A Fuzzy Controller Design for a Mechatronic Ski Binding

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Introduction: Previous publications report on the advantage of integrating a mechatronic component in the ski binding with regard to possible reductions of knee injuries while skiing [1, 2]. In our previous work [1] we proposed a mechatronic system that uses five input parameters: the knee flexion angle, the muscle activity of the thigh, the loads acting on the foot, the skiing velocity, and information about the skiing individual (e.g. gender) and presented prototypes for measurement systems to record these parameters. In this work, we now propose an algorithm for this mechatronic ski binding based on fuzzy controllers to determine the risk of injury by processing the input variables and providing an output signal to allow an adjustment of the retention settings of the binding.
Method: In a literature study, the relationship between the input parameters and injury mechanisms of the knee in skiing were derived. The gained knowledge was used to define the structure of the algorithm and to define fuzzy membership functions and fuzzy rules. The final algorithm was applied to a data set of case studies of six patients who have suffered an ACL injury while skiing which was published by Fischer et al. [3]. The data set provides information about the skier and the injury mechanism. No information about muscle activation and binding loads is provided. Therefore, assumptions were made for the missing input parameters with respect to the described injury mechanisms and the defined fuzzy membership functions.
Results: A total of 30 load cases were defined and respective risk values for these load cases were assessed. The proposed fuzzy controller algorithm includes three independent Mamdani fuzzy controllers providing each a respective risk level as output (Fig.1). The first controller determines a risk due to the combination of an internal or external torque on the knee, a varus or valgus moment, the knee flexion angle, and the muscle activation. Moreover, the retention values of the binding as defined by the DIN ISO 8061 are included. For the determination of these values, individual information about the skier (e.g. gender, age, weight, height) is used. The second controller determines a risk level due to a backward or forward-leaning position of the skier, the knee flexion angle, and the muscle activation. The third controller determines a risk level due to the speed of the skier. In the overall algorithm, the gender and measurement accuracies are also taken into account. The different risk levels are aggregated to define the output signal. The maximal

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reduction of the retention value as given by the standard was 15%, as this reduction is allowed by the standard. As females are reported to have a higher risk of injury [4], the retention setting for female skiers is decreased by 15% independent of the risk levels given by the fuzzy controllers. The simulative application of the algorithm on the six case studies results in a reduction of the retention settings of the binding in four cases.

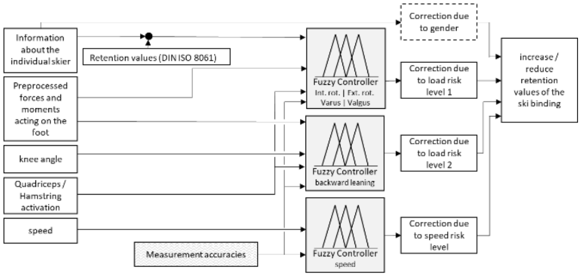

Fig. 1: Proposed structure of a Fuzzy controller algorithm for a mechatronic ski binding.

Discussion: The design of the algorithm is based on knowledge about injury mechanisms described in the literature. The available information is still incomplete and further research is encouraged. Besides using expert knowledge from different disciplines and results from further scientific investigations, artificial intelligence may help to allow a better definition of the various parameters of the algorithm. The application of the algorithm on the case studies just allows the demonstration of the principle workings of the algorithm. The main challenge will be the real-life validation of the algorithm for which data of many skiing days is needed. For ethical reasons, the data collection must be done with traditional bindings and the sensor systems alone. The data can then be used to adapt the algorithm iteratively and only when a safe behavior of the mechatronic system can be guaranteed can the algorithm and the active element be implemented.

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