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EXPERIMENTAL DETERMINATION OF HUMAN ARM FORCE/ELBOW JOINT ANGLE RELATION

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Summary: *The achievable force at the end of human forearm depends on the forearm position. The actual value of this force is one of the most important variables affecting the design of the motorized splint, but reliable data are hard to find. Sophisticated measuring device was constructed to determine this force. The force is measured during the movement of the forearm, as such method yields better results than static measurement. The trajectory of movement is enforced by the measuring device, so the influence of the subject on the trajectory is eliminated.*

1. Introduction

Both posttraumatic states and primary accident occurrences concerning joint structures are burdened with great socioeconomic encumbrance in the form of partial or permanent disability. The effort for the best possible functional result is directed among other towards consequent rehabilitation treatment, which seems to be one of essentials according to a number of multicentric studies. The efficiency of performed rehabilitation is variable to great extent with respect to intensity and applications of actual knowledge of rehabilitation treatment. Assisted motion in disabled joint is one of important attributes, which determine the efficiency of recovery in posttraumatic period. At the moment the individual approach of physiotherapist which observes the patient's voluntary muscular activity and correspondingly helps to extend the motion range is irreplaceable. Currently used motorized splints have a number of limitations. The devices are stationary, of large dimensions, often expensive and what is the most important, the devices are based on simple motion transformation (for example crank-type mechanism) and do not respect the voluntary muscular activity of the patient. Therefore such devices are passive and do not respect the basic principle of efficient motion: no drive - no motion. Based on the discussions with the representatives of clinical practice the need arise for the development of device, that would enable the controlled motion, evoked directly by the patient, while the range of the motion could be defined by attending physician if necessary. As far as we know, there is no such device available in clinical practice nor experimental studies, apart from very basic research (Rahman, 2000).

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The current state in the area of control algorithms, reasonable prices of sensors and electronics, advanced modeling techniques and tools enable to develop the device on qualitatively new level (active, motion controlled by patient's motion) while keeping the cost at acceptable levels. The goal is to develop the new generation of rehabilitation device which would remove the drawbacks of currently utilized motorized splints by using principally different approach based on intelligent control of the device by active motion of the patient, with the focus on synthesis of mechanical, drive, sensoric, control and interactive subsystems. The equipment of the device by sensor subsystems enables to reach totally new level of rehabilitation quality. Developed device will enable to qualitatively analyze the course of rehabilitation and will bring the reduction of cost for attending medical personnel and the ability of individual form of rehabilitation. Design process requires several key steps to be realized, in particular:

- Detail specification of clinical practice requirements and evaluation of its feasibility taking into consideration technological and financial limitations.
- The research regarding the biomechanical input variables for solving the problem in question.
- Modeling of mechanical, drive and control subsystems.
- Sensing the voluntary muscular activity of the patient (determining sensor types, the way of its calibration, patient response, etc.).
- Research in the patient - device interaction area.
- Particular subsystems design and realization.
- The verification of the rehabilitation device in practice on representative sample of patients, results evaluation and possible modification of design/drives/control algorithms/interactive subsystem.

This paper is focused on the second step: obtaining biomechanical input variables. In order to design the prototype of rehabilitation device of the new generation with active assisted motion based on the motion stimulus from the patient the estimate of forces acting upon the device is necessary. Such estimate is required to properly dimension the frame of the device and its drive(s). Overdimension would increase the total weight of the device, making it less mobile, underdimension might cause the faults in the frame or (more likely) insufficient motion range. Reliable data containing the forces (torques) that human arm can exhibit depending on elbow angle during the motion are very hard to find. Therefore we decided to build a measuring device and get the data ourselves. The design of this measuring instrument and measured results are shown in next chapters.

2. Design and realization of the measuring device

Our first measurements of the force at the end of the forearm were carried out using the simplest possible method: the forearm is set to desired position, the force gauge is attached to the forearm using the wristband (the body of gauge is connected to unmovable frame) and the peak value of the force exerted by the subject is captured. The measurement must be repeated for various positions to get full force/position relationship. Each measurement includes repositioning of the force gauge, therefore the method is time consuming. Moreover, the force at the end of the forearm is affected by the will of the subject. The effort of the subject fluctuates with time and it can significantly degrade the accuracy of measurement up to a point that the influence of the subject's will prevails the influence of the forearm position. Therefore it is difficult to get reliable results using this method. The overall time from the first to the last measurement must be significantly shortened to obtain utilizable results. This requirement brought us to the idea of replacing many discrete measurements by single continuous one. The continuous measurement can be accomplished during single movement of the forearm between it's limit positions. The duration of motion must be chosen wisely – the speed must be kept low to minimize dynamic effects, but the duration must be short enough to prevent fatigue or change of the subject's effort. The typical range of the elbow joint angle is 150 degrees. The speed of 30 degrees per second results into duration of about 5 seconds and these values were chosen as a compromise.

