Characteristics of Human Arm Impedances: A Study on Daily Movement

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***Abstract*— This paper presents the impedance characteristics of human arm in daily spatial activity. Human arm is considered as a mass-spring-damper system. The input data in the form of Cartesian position is measured to get dynamic impedance relationship by the motion equation for the mass-spring-damper system. Mappings are done by various combinations to observe the nature of the different impedance components during dynamic movement. The significant amount of variation in damping and inertia components are observed in every turning of the arm movement while the stiffness shows the changing behavior throughout the movement. From this study it is known that for this particular movement the arm follows a pattern and same behavior is followed for the repetitions of the movement. The obtained result could be beneficial for the study of upper extremity exoskeleton for human rehabilitation.**

Keywords—Human arm movement, impedance, Kinematics, Dynamics.

I. Introduction

Many research works have been devoted to mapping of static impedances. In most of the study, impedance is being considered as stiffness mostly for two degree of freedom systems. Of the various papers dealing with the human arm's impedance measurement with the 1dof planner motion ([1], [2]), 2dof planner motion ([3], [4], [5]) and 3dof spatial motion ([6]). Most of these researches assume the musculoskeletal system as a mass-spring-damper system and modeled it as equation of motion ([7]- [20]).

Reference [6] used the dynamic equation of motion for mass-spring-damper system as mathematical model, by using robot manipulator, kinematic data were acquired and by force sensor the corresponding force is measured at the end point. In their experiment, movement was discrete and impedance characteristics of the human arm are measured in 3D space. The limitation with the mentioned studies is that they either considered a limited part of an entire movement or a discrete movement while the main focus of this study is impedance characteristics mapping based on complete dynamic movement conducted in 3D space.

Impedance measurement for 2dof planner motion, investigated by [3], is pioneer in this area of research. They introduce an identical way to represent impedance characteristics. By investigating the human arm's muscle's behavior they found that it behaves like spring. In continuation to this work [11] has done the investigation of the impedance characteristics for impedance in skilled human hand, which they measured the human arm impedance on controllability's of the task related impedance. The inertial, viscosity and stiffness factor as impedance are also calculated. In addition to aforementioned investigations, many researchers have found that human muscles behave like spring; hence, several experiments have been conducted to find out the stiffness of the arm ([3], [4], [5]). In [21] human arm is considered as a mass-spring-damper system and the relation between inertia, damping and stiffness factors are reported.

Among the studies conducted on impedance measurement in the past two decades ([8]- [12]), [8] has chosen the arm movement as discrete and point-to-point movement, where only the stiffness as the impedance is considered. In this study, they compared the dynamic hand stiffness during discrete point-to-point multi joint arm movement and the static stiffness. Movement of the arm was on a horizontal plane, the applied model was a second order nonlinear differential equation. From this experiment it was found that there is very small variation in dynamic characteristics and static stiffness. In 1997, a highly efficient design of manipulandum along with estimation algorithm was introduced by [9]. They found that the arm stiffness during the transverse movement is much greater than the corresponding arm posture but this phenomenon is not followed during longitudinal movement.

Reference [10] found impedance characteristics for 2DoF goal oriented arm movement. At the beginning and ending, stiffness value is higher than the middle of the arm movement as the velocity changes.

In [13] it was investigated and compared the impedance of the forearm through different measurement techniques. Their movement was response to test pulse. They calculated the elbow stiffness and viscosity and compared these results with those where the subjects were asked for static displacement.

Except aforementioned studies, many other methods for measuring impedance are proposed by other researchers ([14] - [18]). Reference [15] developed a method for measuring endpoint stiffness during motor adaptation. Their method requires less trial in comparison with the study done by [9]. Reference [16] set an experimental device which was able to measure dynamic impedance characteristics of a human arm movement. In this case movement was not short duration and wrist covers a certain distance. They calculated the stiffness component of the human arm impedance and suggest that this device can be used to monitor the progress and recovery of the motor condition of stroke patients who are taking rehabilitation. Reference [18] introduce a new

978-1-4799-4923-6/14 $31.00 © 2014 IEEE
DOI 10.1109/UKSim.2014.90

device for measuring hand's dynamic impedance characteristics which could represent the inertial component and stiffness component as impedance characteristics.

