

# Towards the Quantification of Human-Robot Imitation Using Wearable Inertial Sensors

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## ABSTRACT

In this study, we propose a metric in order to quantify how closely a healthy participant imitates a robot, for which we use inertial sensors attached to both individual participant and to a humanoid-robot. For the experiment, twelve healthy participants were invited to perform simple arm movements in order to apply the state space reconstruction which is based on the method of time-delay embedding and PCA. Although the performed arm movements of the healthy participants were very simple, the study reveals that the participants showed different ranges of the proposed metric that can be linked to the level of imitation. Such a metric can be improved in order to determine a detailed scoring of human-robot imitation during training or rehabilitation activities.

## CCS Concepts

•Computer systems organization → External interfaces for robotics; *Robotic components*;

## Keywords

Human-robot Imitation, Movement Variability, Wearable Inertial Sensors, Non-linear Dynamics, State Space Reconstruction

## 1. INTRODUCTION

Recently, NAO, a humanoid robot, has successfully been used both as a fitness coach for the elderly and as an instructor of rehabilitation for children. For instance, Görer et al. [3] used NAO as an exercise tutor and an Asus Xtion RGB-D camera which were employed to extract the joint angles of a human demonstrator and some participants. Absolute differences of the joint angles between the human demonstrator and the participants were used to create a corrective feedback for the movement of the elderly with respect to (i) speed adjustment, (ii) amplitude adjustment, (iii) mirror-

ing detection, and (iv) motion. However, when participants are seated, the RGB-D camera cannot provide correct skeletal information of the participant. There is also room for implementation of a detailed scoring system for the human-robot imitation since the score is only based on how well the participant follows the verbal commands of the robot. Similarly, Guneyasu et al. [4] used NAO and wearable inertial sensors to monitor the motions of arm rehabilitation of children. The challenge for Guneyasu et al. was to keep the children motivated in order to imitate movements for arm rehabilitation therapy. For this, NAO successfully captured the attention of the children, while the use of inertial sensors were ideal to avoid any obstructions between the children, the therapist and the robot. However, as part of their study, it was revealed that the four physiotherapists all moved in slightly different ways while performing arm motions; which is reflected in the differences of frequency and amplitude of the movements as well as in the initial positions of their hands.

For this study, we are therefore proposing a framework based on the state space reconstruction in order to explore a metric that can help us to determine how close the participants mimic the original movement of the robot. We also use inertial sensors to avoid any obstructions during the interaction and NAO to control simple movements that participants have to imitate.

## 2. METHODS

### 2.1 Research Question

How to analyse data collected from wearable inertial sensors attached both to a person and to a humanoid robot in order to quantify how closely a participant imitates a robot.

### 2.2 Participants

Twelve right-handed healthy participants (two females and ten males) with a mean age of  $19.5 \pm 0.79$  (from now on abbreviated as p01 to p12) were invited to participate in this study. All participants provided informed consent forms prior to participation. The design of the experiment was approved by the University of Birmingham's ethics approval process.

### 2.3 Procedure

Participants were asked to imitate horizontal and vertical arm movements performed by NAO. Such simple movements were repeated ten times for both the participant and the robot in a front to front imitation activity and wearable

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inertial sensors were attached to the right hand of the participant and to the left hand of the robot (Figure 1A). Data were then collected at a sampling rate of 50Hz with two NeMEMSi inertial sensors which provide the tri-axial data of the accelerometer, gyroscope and magnetometer sensors and quaternions [1]. It is important to note that due to the 2-page limit, we only present results for the horizontal movement and focus our analysis on the  $z$  axis from the gyroscope sensor ( $g_z$ ) which is mostly affected by the nature of the horizontal movement (Figure 1A).

### 3. STATE SPACE RECONSTRUCTION

The state space reconstruction (SSR) is based on the methods of time-delay embedding and PCA [2]. Our motivation to use the method of time-delay embedding is due to the non-linear structure of the time-series which is presented as different periods and amplitudes of the time-series between repetitions of movements and across movements of participants (Figure 1B and 1C). The method of time-delay embedding is an array of delayed copies of the available time series  $x(n)$  and is defined as  $\bar{x}(n) = \{x(n), x(n-\tau), x(n-2\tau), \dots, x(n-(m-1)\tau)\}$ ; where  $m$  is the embedding dimension and  $\tau$  is the delay embedding. PCA is used as a method for dimensionality reduction due to its non-parametric features. PCA is therefore applied to  $\bar{x}(n)$  in order to get  $PC_1, PC_2, \dots, PC_m$  to which we use  $PC_1$  and  $PC_2$  to create a state space reconstruction (Figure 1D, 1E, and 1F). Finally, we computed euclidean distances in the state space from (0,0) point to each  $(PC_1(i), PC_2(i))$  point where  $1 \leq i \leq m$  in order to obtain the box-and-whisker plots for each participant (Figure 1G).

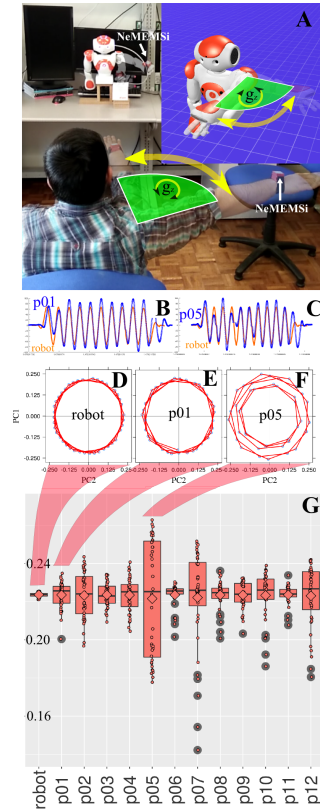
### 4. PRELIMINARY RESULTS

The robot's performance was highly consistent as indicated by the orange line in time-series in Figure 1B and 1C, and by the tight circular shape in the state space in Figure 1D. Compared with the consistency of the robot, p01 was able to imitate the robot's movement well by maintained a good level of consistency as shown both by the blue line in Figure 1B and by the circular shape in Figure 1E. The other participant here, p05, had some problems in following the robot. This is shown by the blue line in Figure 1C and the disjointed circular shape of the state space in Figure 1F. Such shapes in the state space are linked either to a maximum interquartile range or to a minimum interquartile range of the respective box-and-whisker plot (Figure 1G). Therefore, one can see that participants p02, p05, p07, and p12 seemed to have more difficulty than others in maintaining a consistent response to the robot's movement.

### 5. CONCLUSIONS AND FUTURE WORK

We proposed a metric to quantify how closely a participant can imitate a robot for simple arm movements. It can be noted that participants show different ranges of imitation which can be linked to a scoring system of human-robot imitation. However, the quality of such metric is debatable and needs further investigation.

For future research, there are four areas that we intend to investigate: (i) data collection from a wider range of individuals (differing gender, age and state of health) and from additional inertial sensors attached to the body; (ii) exploration of complex movements which can be performed by



**Figure 1: Horizontal movement performed by both NAO and participant 05 (A). Smoothed angular acceleration  $g_z$  for participant 01 and robot (B) and for participant 05 and robot (C). Reconstructed state spaces ( $m = 40$ ,  $\tau = 10$ ) for robot (D), participant 01 (E), and participant 05 (F). Euclidean distances from the state space for the robot and twelve participants (G).**

both persons and NAO; (iii) undertake a wider review of non-linear techniques that can be used for the assessment of human-robot imitation; and, (iv) exploration of convolutional neural networks for automatic classification of the levels of human-robot imitation.

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