is shown. In particular it can be clearly observed that the two signal have a shift of π radians in phase, since one is proportional to the second derivative of the other.

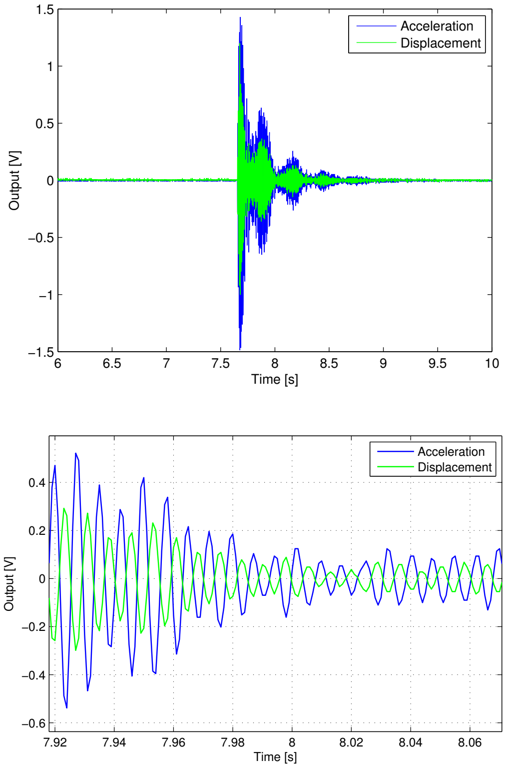

Fig. 7. Time response of the system to the impulse-like shock input. In the bottom detailed picture, it can be seen the difference of phase of the two sensors

After the filtering and the double integration, the acceleration signal is plotted as in fig.V. The cloud of points obtained is arranged along a line, whose parameter are extracted by a linear regression. The coefficient of determination (also known as R^2 factor) is 0.7755.

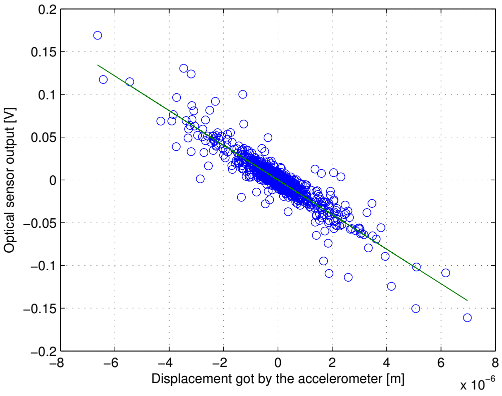

Fig. 8. The cloud of points derived after the elaboration

Then the static calibration of the optical sensor through the use of a micrometric screw with $10\mu m$ step is performed. It is important to notice that in this calibration, is different from the other one described above showed in fig.II; infact in this case only the optical sensor is involved while the mechanical structure is excluded. So the input signal will be a displacement, not a force. Once more the linearity of the curve is shown in the fig.V

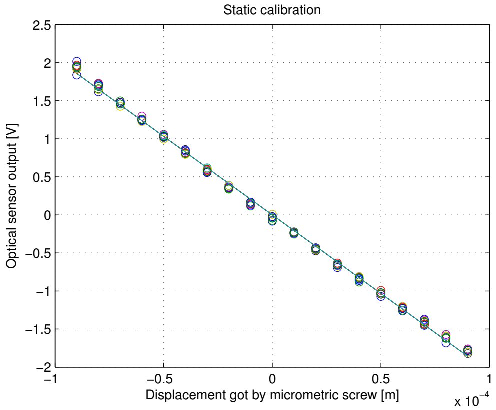

Fig. 9. The static calibration of the optical sensor. Once more its calibration curve is almost linear

Finally to verify the results obtained, the proposed calibration techniques and the static calibration performed with the micrometric screw were parallely compared. So the two regression lines are plotted together. It can be seen almost the overlapping of the two lines, highlighting an identical trend. In particular the maximum difference between the two lines (at the two ends) is around 0.99% of the full scale.

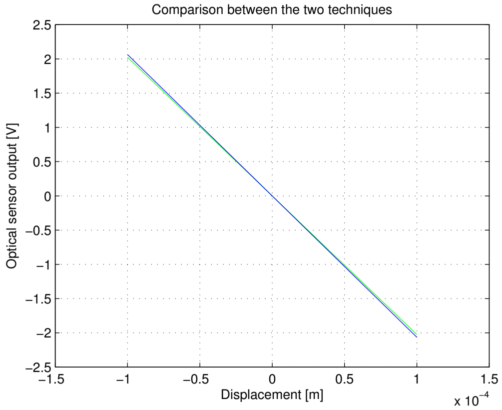

Fig. 10. The two lines obtained by the static calibration and the new dynamic method are compared

VI. CONCLUSION

In this paper a novel method for calibrating 2-DOF force platform for tremor detection in animal models has been described. The problem of calibration of sensors to be used in non-structured (engineered) environment is introduced. Different examples of calibration techniques (static and dynamic) reported in literature have been shown. Then the new calibration method has been technically illustrated, highlighting the problems occurring in numerically integration of acceleration signals and a possible approach to the solution. Finally tests performed and results obtained have been presented, confirming the validity of the approach.

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