Towards the Measurement of Human-Robot Imitation Using Wearable Inertial Sensors

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ABSTRACT

In this study, we use inertial sensors attached both to a humanoid-robot and to a person in order to quantify how close a participant imitates a robot. Twelve healthy participants were invited to perform simple arm movements for which we applied a propose framework based on non-linear dynamics to capture the non-linear structure of the time-series and PCA to reconstruct the state space. It turns out that participants show different ranges of the proposed metric which can be linked with to level of imitation. Such proposal can be useful in determining a detailed scoring of human-robot imitation during training or rehabilitation.

CCS Concepts

•Computer systems organization → External interfaces for robotics;

Keywords

Human-Robot Imitation, Movement Variability, Wearable sensors, Inertial sensors, Non-linear Dynamics

1. INTRODUCTION

Recently, NAO, a humanoid robot, has successfully been used either as a fitness coach for elderly or as an instructor of rehabilitation for children. For instance, the work of Görer *et al.* takes advantage of an RGB-D camera to extract joint angles of a human demonstrator and participants in order to compute the absolute differences between them [2]. Such absolute differences in joint angles are useful to create a corrective feedback for the movement of the elderly with regard to (i) speed adjustment, (ii) amplitude adjustment, (iii) mirroring detection and (iv) no motion. However, on one hand, when participants are seated the RGB-D camera cannot provide correct skeleton information, and, on the other hand, there is room for implementation of a detailed scoring of human-robot imitation. Guneysu *et al.* used NAO and wearable inertial sensors to monitor arm rehabilitation motions in children [3]. The challenge for Guneysu *et al.* is to keep the children's motivation in order to imitate movements for arm rehabilitation therapy. For this, in their previous study they used Kinect sensor to compute joint angles of motion but when therapists interact with children they obstruct the kinect sensor to which inertial sensors were used in order to avoid obstructions between the children, the therapist and the robot. However, as part of their study, it turns out that four physiotherapists have their own way to move when they were asked to perform the arm motions which is reflected in the differences of frequency and amplitude of the movements as well as the initial positions of the hands.

For this study, we are therefore proposing the use of inertial sensors to avoid any obstructions when using video-based sensors and the use of NAO to control simple movements that participants are going to imitate. Similarly, we are proposing a framework based on a non-linear dynamic technique and PCA in order to explore how close the participants mimic the original movement of the robot.

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2. METHODS

2.1 Research Questions

How to use and analyse the data collected from inertial sensors attached both to a humanoid-robot and to a person in order to quantify how close a participant imitates a robot?

2.2 Hypotheses

With this preliminary study, we expect to generate an intuitive explanation of the problem of measurement of human-robot imitation in order to provide metrics on how close a participant can imitate the original movement.

2.3 Participants

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

2.4 Procedure

Participants were asked to imitate two simple arm movements: (i) horizontal movement (Figure 1-A) and (ii) vertical movement; such simple movements were performed by NAO and each movement were repeated ten times for both the robot and the participant. Data were then collected at a sampling rate of 50Hz with two NeMEMSi inertial sensors which provide tri-axial data of accelerometer, gyroscope and magnetometer sensors and quaternions [1]. Because of the front to front imitation activity, inertial sensors were attached the right hand of the participant and to the left hand of the robot.

It is important to note that due to the reduced space, we are only presented results for the horizontal movement and we 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 1-A).

3. STATE SPACE RECONSTRUCTION

The proposed framework to measure human-robot imitation is based on the method of time-delay embedding and PCA. Our motivation to use the method of time-delay embedding is due to the non-linear structure of the time-series. Such non-linear structure is presented in different periods and amplitudes between repetitions of movements and across movements of participants (Figure 1-B,C). Similarly, we use PCA as a method for dimensionality reduction due to its non-parametric feature. The method of time-delay embedding is an array of time delayed copies of the available time series $x(n)$ and is defined as $\overline{x}(n) = \{x(n), x(n-\tau), x(n-2\tau), \dots, x(n-(m-1)\tau)\}$ where m is the embedding dimension and τ is the delay embedding [4]. We then applied PCA to $\overline{x}(n)$ 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 1-D,E and F). 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 1-G).

4. PRELIMINARY RESULTS

We want to emphasise that the use of the time-delay embedding method in order to characterise the non-linearities of the time-series and the use of PCA as a tool for dimensionality reduction is useful to measure how close participants imitate the original movement from the robot.

On one hand, it is expect that the robot performs very similar repetitions of movements which are visualised in the orange time-series Therefore, a tight circular shape of the reconstructed state space (Figure 1-D) is linked with little interquartile range of the respective box-and-whisker plot (Figure 1-G). On the other hand, the time-series of participant 05 shows (Figure 1-C) different amplitude and periods per repetitions which are related to the disjointed circular shape of the reconstructed state space (Figure 1-F) and therefore linked with a maximum interquartile range in the box-and-whisker plots (Figure 1-G).

We also show that participant 01 is an example of a good imitator of the robot movement (Figure 1-B,E and G).

5. FUTURE WORK

One our main concerns when quantifying human-robot imitation is the lack of metrics to say who can be considered a bad, intermediate or good imitator.

For future work, there are four areas that we are going to investigate: (i) data collection from a wider range of individuals (gender and age) and from additional inertial sensors attached to the body, (ii) explore complex movements which can be performed by both NAO and persons, (iii) undertake a wider review of non-linear techniques that can be used for the assessment of human-robot imitation, and, (iv) explore the use of convolutional neural networks for automatic classification of the levels of human-robot imitation.

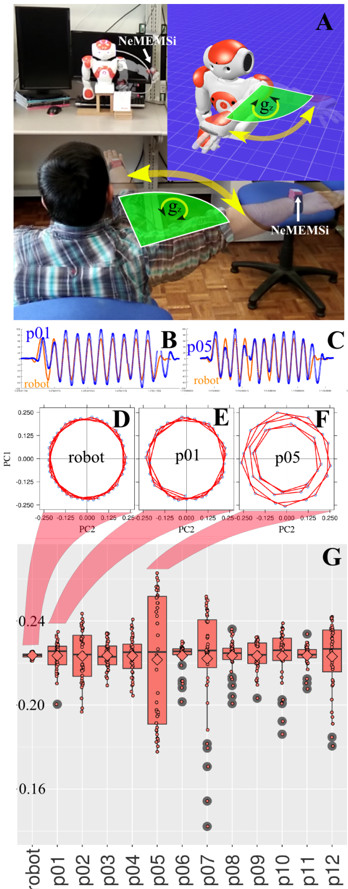

Figure 1: NAO and participant performing the horizontal movement (A). Smoothed angular acceleration g_z for participant 01 and robot (B) and for participant 05 and robot (C). Reconstructed state spaces ($m = 40$, $\tau = 10$) for robot (D), participant 01 (E) and participant 05 (F). Euclidean distances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

6. REFERENCES

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