

EXPERIMENT DESIGN

Measuring Movement

To understand the movement variability of the participants, we use a ~~very~~ cheap Inertial Measurement Unit: SparkFun 9DOF RAZOR IMU SEN-10736 sensor board which transmit data via RN42 bluetooth module. For data collection, we set a sampling rate of 50 Hz from four RAZOR's sensors using ROS [8] (Figure 2A). *and each collected data*

Time Series from the Accelerometer

The sequence $a_x(n)$ is the raw data collected from a triaxial accelerometer sensor $a_x(n)$. Then, for instance, the time-series $a_x(n)$ with a length of N samples is *employed* to get the embedded state space matrix, Ea_x , with m rows and $N - (m - 1)\tau$ columns. Finally, PCA is applied to reduce the dimensionality of the data *to get* the first two components of the rotated data in order to reconstruct the state space.

Head Pose Estimation

Estimating head pose in human-robot interactions is an active area of research where challenges like real-time tracking, the use of less invasive equipment or the preparation of calibration techniques remain to be solved. However, Lemaignan et al. [6] proposed a head pose estimator using a monocular RGB webcam which is able to track a head with rotations up to $\pm 40^\circ$ horizontally and $\pm 30^\circ$ vertically. *More recently*, OpenFace, a fully open source real-time facial behaviour analysis, not only provides head pose (orientation and motion) but also state-of-the-art performance in facial landmark motion, facial expressions, and eye gaze [1]. We therefore select *the use of* OpenFace because it can operate with a simple webcam in real-time (Figure 2B). *at the simple set up, less invasive and features for face behaviour understanding and it can operate with a...*

EXPERIMENT

Hypothesis

In our previous experiments of a face-to-face human-humanoid imitation activity [12], we applied the State Space Reconstruction's Theorem to quantify the level of imitation for horizontal and vertical upper arm movements. In such experiment, we observed *in the recorded videos* (only by naked eye) that the effects like boredom, fatigue or level of engagement play an important role in the influence that each persons moves. With this in mind, we hypothesised that not only the inertial sensors attached to the body can provide information about movement variability but also the face expressions and head pose estimation which, we believe, will lead us to get better understanding of the movement variability in human-to-humanoid activities and therefore create more reliable metrics to quantify such variability.

Participants and Procedure

To test our hypothesis, we collected data from eighteen healthy participants: eight male participant (age 18 ± 3.43) and ten female (age 18 ± 0.43) in which inertial sensors were attached to the wrist of both the participant and the humanoid robot, and put the webcam in front of the participant for the head pose estimation (Figure 2A). In the experiment, participant were asked to imitate ten upper arm movements performed by NAO at a constant speed of 30 frames per seconds.

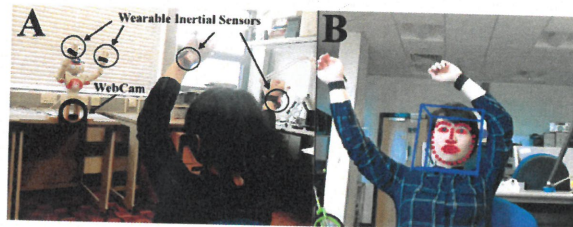


Figure 2. A. Experimental set-up: face-to-face imitation with NAO humanoid robot; B. Head pose estimation with OpenFace [1]

RESULTS

In Figure 3A), we only presented time series for the participant 12 for the sensor 03 and sensor 04 to show the asymmetry of the signals which is reflected in p12-s03 and p12-s04 in (Figure 3B) as well as in the error plot for s03 and s04 (Figure 3C). *less wrist movement* On the other hand, you can also notice that p17 in the error plot (Figure 3C) for the OpenFace presents a well distributed data in the interquartile range which means that the p17 were moving his head which is opposite to what the p14 did which head's movement was quite static. *rewrite*

CONCLUSION

Having proposed the use of the state space reconstruction and analysed *the data from* human-humanoid imitation activity, several questions remain to be investigated like the understanding of emotions and motions in one-to-one or one-to-many human-humanoid interactions. Considering the head pose estimation and the outcomes of the proposed metric, we observed that p04 and p17 participants moved their head as a tendency for the arm movement given the fact that the robot's head was static in the activity. Such behaviour requires further investigation in which, we believe that, the perception of movement is involved in this human-humanoid interactions. As pointed out by Blake et al. [2], the motor experience affects the visual sensitivity of human action. *to*

In future experiments, there are four areas that we intend to investigate: (a) performance of experiments of with two-humans to one-humanoid and three-humans to one-humanoid interactions; (b) exploration of complex movements which can be performed by both persons and NAO; (c) data collection from a wider range of individuals (differing gender, age and state of health) and from additional inertial sensors attached to the body; and (d) application of deep learning techniques to automatically classify the movement variability. *rewrite*

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REFERENCES

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