In the current work an investigation of human arm for 3DoF spatial task was done. Investigation was done on the activity more than 5 sec duration. In this study all the data processing and plotting were done by MATLAB (the procedures were stated in the section II). The investigated results were mapped by plotting (the obtained results are presented and discussed in section III).

II. Materials and Method

The mathematical model applied in this study is same as dynamic equation of motion for mass-spring-damper system. For acquiring kinematic data we have used Measurand Inc., Shapetape device. This device is able to give positional value of the desired Cartesian coordinates against time. Six healthy subjects, ranged from 25-30 years old, participated in the experiment. There was no report on muscle injury, sensory, perceptual, or any motor disorders associated with any of the subjects. Subjects were not familiar with the topic and had no prior knowledge of the field of study. Experimental procedure was explained to the subject before participation/trail. Subjects were asked to move their right arm horizontally to carry an object from A to B and return to A considering this as one full cycle of movement as shown in Fig. 1. For the uniformity of the movement subjects are asked to move their arm according to the path. The path was indicated by a line.

A. Experimental set-up

ShapeTape® device was attached to the right arm of the subject to measure the position of the wrist as shown in Fig.2. In trial subjects were asked to complete three cycle. Several trials are recorded to the movements similar to the real path. Each subjects were required to participate three different days to avoid stress and other psychological effects. An adjustable chair was used to maintain arm posture. The considered movement was an active daily routine tasks, some external force was applied by handling an object of 1.5 kg weight.

B. Procedures

The hand impedance model (shown in Fig. 3) can be expressed in the end-point level when the human arm is under a stable posture, by the following equation:

$$M\ddot{X} + B\dot{X} + KX = F \qquad (1)$$

Where $M, B, K \in \mathbb{R}^{3\times3}$ represented the hand inertia, damping factor, and stiffness matrices respectively. $X \in \mathbb{R}^3$, and $F \in \mathbb{R}^3$ represented the end point position and force vector. The movement considered in this study is fast movement, due to this some terms were compensated [22].

