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Analysis of a hand arm system

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ABSTRACT

For this research a prototype for an anthropomorphic hand arm was developed and manufactured. We analyze the periodic motion of this artificial hand arm system for different angles and velocities. For the time series of the wrist joint of the artificial hand system we can conclude that the movement is periodic. For a better understanding of the robotic system next we study the motion of human hand arm. The kinematic data of the radio-carpal flexion–extension angles were analyzed for different initial conditions. The experimental data were acquired with a complex goniometer system. The human motion was characterized with the correlation dimension and the largest Lyapunov exponent (LLE) as nonlinear measures. The LLE obtained for each test of human hand were positive values and the mean value ranged from 0.020 to 0.032.

1. Introduction

Quantitative analysis of human movement has become very important for basic and applied studies of sports performance and for diagnosis and treatment of orthopedic, muscular and neurological diseases. The human upper and lower limbs have been an inspiration for engineers in their attempt to produce artificial devices that could attain and reproduce their outstanding capabilities. In the industrial field one can observe that the majority of these products are based on simple gripping devices whose mechanical model is very often characterized by one or two degrees of freedom. This simple concept leads to reduced grasping potential due to the many shortcomings of this design: limited range of motion and small forces exerted on a grasped object, the poor performance to pick objects of different shapes and sizes, the instability of the grasp due to a small number of points of contact or gripping surfaces, the impossibility to perform fine motion without moving the entire arm and to reorient the grasped object. The artificial structures are used in medical field as prosthetic devices, modules and robotic structures used in minimal invasive surgery, or in robotics field as a robot end-effector [1–6]. The artificial hands created to this moment strive to achieve the mechanical structure, aesthetics (shape, dimensions), mass, force capabilities and, of course, exteroceptive and proprioceptive sensor system as the human hand possesses. A multi-degree of freedom hand design represents the state-of-the-art for grasping devices [7].

In this paper we start the analysis with an anthropomorphic hand-arm and next we will focus on the nonlinear dynamics of human motion.

Variability is inherent within all biological systems and reflects variation in both space and time. Optimal variability as a central feature of normal movement is consistent with a nonlinear approach [8]. Counter to a therapeutic assumption that equilibrium is an indicator of health, nonlinear theories emphasize disequilibrium as healthy. A complex dynamic system is in slight disequilibrium with the environment and maintains this disequilibrium over time [9]. The normal human health is indicated by a dynamic equilibrium. The theory and methodology of nonlinear dynamics has been applied to experimental time series and the chaotic analysis is an analysis approaches. The complexity in the many physical and biological systems was interpreted as existence of deterministic chaos.

Gait kinematics and dynamics of polio survivors were analyzed by Hurmuzlu et al. [10] using phase plane portraits and first return maps as graphical tools to detect abnormal patterns in the sagittal kinematics of polio gait. The subjects walked down a track at a comfortable constant speed for several passes. For each subject, the phase plane portraits were obtained from averaging the data over all passes of each individual. Same methodology and analysis were used for the development of quantitative measures in order to evaluate the dynamic stability of human locomotion.

Yang and Wu [11] showed the potential of the Lyapunov exponents used to measure the balance control of human standing, an important aspect in the development of bipedal walking machines. The movement of the human arm was studied as a

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chaotic system [12–14] and the chaotic characteristics, Lyapunov exponents and correlation dimension are included in the rhythmic movements. Nonlinear dynamic analysis tools have been used to extract characteristic features of human postural sway. The results obtained in [13,14] confirmed that the chaotic characteristics represented by the correlation dimension and the largest Lyapunov exponents were included in the rhythmic forearm movements. Furthermore, it was clarified that there existed the difference in the values of the Lyapunov exponents and fractal dimensions between right-left forearms and there existed the difference in the dynamical properties between the dextral and the sinistral forearms.

Using a rhythmic task where human subjects bounced a ball with a hand-held racket, fine-grained analyses of stability and variability extricated contributions from open-loop control, noise strength, and active error compensation [15]. The results showed that stability and variability are not simply the inverse of each other but contain more quantitative information when combined with model analyses.

The authors [16] analyzed the kinematics and the qualitative and quantitative changes for unimanual hand movements for different periods of time and they found that proportional dwell time and number of peaks in the velocity profile increased as driving periods increased. The results suggested that participants tried to move close to their preferred tempo at different rates, and that they avoided moving slowly.

