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ON THE STATISTICAL ANALYSIS OF BIOLOGICAL ARMS

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Abstract- The statistical analysis of robot manipulators reveals the limitations of joint-actuated machines. Stemming from the results, in this paper we apply the statistical concepts on the study of biological arms. The superior performances of muscle-actuated arms over standard joint-actuated manipulators are demonstrated.

I. INTRODUCTION

Human activities adopt anthropomorphic concepts and therefore, they lead to the requirement for tools and procedures according to these principles. In this sense, a robot manipulator is a tool that extends the human capabilities having the human arm as its reference concept. However, this observation is confronted with the present day situation where robot technology makes an insignificant appeal to the biomechanical aspects of the human arm. In previous articles [1,2] we developed a statistical analysis of robotic manipulators which revealed the limitations of joint-actuated machines. In this paper we apply the statistical method to the analysis of biomechanical arms. Starting from the kinesiological aspects of the human arm, in section two we develop an engineering formulation for the elbow, in section three we analyse the corresponding structure and in section four we present the conclusions.

II. ON THE BIOMECHANICS OF THE HUMAN ARM

Mechanical manipulators are described through the kinematic and dynamic models. These models relate positions, velocities, accelerations and forces/torques on the operational $\{p,\dot{p},\ddot{p},\Gamma\}$ and joint spaces $\{q,\dot{q},\ddot{q},T\}$. The statistical analysis of joint-actuated mechanical manipulators proves that these devices are much more sensitive to $\dot{p}$ than to $\ddot{p}$ requirements. Alternative solutions, using muscle-like actuators [3,4] allow more efficient robotic structures. Extensive biological studies [5,6] have been carried out on the study of the biomechanics of the human arm. Unfortunately, precise conclusions on all of the involved phenomena are still lacking. Due to this reasons, we will focus our attention on the elbow retaining the investigation of the shoulder to work on progress [7]. Furthermore, in order to simplify matters, solely the motion in the sagittal plane will be considered on the analysis of the elbow.

The elbow movement in the sagittal plane (q_2) requires several muscles. Nevertheless, we consider only the biceps brachii and the triceps brachii, as they are the more influential. Fig. 1 shows its simplified engineering model. For this structure we have:

$$z_i=(r_i^2+b_i^2+2r_ib_iC_2)^{1/2} \tag{1a}$$

$$\dot{z}_i=-r_ib_iS_2\dot{q}_2/z_i \tag{1b}$$

$$\ddot{z}_i=-r_ib_i[C_2+r_ib_i(S_2\dot{q}_2/z_i)^2+S_2\ddot{q}_2] \tag{1c}$$

$$F_i=(r_i^2+b_i^2+2r_ib_iC_2)^{1/2}T_2/(r_ib_iS_2) \tag{1d}$$

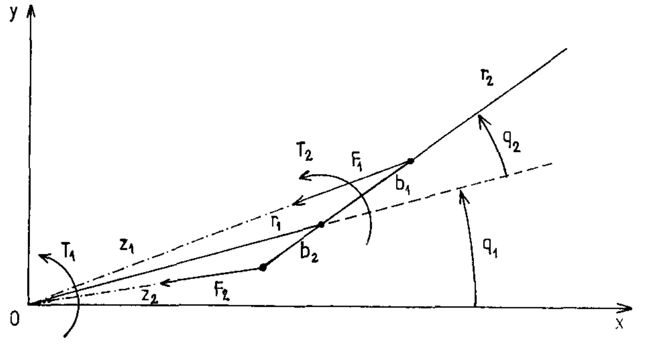

Fig. 1 Engineering model of the elbow structure.

where $\{z_i,\dot{z}_i,\ddot{z}_i,F_i\}$ are the length, velocity, acceleration and force on the biceps brachii (i=1) and triceps brachii (i=2). Expression (1b) shows that the S_2^{-1} degrading factor, that affects $\dot{q}_2$ in the kinematic relation $\dot{q}_2=\theta(p,\dot{p})$ is now compensated for the elbow actuators. Moreover, in the sequel, we consider the upper (q_{2MAX}) and lower (q_{2MIN}) limits of the range of motion of the elbow to be:

$$q_{2MAX}=\pi,\quad q_{2MIN}=0 \tag{2}$$

III. STATISTICAL STUDY OF THE ELBOW

In this section we study, statistically, both the kinematics and kinematics + dynamics of the elbow. We conclude that [2,7]:

- The "amplification between $\dot{p}$ and $\dot{z}$ ($\ddot{p}$ and $\ddot{z}$) is much smaller than the resulting from $\dot{p}$ and $\dot{q}$ ($\ddot{p}$ and $\ddot{q}$).
- Histograms are, predominantly, positive (negative) for the flexion (extension) muscle. This observation confirms that our statistical approach is, indeed, consistent with the way biological muscles work.
- The muscle forces are dominated by gravitational effects for low and medium velocity requirements. For high velocities forces become higher.
- Acceleration requirements have a small effect upon the muscle forces.

In conclusion, biological arms have superior performances because muscle-actuated anatomic-levers adapt the operation requirements in contrast with joint-actuated machines where actuators have to fully support those exigencies.

IV. CONCLUSIONS

A statistical approach to the analysis of biomechanical manipulators was presented. The new method stems from previous studies on mechanical joint-actuated manipulators. Motivated by the kinesiological aspects of the human arm we demonstrate that biomechanical structures have better performances than standard manipulators. In fact, joint-actuated robotic structures are non-optimal because they have to support the direct impact of the operational requirements. On the other hand, muscle-actuated arms are, intrinsically, superior because the anatomic-levers adapt the operational exigencies to the actuators. This observation is of utmost importance as it gives a clear basis to the design of new mechanical manipulator structures, with performances close to the biological systems.

REFERENCES

[1] A.S.F. Galhano, J.L. de Carvalho and J.T. Machado, "Statistical Modelling of Robot Manipulators," IEEE Int. Work. Intelligent Motion Control, Istanbul 1990
[2] A.S.F. Galhano, J.L. de Carvalho and J.T. Machado, "The Statistical Study of Biomechanical Arms," Fifth IEEE I. Symp. Intelligent Control, Philadelphia 1990
[3] Y. Tatara, "Mechanochemical Actuators," Advanced Robotics, vol. 2, pp. 69-85, 1987.
[4] D.G. Caldwell and P.M. Taylor, "Artificial Muscles as Robotic Actuators" SYROCO'88, Karlsruhe, FRG 1988
[5] K.F. Wells and K. Luttgens, Kinesiology -Scientific Basis of Human Motion. W. B. Saunders Company, 1976.
[6] J.V. Basmajian, Muscles Alive, Baltimore, MD: Williams & Wilkins, 1978.
[7] A.S.F. Galhano, J.T. Machado and J.L. de Carvalho, "On the Analysis and Design of Robot Manipulators: A Statistical Perspective," IEEE Int. Workshop on Advanced Motion Control, Yokohama, Japan, 1990.