The forearm has naturally more then one degree of freedom, but only the relationship between force and the elbow joint angle (the angle between forearm axis and upper arm axis) is in our interest. That implies the other degrees of freedom should be restricted to get repeatable results. This can be accomplished by mounting the upper arm to the frame and simultaneously mounting the forearm to the lever. The fulcrum of the lever is coincident with the elbow joint axis. During the static measurement, the force vector retains its orientation, so stationary force gauge is acceptable, but the force vector changes its orientation during the continuous measurement as the forearm moves. That implies the force gauge must move along with the forearm or the magnitude of the force must be transferred to the stationary force gauge by some mechanism. The latter approach was used because the short duration of measurement requires utilization of electric transducers and connecting the transducer to the data acquisition system could be problematic. During the measurement, the speed of movement should not change, so the movement must not be driven by the subject; it must be enforced by some external driving mechanism. Although industrial drives with closed loop speed regulators are available, an ordinary induction motor was used for its simplicity and reliability. Generally, the rotational speed of induction motor is only little affected by its load if the load is reasonably low.

Figure 1 shows the final design of the measuring device, that is the result of the bachelor's thesis (Zezula, 2009). The frame of the device is constructed from thin-walled steel profiles and it is mounted on the heavy steel base plate with T-grooves. The lever axis is carried by the ball bearings. The upper arm and forearm fixtures are made of wooden board and they are directly mounted to the frame and to the lever. All fixtures are adjustable to accommodate different sizes of the upper limb. The fixtures are open in the side direction, so the subject's upper limb can be mounted and unmounted easily. The induction motor drives the screw with the nut and the cable is attached to the nut. The cable runs over the small pulley to the main pulley. The cable is fixed to the main pulley in one point of the rim, so the main pulley acts as a cable drum. The main pulley is fastened directly to the lever. This mechanism formes the desired transmission ratio between the motor and the lever. The small pulley is mounted to the base plate via the force transducer, so the force on the transducer is proportional to the perpendicular force at the end of the forearm. The industrial force transducer U9A (10 kN range, strain gauges in full bridge configuration) was used. The position of lever with forearm is measured by the angle transducer. The specific layout of bearing house makes the utilization of industrial angle transducers very difficult, so a custom-made incremental encoder was used instead. This encoder has relatively low resolution of 1 degree. Both transducers are connected to the Spider8 data acquisition system (HBM, 2006).

