Patient state assessment in virtual rehabilitation using adaptive discriminant analysis

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In neurorehabilitation, virtual environments improve patient motivation by allowing exercise in interesting, varied settings. However, to best adapt the therapy and virtual environment to the patient's needs, capabilities and desires, it is important to merge data obtained from the patient and virtual environment into an estimate of the patient‘s current state. If the system can identify the patient's physical, physiological and psychological state, it can respond to this information by changing the parameters of the virtual scenario. For instance, if the patient is bored, the virtual environment can be made either more challenging (by presenting more difficult rehabilitation tasks) or more varied (by changing the audiovisual properties of the environment).

We propose a method of fusing multimodal information for patient state assessment in virtual rehabilitation based on adaptive discriminant analysis. Discriminant analysis is a well-known method for feature extraction and classification, used to find a discriminant function that best separates data from multiple sensors into two or more classes. In virtual rehabilitation, it can be used to classify multimodal (e.g. force and physiological) data into user states such as 'bored' or 'frustrated'. However, since data such as physiology or movement patterns can exhibit large intersubject variability, the patient state assessment system should be able to adapt to a particular patient, estimating his or her state more accurately as the therapy progresses and more data about the patient becomes available. A variant of discriminant analysis, Kalman adaptive discriminant analysis, can be used for this purpose. With this method, the rules of the state assessment system are initialized offline from training data, then recursively updated online using Kalman filtering.

Adaptive discriminant analysis was implemented in a virtual environment for robot-aided upper extremity rehabilitation. 23 healthy subjects and 10 hemiparetic patients performed reaching and grasping exercises for twelve minutes. Every two minutes, the subject was asked whether he or she would prefer the task to be easier or harder, and the difficulty was adjusted accordingly. Simultaneously, measurements of task performance, forces, movements, and psychophysiology from the previous two minutes were fused using adaptive discriminant analysis into a prediction of the subject's choice ("prefer easier" or "prefer harder"). For both healthy subjects and patients, prediction accuracy of adaptive discriminant analysis was near 90%, proving that the method is an effective tool for multimodal sensor fusion and patient state assessment in virtual rehabilitation. It can also be easily modified for more than two possible states, making it potentially useful for more complex situations.