Skill Modelling for Human Operator Performance Assessment

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1 Introduction

In manufacturing industry, many tasks are still performed by human operators due to the required craftsmanship skills. However, the manufacturing industry is suffering from a shortage of skilled workers, with growing flexibility demands further decreasing the level of experience of the workforce. To resolve these problems, this work aims to facilitate the transfer of skills to novice operators, working towards a more skilled and flexible workforce. More specifically, this work describes a general framework that learns an expert model using Probabilistic Principal Component Analysis (PPCA) starting from a small set of expert demonstrations, assesses the similarity between a new execution and the expert model, recognizes whether the new execution is performed by an expert or novice operator and identifies the main problem regions in the execution while accounting for the operator's skill level. To demonstrate this, the framework was tested on a sawing case recorded at UHasselt.

2 Approach and First Results

The first step in the framework is to learn an expert model from a small set of expert demonstrations. To this end, the expert demonstrations are first expressed in terms of normalized time progress instead of explicit time, aiming to improve the alignment of the different demonstrations, which improves the model quality. This step makes the measured features independent of the execution speed, although execution speed can be relevant. Therefore, speed is explicitly reintroduced as a separate signal. Then, PPCA [1] is used to learn a probabilistic linear latent variable model of the expert executions.

The next step is to quantify the similarity between the probabilistic expert model and a new execution. To achieve this, the distance between each time sample of the new execution $\mathbf{q_i}$ and the expert model at the corresponding progress value s_i is first obtained using the squared Mahalanobis distance M (1). Then, to obtain a local similarity measure over a section of the execution, the squared Mahalanobis distances inside a moving window are summed. Since the summed squared Mahalanobis distance follows a χ^2-distribution, an easier to interpret probability value can be calculated, which indicates the probability that a segment of the new execution is consistent with the corresponding segment of the expert model. Based on this, expert and novice executions can be distinguished, as shown for the sawing case in Figure 1.

$$M\left[\mathbf{q}_i, \mathbf{f}(s_i)\right] = (\mathbf{q}_i - \mu(s_i))^T \boldsymbol{\Sigma}(s_i)^{-1} (\mathbf{q}_i - \mu(s_i)) \quad \text{with PPCA model: } \mathbf{f}(s_i) \sim N(\mu(s_i), \boldsymbol{\Sigma}(s_i)) \tag{1}$$

Finally, to provide useful feedback to the operators, the main problem regions in a new execution can be identified. This is achieved by refining the above probabilistic model such that it better encodes measurement errors and expected deviations in the execution of the skill. Using this refined model, the main problem regions of the execution can be identified by looking at the probability, as shown for the sawing case in Figure 2.

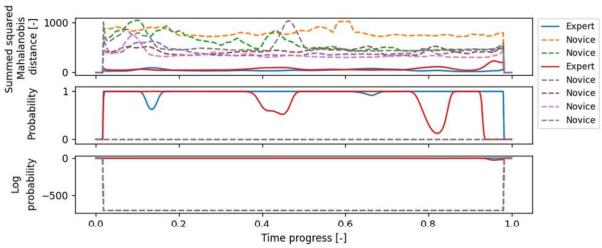

Figure 1: Results for 6 novice and 2 expert demonstrations of the sawing case, calculated based on saw angle, saw position, sawing amplitude and progress speed, demonstrating the ability to distinguish novice and expert operators.

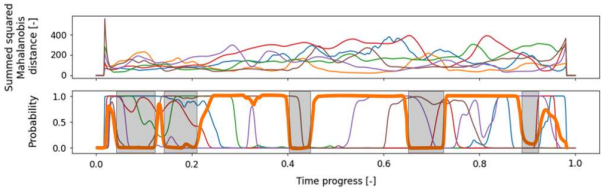

Figure 2: Results for the 6 novice demonstrations of Figure 1 after skill level correction, identifying the main problem regions for one of the demonstrations (shaded).

References

[1] E. Aertbeliën and J. De Schutter, "Learning a predictive model of human gait for the control of a lower-limb exoskeleton," in *5th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics*, 2014, pp. 520-525.

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