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Application of Splines for Measuring of Musculature Local Disposition

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BIOGRAPHICAL NOTES

doc. RNDr. Dušan Knežo, CSc. is a vice-dean of the Faculty of Mechanical Engineering, Technical University of Košice and a head of the Department of Applied Mathematics. He graduated at the Faculty of Natural Sciences, University of P.J. Šafarik in Košice. He received the PhD.-degree at the Mathematic-Physics Faculty, University of J.A. Comenius in Bratislava, and he was habilitated at the Faculty of Mechanical Engineering, University of Žilina, in the scientific branch of applied mathematics. His scientific focus is oriented to the modelling of processes in the biomedical engineering, to the research of materials, as well as to the measurement and diagnostic equipment, prognostics and evaluation of medical proceed. He is a co-author of one monograph, one academic textbook and author of several textbooks. He has published more than 60 papers in the scientific journals and in the proceedings of the conferences and he has more than 80 quotations concerning his professional works. He was also incorporated in various grant research projects and industrial projects.

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KEY WORDS

Interpolation, Bilinear Splines, Cubic Splines, Musculature Local Disposition

ABSTRACT

Information about actual disponibility of the rehabilitated muscular locality is important with regard to efficiency and safety of the rehabilitation process. There was designed a sensor of the musculature local disposition for measuring of the musculature local disposition status. In function of the sensing element there was applied an electrically conductive rubber. This paper describes an application of the bilinear splines for evaluation of the musculature local disposition measuring by means of the above-mentioned sensor.

INTRODUCTION

There are two very important aspects in the machine-supported process for rehabilitation of limbs:

- *safety of rehabilitation,*
- *efficiency of rehabilitation.*

From this point of view it is necessary to monitor disponibility of the rehabilitated muscular locality by means of a feedback. Otherwise the rehabilitation could be inefficient or painful; in some cases it can induce even further health complications. The feedback enables to correct extension of limbs movements and quantity of loading or to interrupt the rehabilitation process, eventually. The required feedback can be obtained by means of a sensor of the musculature local disposition, which is applied into the rehabilitation process and it enables on-line monitoring of muscular tonus in the rehabilitated locality.

SENSOR OF THE MUSCULATURE LOCAL DISPOSITION

There is presented a scheme of the sensor of musculature local disposition (SMLD) on the (see Fig. 1).

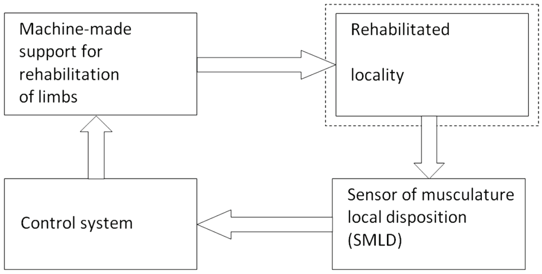

Fig. 1 *A new Virtual Education & Training Framework*

The SMLD in itself consists of three parts, (see Fig. 2):

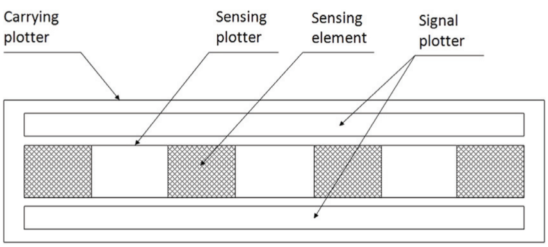

Fig. 2 *Internal structure of the SMLD*

- ***carrying plotter*** - it fulfils function of a sensor cover, as well as function of a fixation module, which enables fixing of the SMLD to the rehabilitated limb,
- ***signal plotter*** - it serves as a bus of signals coming from the sensing plotter,
- ***sensing plotter*** - it is a carrier of the pressure sensing elements, whereas there was applied the conductive rubber in function of the sensing element (see 1, 2, 3).

The sensing plotter is rectangle-shaped and its area is divided into *m x n* identical square-shaped parts, whereas in the every part is arranged one pressure-sensing element (i.e. sensing point or point of sensitivity). Let the sensing plotter area is denoted *M* and the pressure, which is acting from musculature on the sensing plotter in the time t on the point $[x,y]\in M$, is marked $p(x,y,t)$. To this pressure value corresponds the signal value, (i.e. value of the pressure equivalent), which is denoted $w(x,y,t)$, thus $p(x,y,t)\approx w(x,y,t)$. It is evident that value of the total pressure force acting on the surface *M* in the time t is:

$$F(t) = \iint_M p(x,y,t)\,dM$$

and

$$F(t) \approx E(t) = \iint_M w(x,y,t)\,dM,$$

where $E(t)$ is equivalent of the pressure force. Since the momentary measured values are varying in dependence on many factors, it was approved that it is suitable to apply a mean value $E_s(t)$ of the pressure force equivalent $E(t)$ from the time interval $(0,t)$, in order to evaluate a trend of the muscle disposition in the time *t*

$$E_S(t) = \frac{1}{t}\int_0^t E(\tau)\,d\tau.$$

APPLICATION OF BILINEAR AND CUBIC SPLINES

Let the individual parts of the area *M* are denoted M_{ij}, $i=1,2,\cdots,m$, $j=1,2,\cdots,n$, let the related sensing points are $P_{ij}=[x_i,y_j]$ and the signal value, i.e. the value of the pressure equivalent on the point P_{ij} in the time t is marked $w_{ij}(t)$ (see Fig. 3). Then is $p(x_i,y_j,t)\approx w(x_i,y_j,t)=w_{ij}(t)$ and the values measured on the sensing points in the time *t* represent a matrix $W(t)$ of type $m \times n$.

