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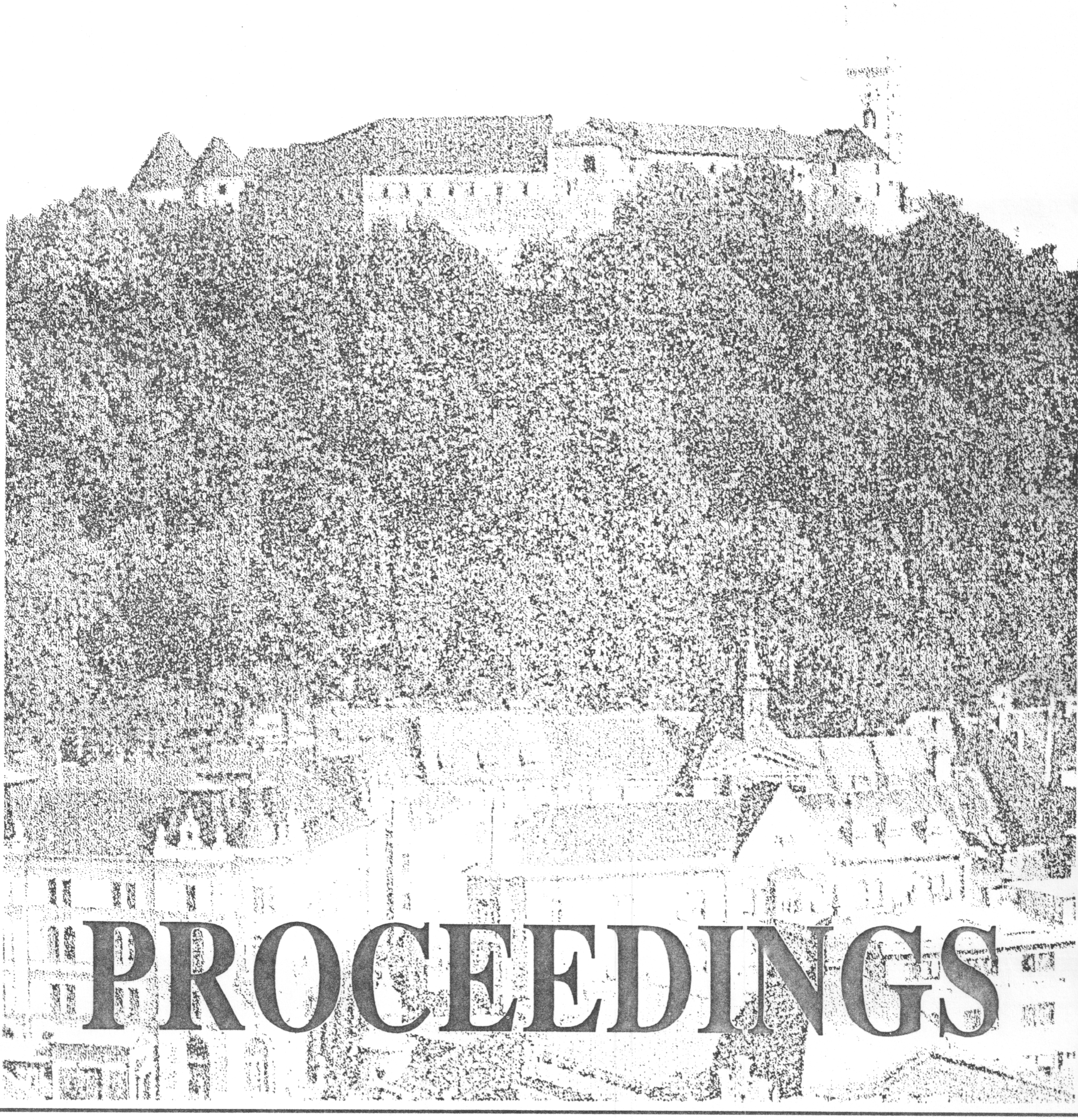

PROCEEDINGS

UPPER EXTREMITY KINEMATICS FOR STUDYING FES INDUCED MOVEMENTS

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Abstract - The paper presents recent results in the study of motion in the human upper extremity. It describes the mathematical model of the human arm that was used, and a series of motion properties of the arm that were synthesised from the model. An improved system for monitoring the human motion is presented, as well as a system for 3-dimensional anthropometric studies of the human upper extremities. Both are based on one CCD camera and contain relatively inexpensive commercially available hardware.

