Assisting the practice of motor skills by humans with a probability distribution over trajectories

Marco Ewerton[1], Guilherme Maeda[1], David Rother[1], Jakob Weimar[1], Lars Lotter[1], Gerrit Kollegger[2], Josef Wiemeyer[2] and Jan Peters[1,3]

Abstract— **In sports training, rehabilitation or in the practice of motor skills in general, errors in the execution of movements may go unnoticed when a human instructor is not available. In these situations, a computer system or robotic device able to detect movement errors and propose corrections could be helpful. This extended abstract presents an approach for detecting errors in the execution of movements and for providing feedback to the user in order to correct these errors.**

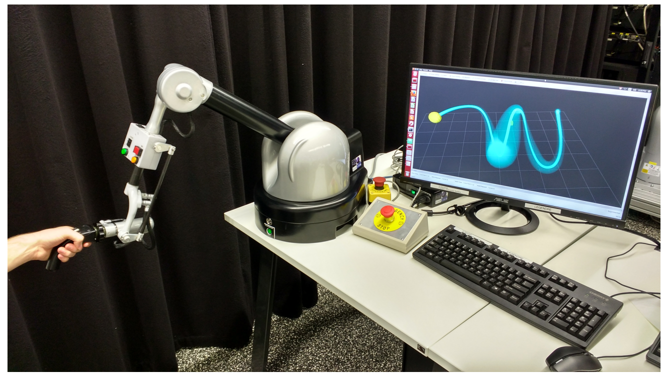

Fig. 1: Human manipulating a haptic device, the Haption VIRTUOSE 6D. In the depicted experiment, the haptic device assists the movements of the human by providing force feedback which is inverse proportional to the standard deviation of the distribution over trajectories (shown on the computer screen).

I. INTRODUCTION

In the absence of an instructor, errors in the execution of movements by a patient recovering from a stroke, by an athlete performing weightlifting or by a person practicing calligraphy, for example, may go unnoticed. As a result, recovery or performance improvement may be hindered.

In order to counter this problem, we propose recording demonstrations of a motor skill provided by an instructor and processing them such that someone practicing that motor skill in the absence of the instructor can have his/her trials automatically assessed and receive feedback based on the demonstrations.

Here, the generation of feedback is exemplified by the task of assisting the practice of Japanese calligraphy using visual feedback. Haptic feedback based on our proposed method is currently being evaluated (see Fig. 1).

II. RELATED WORK

In this section, related work on assisting human movements is discussed.

Solis et al. [1] presented a method to teach people how to write Japanese characters using a haptic interface. The system recognizes online what character the user intends to write and applies a proportional derivative (PD) controller with constant stiffness and damping to restrict the user to move along the trajectory that corresponds to the recognized character. In our currently ongoing work, a proportional controller is used to give haptic feedback to the user. The gains of this controller, however, are not constant but depend on the standard deviation along the probability distribution over demonstrations of the intended motor skill. By adopting variable gains, we expect to allow for practicing motor skills with multiple correct possibilities of execution or that require different levels of precision at different parts of the movement.

A variable impedance controller based on an estimation of the stiffness of the human arm was proposed in [2]. This controller was used to enable a robot to assist humans in calligraphic tasks. In the cited work, the tracked trajectories were not learned from demonstrations.

Our work is in line with approaches that aim at learning assistance from demonstrations. Raiola et al. [4], for instance, used probabilistic virtual guides learned from demonstrations to assist humans manipulate a robot arm. In another related work, Soh et al. [5] presented a system that learns from demonstrations how to assist humans using a smart wheelchair.

Haptic systems have also been investigated for applications in sports such as in [3] to assist golf putting.