All measurements were realized in periodical time intervals, i.e. in times $t=k\cdot T$, $T>0$, $k=0,1,2,\cdots$. After every measuring was performed an interpolation of the discrete measured values $w_{ij}(k\cdot T)$ by means of the bilinear splines (according to 4), using the function $w^{(k)}(x,y)=w(x,y,kT)$. The interpolation function $w^{(k)}(x,y)$ is given as follows:

$$w^{(k)}(x,y) = \sum_{\substack{-1\le i\le m-1\\ -1\le j\le n-1}} w_{i+1,j+1}(kT).w_{ij}^{(k)}(x,y),$$

$$w_{ij}^{(k)}(x,y) = \begin{cases} \dfrac{(x_{i+2}-x)(y_{j+2}-y)}{(x_{i+2}-x_{i+1})(y_{j+2}-y_{j+1})} & for\left[x,y\right]\in D_I,\\ \dfrac{(x-x_i)(y_{j+2}-y)}{(x_{i+1}-x_i)(y_{j+2}-y_{j+1})} & for\left[x,y\right]\in D_{II},\\ \dfrac{(x-x_i)(y-y_j)}{(x_{i+1}-x_i)(y_{j+1}-y_j)} & for\left[x,y\right]\in D_{III},\\ \dfrac{(x_{i+2}-x)(y-y_j)}{(x_{i+2}-x_{i+1})(y_{j+1}-y_j)} & for\left[x,y\right]\in D_{IV}, \end{cases}$$

$for\ i=-1,0,\cdots,m-1, \qquad j=-1,0,\cdots,n-1,$

whereas

$$D_I = \langle x_{i+1},x_{i+2}\rangle \times \langle y_{j+1},y_{j+2}\rangle,$$

$$D_{II} = \langle x_i,x_{i+1}\rangle \times \langle y_{j+1},y_{j+2}\rangle,$$

$$D_{III} = \langle x_i,x_{i+1}\rangle \times \langle y_j,y_{j+1}\rangle,$$

$$D_{IV} = \langle x_{i+1},x_{i+2}\rangle \times \langle y_j,y_{j+1}\rangle,$$

and $x_i=i{\cdot}A/m$, $y_j=j{\cdot}B/n$, where A, B are dimensions of the sensing plotter. After calculation of the $E(kT)$ value there were known also the discrete values $E(0),E(T),\cdots,E(kT)$ that were interpolated by means of the cubic splines with natural end conditions (with regard to 4), using the interpolation function $E^*(t)$, $t\in(0,kT)$, where

$$E^*(t) = \sum_{l=-3}^{k-1} \alpha_l.E_l^*(t),$$

$$E_l^*(t) = \frac{1}{6T^3}\begin{cases} 0, & t < t_l\\ (t-t_l)^3, & t_l \le t < t_{l+1}\\ T^3+3T^2(t-t_{l+1})+3T\left(t-t_{l+1}\right)^2-3(t-t_{l+1})^3, & t_{l+1}\le t < t_{l+2}\\ T^3+3T^2(t_{l+3}-t)+3T\left(t_{l+3}-t\right)^2-3(t_{l+3}-t)^3, & t_{l+2}\le t < t_{l+3}\\ (t_{l+4}-t)^3, & t_{l+3}\le t < t_{l+4}\\ 0, & t_{l+4}\le t \end{cases}$$

$t_l=l{\cdot}T$ for $l=-3,-2,\cdots,k+3$. In order to calculate the $E_s(t)$ value, it was applied the next relation:

$$E_S(t) \cong \frac{1}{t}\int_0^t E^*(\tau)\,d\tau.$$

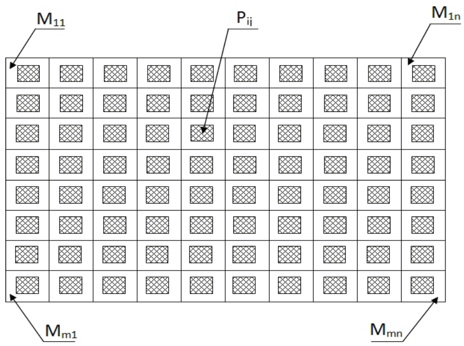

Fig. 3 *Areal arrangement of the sensing plotter*

Trend of a muscular fatigue, in the case of one measurement, is presented on the Fig. 4.

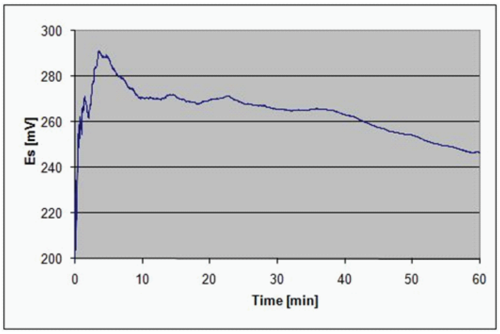

Fig. 4 *Time behaviour of the muscular fatigue*

CONCLUSION

Application of splines during measuring of the musculature local disposition enables "on line" performing of calculations, which makes possible:

- ***to monitor musculature local disposition of the rehabilitated limb,***
- ***to regulate loading of the rehabilitated locality with regard to momentary muscular tonus,***
- ***to interrupt training in the case of limiting muscular loading.***

An arrangement of the SMLD, which is ready for measuring of upper limb, is visible on the Fig. 5.

Fig. 5 *Measuring configuration of the SMLD*

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