INTRODUCTION

A thorough analysis of the kinematics of human upper extremity can provide information that helps better understand the proportions of links and ranges of joints, as well as its motion properties. It can imply new directions of the development of mechanical arms and similar devices in robotics and rehabilitation, and can provide mathematical basis for the evaluation and control of human motion, for example, in FES induced movements. A significant contribution in understanding the human arm properties was reported in a series of papers by Engin (1990) whose interest is mainly in the biomechanics of the arm. Similar are reports of Wood et al. (1989), Hogfors et al (1991), and several others. A more mechanical approach was presented by Morasso (1983). Among the most significant contributions in motion analysis were the reports of Flash and Hogan (1984) and recently Cruse et al. (1990). Useful dexterity measures for motion evaluation of mechanisms, such as the human upper extremity, were described in Klein and Blaho (1987), and Kieffer and Lenarčič (1992). Nevertheless, this area has still to be investigated.

The background of the paper form the investigations that have been carried out in the recent years in the area of mathematical modelling of the human upper extremity kinematics with the objective to develop a simplified kinematical structure representing the reachablity of the arm (Lenarčič and Umek, 1991). The aim of the paper is to present recent results that can interpret the human upper extremity motion, as well as the methods and devices that have been specially developed for monitoring the motion characteristics.

REACHABILITY OF HUMAN UPPER EXTREMITY

The reachability of the upper extremity is here referred to as the reachable workspace of a selected point on the wrist (in our case proc. styloideus). In the presented investigation, the structure of the kinematic model that was used to calculate the reachable workspace was developed on the basis of the measurements in the sagital, frontal, and horizontal plane. Based on the analysis of the trajectories performed by a number of markers attached at the arm, the kinematic model consisted of six revolute degrees of freedom, two in the sternoclavicular joint, three in the glenohumeral joint, and one in the elbow joint (Umek and Lenarčič, 1991). The model didn't include the elbow pronation-supination and the joints of the wrist. The shoulder links, the upper arm and the forearm, were modelled as rigid, emphasising the gross motion of some bones, for instance humerus, although there was no direct reference to some other bones, such as clavicula or scapula. The objective was to use as simple model as possible, since the calculation of the workspace is numerically very expensive and also includes the collision detection between the arm links and the body.

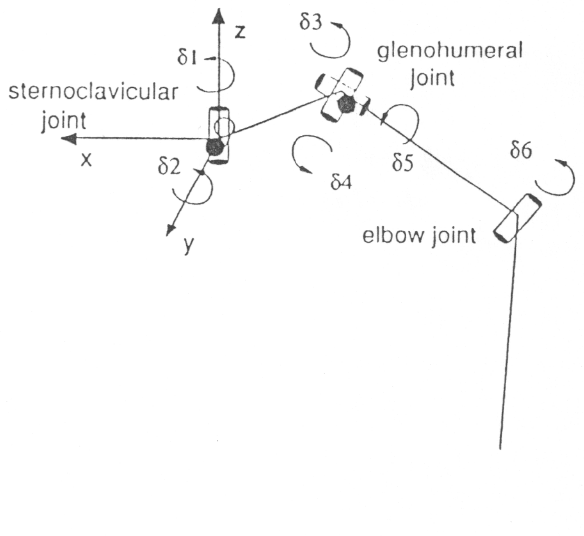

Fig. 1: A kinematic model of the human upper extremity

Recently, the calculated reachability was compared with e measurements that were carried out on a real subject in selected horizontal planes. There were similarities, but there were also observed some differences in the posterior part of the workspace. These are still to be corrected.