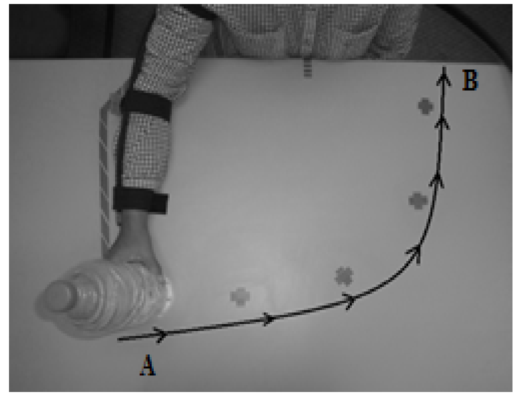


Figure 1. Experiment pathway

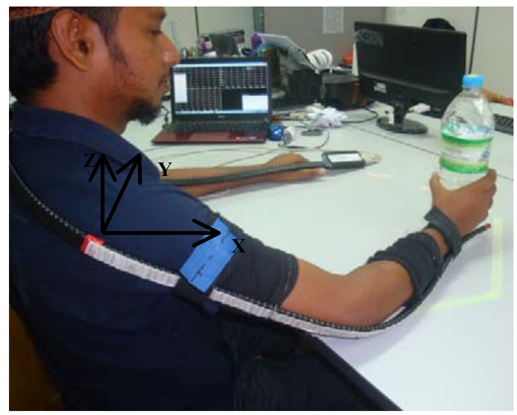


Figure 2. *Shapetape*® mounted on subject's arm

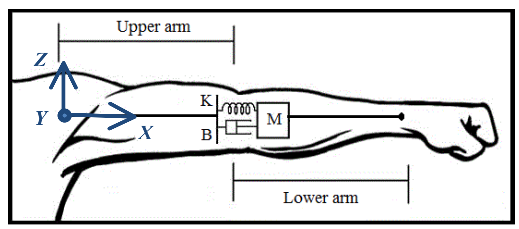


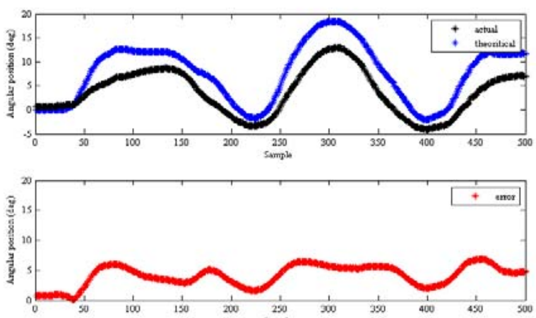
Figure 3. Arm model for dynamic impedance measurement.

In the equation (1), the position values X were measured by the device against time. The velocity ($\dot{X}$) and acceleration ($\ddot{X}$) terms were obtained from X. and the force term (F) is calculated by Newton's Second Law of motion. The Solving procedure of equation (1) is followed by [6].

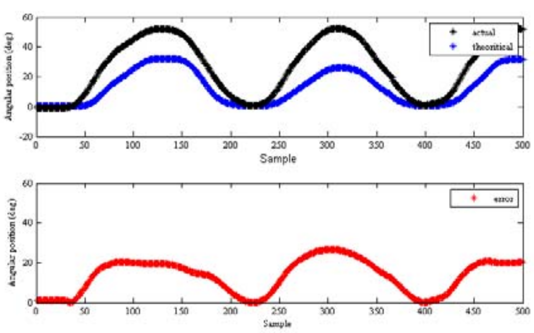
III. Experimental Result and Discussion

Angular velocity at shoulder and elbow are also estimated and compared with the theoretical results obtained from inverse kinematics (figure 4). In the Fig. 4 upper one is for the angular change in shoulder and the lower one is for angular change in elbow. In both of the figure, bold line indicates the actual angular position change, dotted line is from the inverse kinematics' computed angular positional change, red line is the error calculated by least square error method. Initially, measured positional data are verified. Verification was done by comparing the actual data and the inverse kinematics. To estimate the differences, the error was calculated and plotted. Validation was done on wrist position and the elbow position which is shown by Fig. 4. In the figure blue line indicates theoretical data, black line is measured data and the red line is error.

Throughout this paper, figures shown are for subject 3. The Cartesian position change in 3D is shown in Fig. 5. Components of position, velocity, and acceleration are shown in Fig. 6, 7, and 8 respectively. These plotting are done for whole three cycle of movement. According to these figures it is evident that majority of the movement was along the X and Y coordinates. As the most of the movement acted on the X and Y plane, the impedance characteristics along the X and Y is also much greater than Z components, this is evident from Fig. 9. Parallel plotting for the different impedance are shown in Fig. 9 (a), (b), and (c). From the figures it is observed that the dominating components of the impedances are the Y component. The main objective of this study is to map the dynamic characteristics of the human arm movement. Hence a set of mapping was done (shown in Fig. 10). It shows the dynamic change of different impedance components.



(a) Angular velocity change at elbow.



(b) Angular velocity change at shoulder.

Figure 4. Comparison of angular changes between actual measured angle and the computed angles

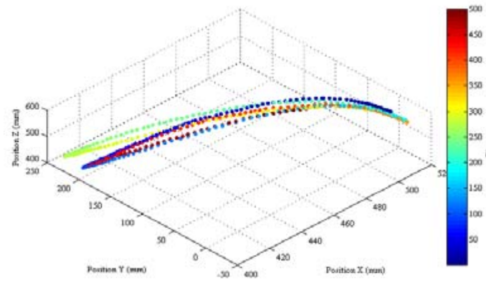


Figure 5. Cartesian displacement of the wrist

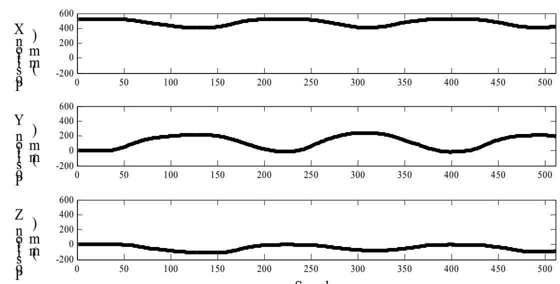


Figure 6. Wrist linear position for subject 3.

