Orthosis Controller with Internal Models Supports Individual Gaits

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1 Motivation

Orthoses for the lower limbs are designed for patients with restricted walking abilities, to support movements they can't perform on their own. The device's capabilities determine the mobility the patient may achieve, for example the gaits and environments the orthosis supports.

In traditional controllers, support for additional gaits, and therefore for increased mobility, comes at the cost of complexity, e.g., for finite state controllers each gait consists of a set of states and transitions between those, which all have to be managed. Furthermore, weather the patient is able to employ these gaits, depends on his/her ability to achieve the conditions which are required to initiate the state transitions and depend on the very individual disease or disability of the patient. This effect is more problematic with orthoses then prosthesis, because of the varying individual manifestations. In general, limited support often leads to avoidance movements or additional work being performed with the contralateral side, which may lead to long-term damages [1].

To extend the patient's mobility and to better fit the device to the individual patient, we propose the application of a model-invalidation approach combined with continuous tracking of the patient's walking. The controller chooses from a set of gait models the one, which fits the current movement best. This approach can be used without discrete states and therefore allows gait switching at any time. If individual gait samples are applied for model training, the patient doesn't need to cope with a general set of transition conditions. This reduces the need to overcome limitations with the contralateral side or to apply avoidance movements, lowering the risk of long-term damages, and leading to a more natural, fluent and individual walking experience.

2 State of Art

Old orthotic devices were splints, which were then extended with mechanic joint locks. While these devices allowed the patients to regain mobility, the rigid structure imposed additional mechanical stress on the patients. With the introduction of micro-controllers, the control mechanisms became more sophisticated and complex joints have been developed, like damped joints, where damping can be controlled fast and accurately.

A frequently employed control scheme is the finite state controller, which defines states, which correspond to walking conditions and control output, and transitions, which define the conditions, for which a state change is initiated. Although very successful, the complexity increases with the number of and transitions between states. At the same time, the device can only be applied to a patient, who can achieve the necessary transition conditions. A finite state controller with support for stair descending and ascending has been tested in [2].

To increase the controller's flexibility and applicability, recent approaches continuously track the patient's gait. This way, transitions are not determined by specific conditions, but by the method of gait classification. This leads to the development of new approaches for gait classification, moving from stationary systems, gathering external information, to sensors in the vicinity of the body or applied to the device, and from step wise, post-hoc classification to in-step, on-line classification. For special cases, like standing and walking[3], and walking on flat ground and slopes[4], such on-line classifying and switching controllers have been implemented.

3 Method

The here presented method consists of two approaches: continuous tracking of gait progress in conjunction with gait classification. The approach is developed and tested on an orthosis prototype by Otto Bock with C-Leg$^{\text{TM}}$-element[5], to ensure real world applicability of the method.

The prototype allows applying additional damping to the knee joint, which is the output parameter of the controller presented in figure 1. Per supported gait the controller consists of one specialised gait-controller, which tracks the gait progress and applies appropriate damping. For each gait-controller, an internal model predicts the sensory input of the next sampling frame. The accuracy of the prediction is used by a decision unit to select the most fitting gait-controller. For security reasons, a default controller takes over, if no model predicts inside the safety margins.

To support patients individually, the method uses individual walking samples for gait progress tracking and extensive control over the applied damping. These two components, make the method independent of the device in question, and the applied set of sensors.

To benchmark the method, we investigate the following aspects in walking experiments: (1) Smoothness of gait tracking, e.g., is the method able to track gait progress accurately with specialised models. (2) Reaction time of the gait switch-

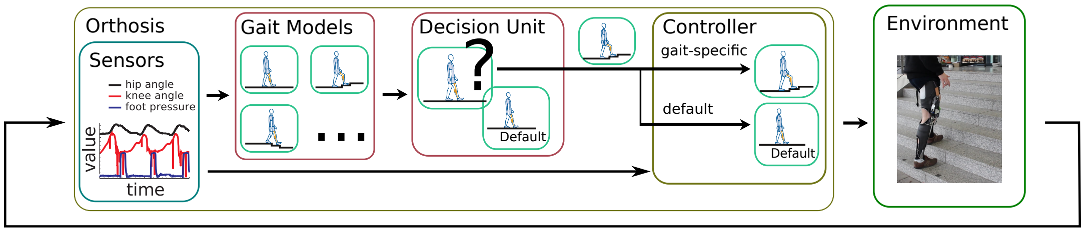

Figure 1: Control flow: Gait models predict the sensory input. The decision unit chooses the model which minimises the error between sensory input and prediction. The actual controller can act according to the specific gait or according to a default mode, if no model fits the current gait. (The human figures are based on a brochure by Otto Bock.)

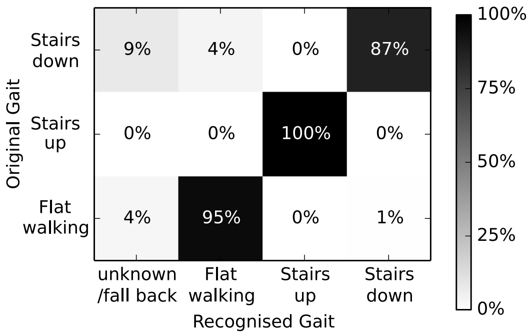

Figure 2: Confusion matrix for 215 steps. Manual annotations in the rows are compared with the method's results in the columns, showing the frequency of steps belonging to an annotation which end up in the corresponding class. The class "unknown/fall back" catches all steps which no model could reliably predict, ensuring basic operation of the device. The false positives show ambiguous transition steps.

ing, focusing on how the classification performance develops between heel-off and heel-strike, for which the confusion matrix is shown in figure 2.

4 Results & Discussion

The presented method constitutes a framework for training of an orthosis to the individual movements of a patient, and we observe smooth and detailed capturing of the patients gaits. This simplifies customisation and extends the group of possible patients, reducing the necessary patient training.

Our results show fast reactions on gait changes with high success rates of the gait classification, enabling seamless gait transitions in the same step, allowing a more natural and untroublesome walking experience. The patient benefits from support for multiple gaits with extended mobility, and at the same time reduced need for avoidance movements to overcome device limitations.

The method is quite general and makes no assumptions on the device's mechanics, the employed sensors, the movements of the patient, or when and how a gait transition occurs. It was developed on prototypes with stiff and mobile ankles, which were equipped with as few as 3 sensors at 100 Hz sampling frequency, achieving an average success rate of above 94 % before heel strike. The applied methods are straightforward and computationally not overly complex. These features make the method suitable for real world application.

The presented method presents a suitable way to recognise patient intend in time for the orthosis to react. For future applications, reliable gait classification allows the system to adapt its support on-line, tracking changes in the patient's movements via retraining. The method could be employed to learn new gaits, which are not captured by existing models, aiming for a completely self-learning and self-adapting orthosis.

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