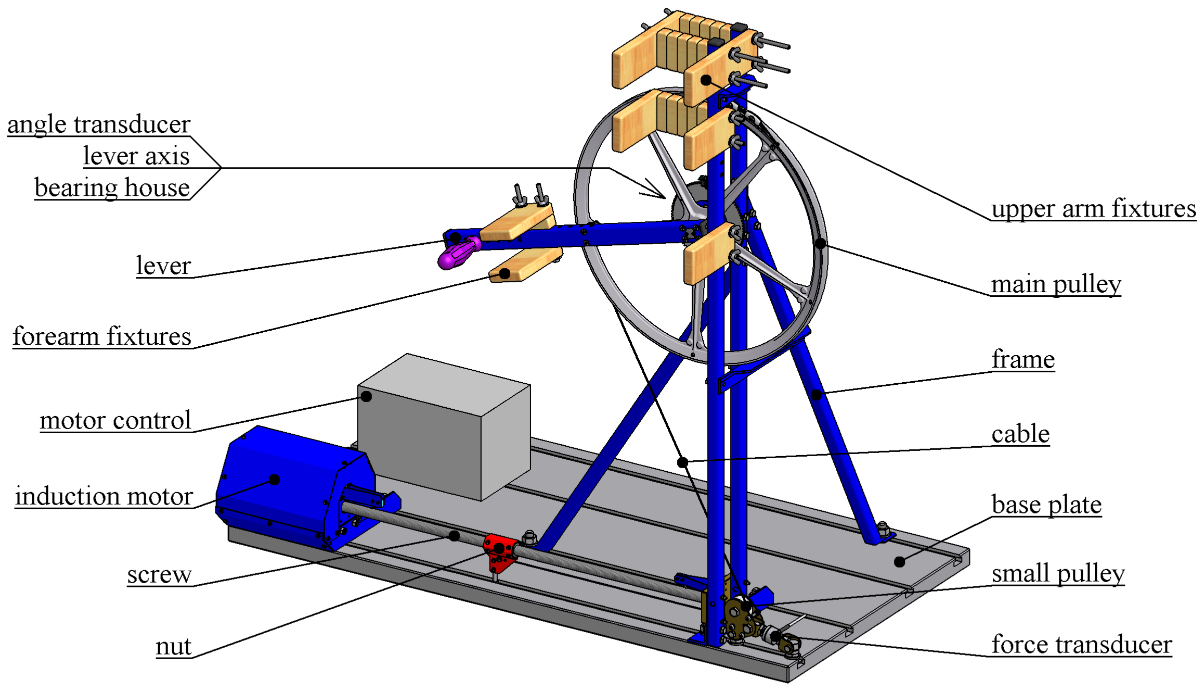

Fig. 1: The design of the measuring device

The measuring device is universal in the sense of right/left arm measurement. To measure the other arm, the bearing house is detached from the frame and mounted from the opposit side. The fixtures are repositioned and the cable is installed accordingly. The upper limb can be measured in both directions of movement. The range of the motion is set by the position of limit switches, that are triggered by the edges of the nut. Motor controller is located in the corner of the base plate. It allows manual start of the motor in either direction and stop (manual or by the limit switch) with braking by powering the motor with DC. Ideally, at the start of the measurement, three events should happen at the same time – the subject starts to exert the force, motor is started and data capturing is triggered. It is difficult to synchronize these events manually, so the circuitry was modified to utilize Spider8 auto-triggering feature. If this feature is activated, the capturing of data is started once a measured value crosses the pre-set threshold. When applied to the signal from the force transducer, the Spider8 can start to capture the data exactly at the moment the subject starts to exert the force. Moreover, status signals $\overline{MSR}$ and $\overline{RDY}$ (Measure, Ready) are available on Spider8 I/O socket and can be utilized to start the motor. The resulting measuring procedure is:

1. The device is configured for the left/right upper limb measurement and the fixtures are adjusted according to the dimensions of the subject.

2. The subject sits next to the device and inserts his/her upper limb into the fixtures.

3. The subject starts to exert the force. This triggers the data capturing and starts the motor.

4. During the movement, the subject exerts the force with maximum effort. The actual courses of angle and force are captured.

5. In the terminal position, the motor is stopped. The data capturing stops after a timeout.

Measured data are further processed: both courses are filtered and cropped (only the central part where the movement is steady is relevant) and the courses are combined to obtain the desired force/angle relationship.

3. Results

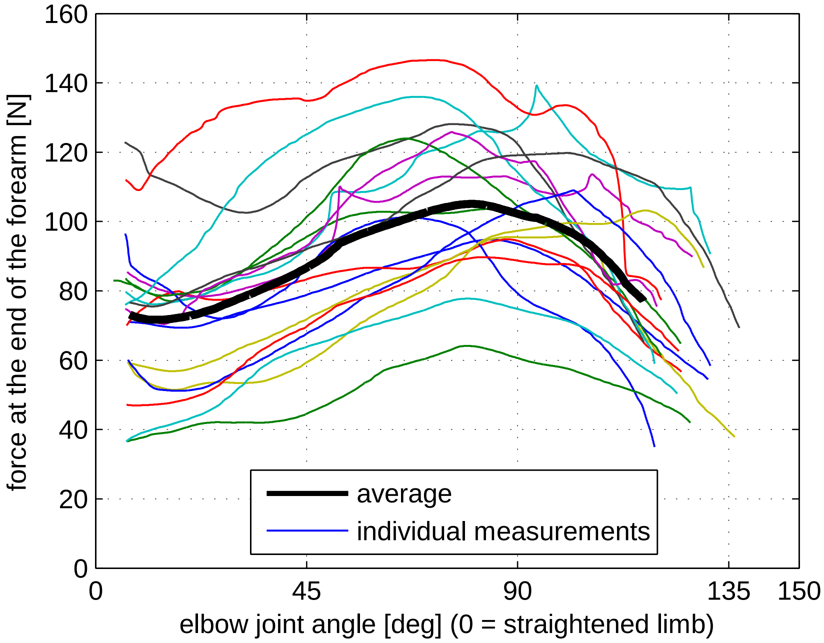

Fig. 2: Sample results – right limb, direction “up”