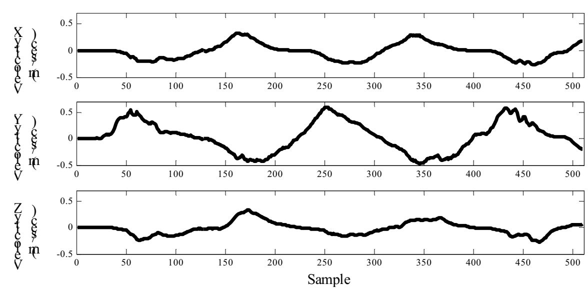


Figure. 7 Linear velocity at wrist for subject 3.

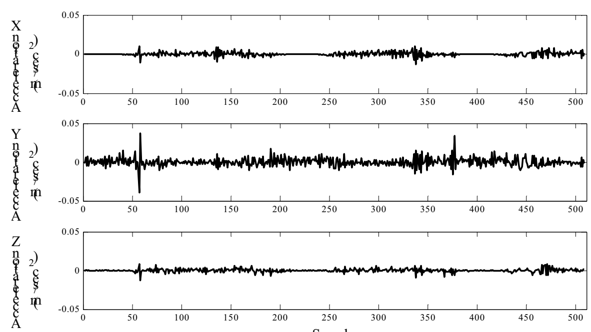
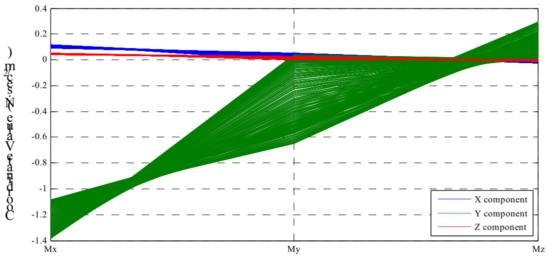
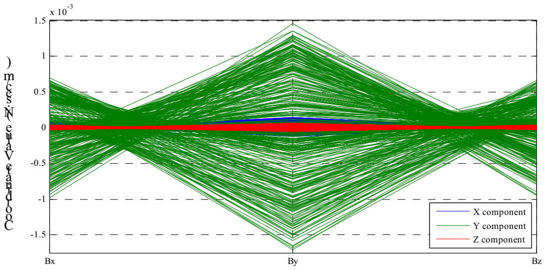


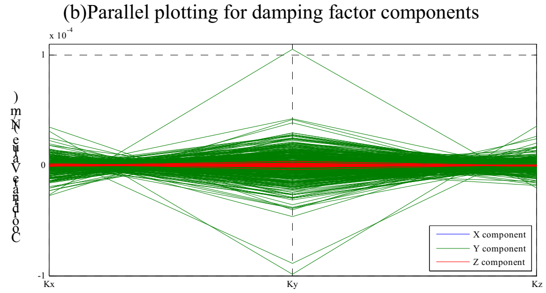
Figure 8. Linear acceleration at wrist for subject 3.



(a)Parallel plotting for inertia components



(b)Parallel plotting for damping factor components



(c)Parallel plotting for stiffness components

Figure 9. Ratio of different impedance components (for subject 3).

IV. Conclusion

In this study 3DoF impedance characteristic of human arm movement for daily activity was investigated. Experimental data were measured from *ShapeTape®* device and fitted to the mathematical model to get impedance characteristics. The main concerns of this work are to map the impedance for dynamic task and the task duration is longer than the tasks done in previous researches. Here the representation of mapping was done in such a way that the dynamic movement can be shown as continuous changing trend. From the mapping it is observed that as the arm moves the impedance characteristics changes. And the large amount of change observed in Y component of the impedances. It is noticeable that the significant movement was done along the Y axis. Thereby, there are still to be examined that if the arm movement direction is changed, how the impedances will change.