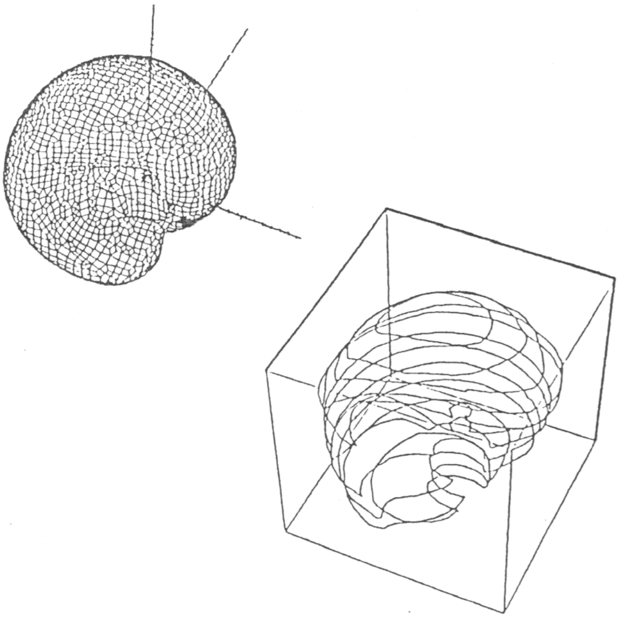

Fig. 2: The calculated measured reachable workspace

OTHER KINEMATIC PROPERTIES

From the viewpoint of positioning the wrist, the mechanism that possesses 6 degrees of freedom is redundant and can achieve a desired position with infinite number of combinations of joint angles. This is evident in the self-motion of the arm (motion of the elbow with a fixed position of the wrist) which changes the kinematic properties of the arm in the same point of the workspace. According to the observations resulting from the kinematic model, the sternoclavicular joint is associated with the collision avoidance between the arm links and the body. Even though the ranges of motion of this joint are small, they are very significant for the workspace geometry. The reachability of the arm, however, basically depends on the range of the elbow joint. It seems that the task of the glenohumeral joint is pointing, so that it contributes mainly in the dexterity, providing different velocities, forces, and other kinematic and dynamic properties (Lenarčič and Umek, 1992). It can be observed that the limitations in joint angles do not permit collisions between the links of the mechanism. A hyper-extension of the elbow joint, for instance, does not significantly affect the reachability but implies other problems in the complex motion of the arm. Manipulability can achieve different values in each point of the workspace due to the self-motion of the arm. From the minimum manipulability is was concluded that there is no positional singularity inside the workspace. The most significant difference between the manipulability ellipses is positioned in the region close to the shoulder and the head. In this region one can exert large force or can produce uniform motion in terms of velocities.

IMPROVED 3D MONITORING OF MOTION

A traditional approach to reconstruct motion of the human body in 3-dimensional space is to analyse the trajectories of markers attached at the body. The coordinates of markers are computed by the triangulation, using two or more TV cameras. The disadvantages of these measurements are in the deformation of the skin at which the markers are attached resulting in significant inaccuracies. The approach adopted in this work consisted of two levels. In the first level, the links of the arm were detected by fitting the arm shape with selected mathematically-defined bodies, such as ellipsoids. The axes of these bodies represented the axes of links between which the joint angles were measured and the link lengths were defined. In the second level, the human arm motion (the trajectories of joint angles) was reconstructed from the orthographic projection of the joint points on the image plane (Qian and Huang, 1992). This method assumes that we know the structure of the kinematic model, the corresponding link lengths, as well as the starting position of the arm (in order to exclude multiple solutions).