III. METHOD TO PROCESS DEMONSTRATIONS AND ASSESS NEW TRAJECTORIES

The workflow of our proposed method is the following: First a human expert provides a number of demonstrations of a motor skill, possibly composed of multiple strokes. Then these demonstrations are aligned in space and time and a probability distribution over these demonstrations is computed. Afterwards a user tries to perform that motor

[1]Intelligent Autonomous Systems group, department of Computer Science, Technische Universität Darmstadt, Hochschulstr. 10, 64289 Darmstadt, Germany {ewerton, maeda, peters}@ias.tu-darmstadt.de

[2]Institute of Sport Science, Technische Universität Darmstadt, Magdalenenstr. 27, 64289 Darmstadt, Germany {kollegger, wiemeyer}@sport.tu-darmstadt.de

[3]Max Planck Institute for Intelligent Systems, Spemannstr. 38, 72076 Tübingen, Germany jan.peters@tuebingen.mpg.de

skill. Based on the probability distribution over the demonstrations, our system highlights which parts of the user's movements need improvement or generates force feedback towards correcting the user's movements. Here is a more detailed overview of the steps of our proposed method:

1) Repositioning and rescaling:

All trajectories are repositioned in such a way that the first position of the first stroke composing a motor skill is at the origin of the reference coordinate system. Moreover, a rescaling step makes the first stroke of each demonstration have the same width or height while maintaining the original proportions of the demonstrations.

2) Time alignment:

The time alignment of all the demonstrations is achieved in our system by using dynamic time warping (DTW) [6]. Each stroke of an execution of a motor skill is time-aligned with respect to the correspondent stroke of other executions of that same motor skill.

3) Distribution over trajectories:

In order to create a distribution over trajectories, we use the framework of Probabilistic Movement Primitives (ProMPs) [7].

4) Assessing new trajectories and providing feedback:

The correctness of each position of a new trajectory is assessed by comparing the likelihood of that position with the likelihood of the correspondent position along the mean trajectory. The mean trajectory is the one with the highest probability under the distribution over demonstrations. It is therefore considered by our system as the best achievable trajectory.

When generating visual feedback, our system uses this measurement of correctness to highlight errors in the execution of a motor skill. When generating haptic feedback, our system produces forces towards the mean trajectory in Cartesian space that are inverse proportional to the standard deviation of the distribution over demonstrated trajectories.

IV. Experiments

We demonstrate our method with the task of writing Japanese characters, because it is a challenging task that requires accurate motor skills and can only be acquired by extensive repetitions with feedback.

Fig. 2 show some examples of feedbacks provided by our system implementing the workflow described in Section III.

V. Conclusion and Future Work

This extended abstract presented a probabilistic approach for assisting the practice of motor skills by humans. The method here presented addresses the alignment in space and time of trajectories representing different executions of a motor skill, possibly composed of multiple strokes. The method builds a probability distribution over demonstrations provided by an expert, which can then be used to assess a new execution of a motor skill by a user and provide visual or haptic feedback.

The effectiveness of our proposed method in helping test subjects practice and improve motor skills is currently being evaluated.

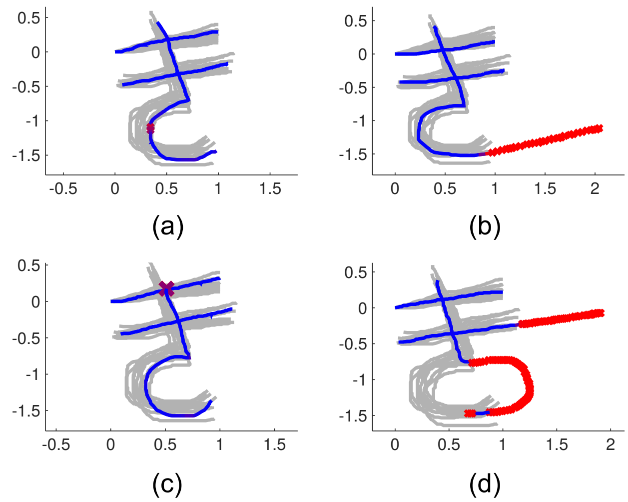

Fig. 2: The demonstrations after rescaling, repositioning and time-alignment are depicted in light gray. Parts of a new trajectory that are considered correct are depicted in blue. Parts of a new trajectory that are considered wrong are marked with red x's . **(a)** Instance with a small mistake in the third stroke. **(b)** Third stroke goes further than it should. **(c)** Third stroke starts too low. **(d)** Second stroke is too long and third stroke has its arch in the wrong direction.

VI. Acknowledgments

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