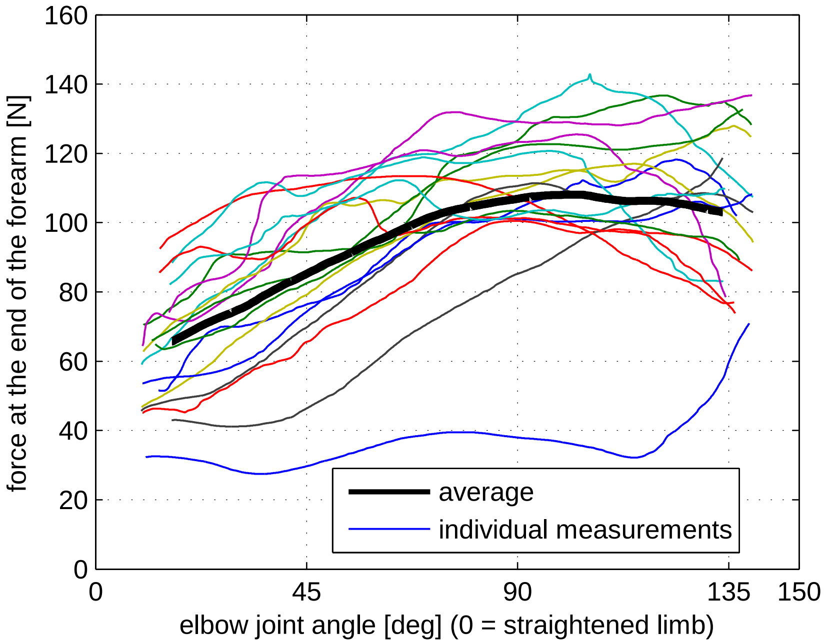

Fig. 3: Sample results – right limb, direction “down”

Figure 2 displays the results for a set of 18 measurements. All measurements were performed on the right limb. The direction of movement was “up” (towards the subject). The results were obtained from 3 different subjects (6 measurements each), with constant length of forearm fixture. The individual courses exhibit some imperfections (mostly caused by the fluctuation of the subject’s effort), but the shape of most courses is similar. The courses can be easily averaged (shown in bold on fig. 2). This is important advantage of the method: because an individual measurement takes only 5 seconds + time for preparation (and provides full force /position relationship), it may be repeated many times to get a representative result. The shown average relationship exhibits a maximum at angle of around 80 degrees.

Figure 3 shows another 18 measurements. The direction of movement was “down”, other conditions are the same. The figure also shows a typical outlier (bottom curve) that was excluded from further processing. The shape of average course is slightly different from “up” direction. The maximum of average course appears at angle of 100 degrees.

The results obtained using our measurement device provide a good insight to the force/position relationship of the forearm. Although the relationship may be different among different people, the common features (e.g. the falling tendency from the center of angular range towards limit positions) can significantly affect the topology of the splint.

4. Conclusions

Designed measuring device gives us the estimate of values that might be expected to act upon the active orthosis. Both the angle dependent courses and range of absolute values can help to dimension the orthosis properly. The wide range (high variance) in obtained data even within the same subject comes from the nature of data to be measured and from the high dependency of the values on the will of the subject. It is questionable whether relevant data can be extracted illustrating the influence of other factors (age, fitness, etc.), however the rough course and highest values can be used for orthosis design.

5. Acknowledgment

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6. References

Hottinger Baldwin Messtechnik GmbH 2006: *Spider8 Spider8-30 and Spider8-01 : PC measurement electronics Operating Manual.* http://www.hbm.pl/pdf/b0405.pdf

Rahman, T., Sample, W., Seliktar, R., Alexander, M. & Scavina, M. 2000: A body-powered functional upper limb orthosis. *Journal of Rehabilitation Research and Development*, Vol. 37, No. 6.

Zezula, M. 2009: *Design and realization of measuring device for determination of human arm force depending on elbow joint angle.* Brno University of Technology, Faculty of Mechanical Engineering, Brno.