The results obtained in [17] suggest that chaotic swaying of the body is a dynamically stable state of the body while receiving information from many segments within the body and its external environment. Proof of this chaotic swaying was provided by reconstruction of the dynamics in phase space and calculation of the largest Lyapunov exponent.

The deterministic and stochastic aspects of various instances of rhythmic movement, including tapping, wrist cycling and forearm oscillations are presented in [18]. The general principles of the presented procedure and its application are explained and illustrated using simulated data from known dynamical systems. The main advantage of the analysis explained here over conventional approaches is that the separation of the dynamics into Kramers–Moyal coefficients allows for detailed studies of deterministic and stochastic parts in dynamical systems with noise. The method does not require any assumptions regarding possible analytical forms of the underlying, generating dynamics and can thus be viewed as an entirely unbiased tool.

The hand trajectories for adults were compared with the trajectories of robotic systems using nonlinear dynamic tools in [19]. Among various methods of nonlinear dynamics, the Rényi fractal dimension and the Rényi spectrum are presented as quantitative descriptors. The center of foot pressure trajectorie's Rényi dimension and Rényi spectra of young healthy subjects with no history of neurological disorder were investigated in comparison to that of elderly patients with balance impairment and history of frequent falls. The results provided different indications of postural control system characteristics between the two groups. The tools of nonlinear dynamics are applied for the study of children with torsional anomalies of the lower limb joints in [20].

Nowak presents the spatial chaos as an analytical tool that can be used in biology and any idea of an evolutionary process or mechanism should be studied with the help of mathematical equations [21]. Rand et al. [22] investigate a problem in evolutionary game theory based on replicator equations with periodic coefficients. This approach to evolution combines classical game theory with differential equations.

The first objective of the study is the 3D virtual model of an anthropomorphic hand-arm conceived and developed in correlation with the design goal: functional capabilities, aesthetics, low mass, an increased degree of freedom number and a good price. We will also study and quantitatively evaluate the periodic motion of the artificial anthropomorphic hand system.

To our best knowledge, however, the use of kinematic and nonlinear dynamic analysis for the wrist joint has not been reported in humans and artificial mechanical systems.

The ability to measure the angles would provide information about the motion and stability of the artificial mechanical and human hand arm system. A quantitative measure of the stability of human hand can provide the clinical team an essential mean to diagnose movement pathologies, administer proper treatments, and monitor patient progress.

Another objective of this study is to quantify and investigate nonlinear motion of the human wrist joint using nonlinear dynamics stability analysis. The largest Lyapunov exponent (LLE) and correlation dimension will be calculated as a chaotic measure from the experimental time series of the flexion–extension angle of human wrist (radio-carpal) joint.

2. Virtual model and prototype for the artificial hand system

The anthropomorphic hand-arm mechanical system was designed and manufactured by similarity with human hand-arm: the mechanical model, the actuation system, the shape, dimensions and general aspect. The anthropomorphic characteristics of the human hand were studied and imposed as input data on the design step. Using a CAD software (SolidWorks) we have created a

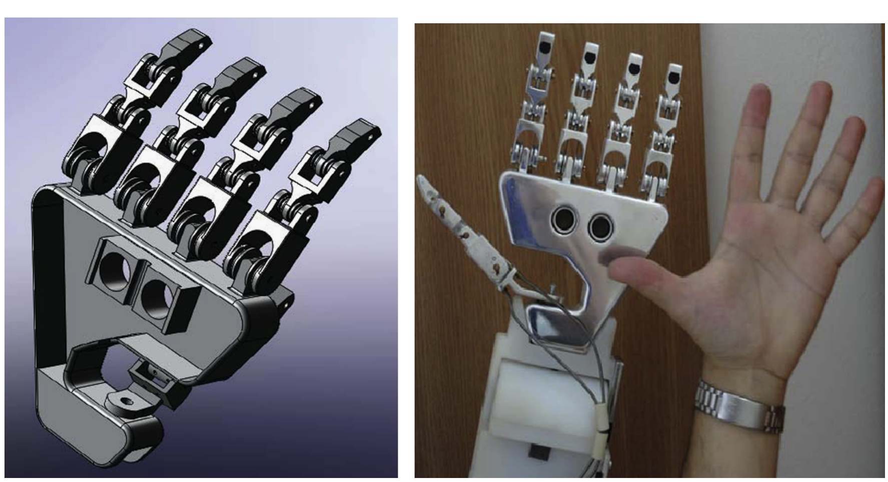

Fig. 1. 3D virtual model, human hand and artificial hand prototype.