Acknowledgment

We acknowledge the financial support of the Ministry of Higher Education, under fundamental research grant scheme (FRGS).

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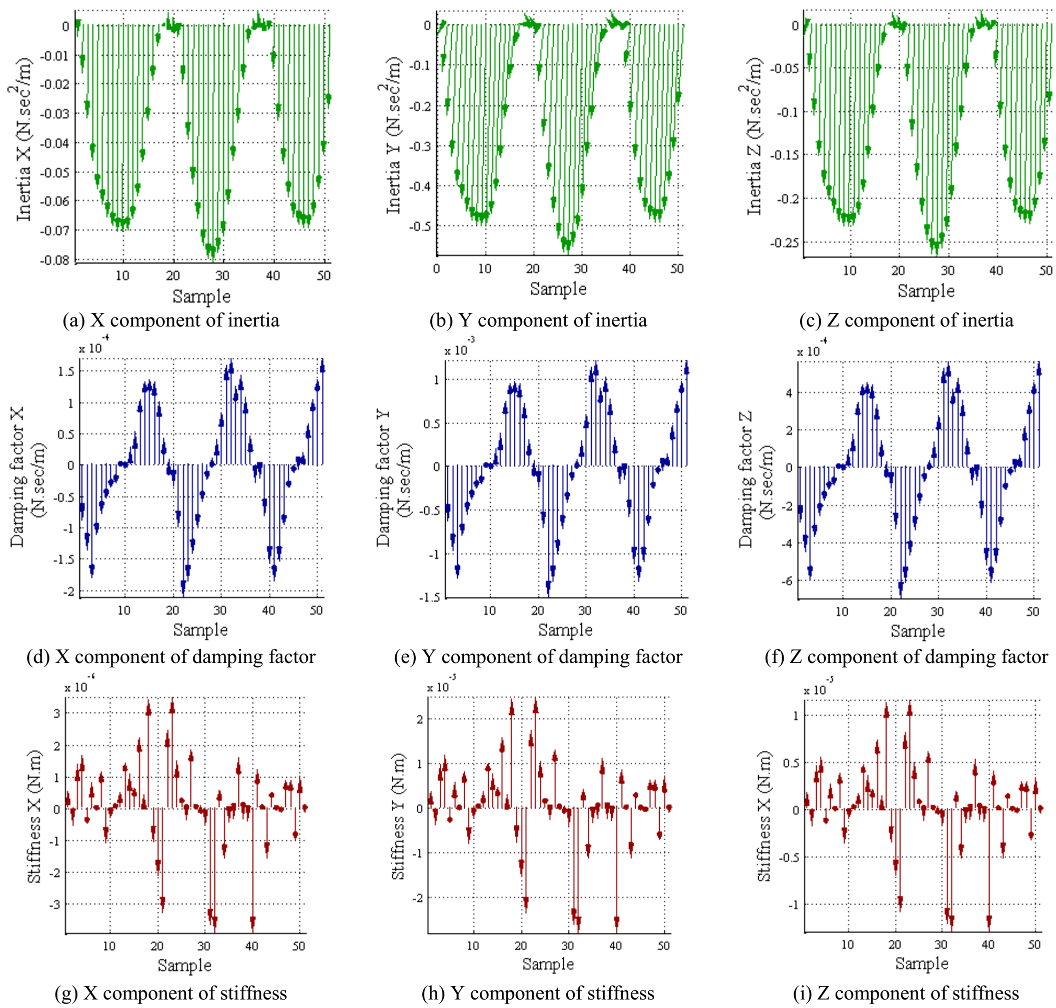

(a) X component of inertia (b) Y component of inertia (c) Z component of inertia

(d) X component of damping factor (e) Y component of damping factor (f) Z component of damping factor

(g) X component of stiffness (h) Y component of stiffness (i) Z component of stiffness

Figure. 10. Components of impedances against sample.