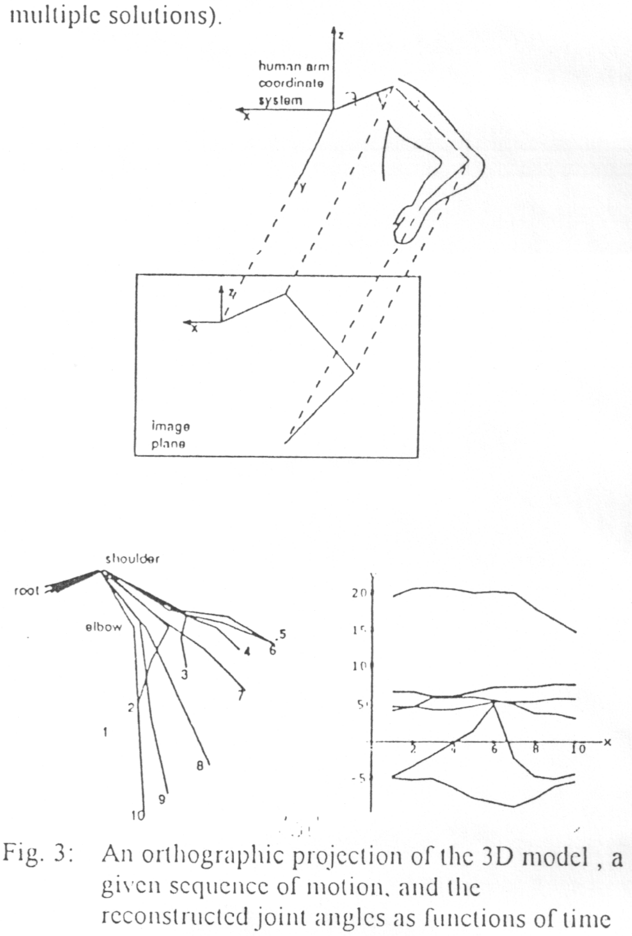

Fig. 3: An orthographic projection of the 3D model, a given sequence of motion, and the reconstructed joint angles as functions of time

ANTRHOPOMETRIC STUDY OF HUMAN UPPER EXTREMITY

In relation to the measurements of the proportions of the human upper extremity an optical system was developed in order to automate the measurement procedure of a 3-dimensional object by the use of modern CCD cameras and computers. The system that has been developed in this investigation consists of one CCD camera and a PC computer with some additional commercially available hardware and software for data processing, as well as specially developed routines. The main principle that has been used is the so-called Fourier Transform Profilometry (Takeda and Motuh, 1983) which can be considered as a variation of ordinary Moire methods. The method uses a grating image projected on a human body and after numerical processing gives an image of lines in equidistant planes that are perpendicular to the axis of the camera. It can be simply automated and provides higher accuracy than the resolution of the grating, which is not the case in ordinary Moire methods.

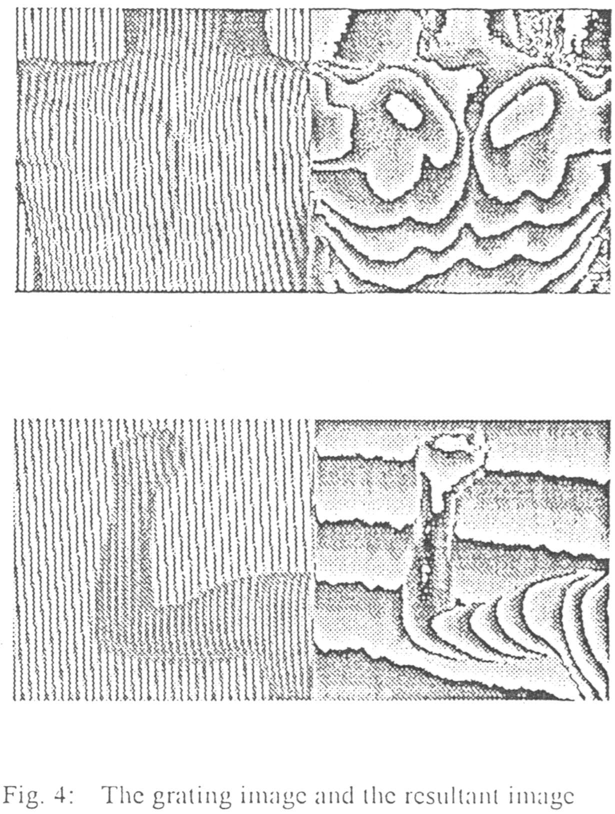

Fig. 4: The grating image and the resultant image after applying Fourier Transform Profilometry in cases of the human back and arm

CONCLUSIONS

The use of various dexterity measures in the evaluation of the human upper extremity motion, which originate in the design of mechanical devices, such as kinematic index, manipulability, flexibility, and other criteria of optimality, can explain different motion properties of the arm and its proportions. The main disadvantages of the mentioned mechanical approach are related to the numerical complexity of computations that request simplifications in the mathematical models, and on the other hand, to the difficulties of proper measuring of the human motion, both resulting in inaccuracies and approximations. However, the conclusions that can be obtained following these studies, are surprisingly close to the real motion of the human upper extremity in performing different tasks. The applications can be foreseen in rehabilitation, and particularly in developing quantitative methods for the evaluation of motion capabilities, for example in FES induced movements, or static postures of the human upper extremity.

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