https://nbn-resolving.org/urn:nbn:de:bsz:ch1-qucosa2-806704

A Fuzzy Controller Design for a Mechatronic Ski Binding

Aljoscha Hermann[1], Dirk Baumeister[1], Patrick Carqueville[1] & Veit Senner[1]

[1]Professorship of Sport Equipment and Materials, TUM School of Engineering and Design, Technical University of Munich, Garching, Germany

Abstract

Mechatronic Ski Bindings are the most promising technical solution to reduce knee injuries in alpine skiing. The key to a successful system is the algorithm controlling the bindings adaption of the retention values. A fuzzy controller has advantages compared to classical controllers due to missing information about injury mechanisms and the complex dynamics of the skier. We present a controller structure and test it using the injury case reported in the literature.

Keywords: Mechatronic Ski Binding, Injuries, Alpine Skiing, Algorithm, Fuzzy Controller

Introduction

Previous publications report on the advantage of integrating a mechatronic component in the ski binding concerning possible reductions in 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 [1, 3–6]. In this work, we propose an algorithm based on fuzzy controllers to determine a risk of injury by processing the input variables and providing an output signal to control allowing the adaption of the retention settings of the binding or releasing the ski.

Methods

In a literature study, the relationship between the input parameters and injury mechanisms of the knee in skiing was 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. [7]. 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 concerning 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. The second controller determines a risk level due to a backward or forward leaning position of the skier derived by the My, 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 simulative application of the algorithm on the six case studies results in a reduction of the retention settings of the binding in four cases.

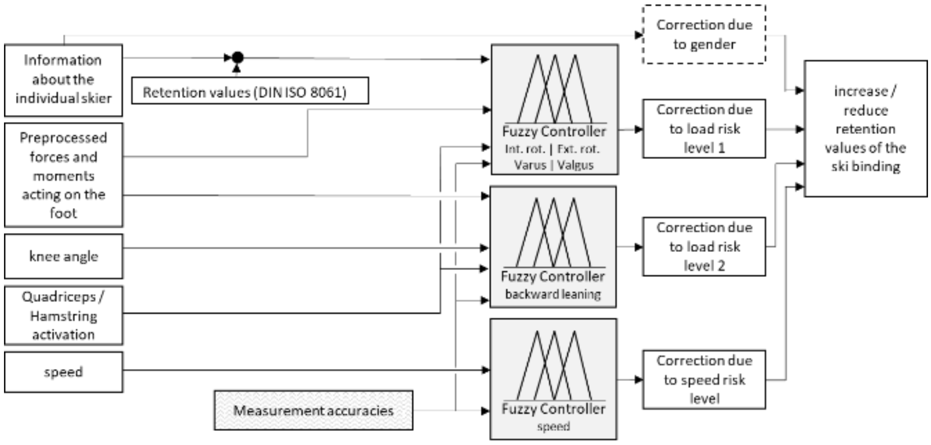

Fig. 1: Proposal for a structure of a Fuzzy controller algorithm for a mechatronic ski binding.

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 principal workings of the algorithm. The main challenge will be the real-life validation of the algorithm for which data from many skiing days is needed. For ethical reasons, the data collection must be done with traditional binding and the sensor systems alone. The data can then be used to adapt the algorithm iteratively and only when a safe behaviour of the mechatronic system can be guaranteed can the algorithm and the active element be implemented.

Conflict of interest We declare no conflicts of interest.

Funding Bayerische Forschungsstiftung AZ-1375-19

References

1. Hermann A, Senner V (2020) Knee injury prevention in alpine skiing. A technological paradigm shift towards a mechatronic ski binding. *J Sci Med Sport*. https://doi.org/10.1016/j.jsams.2020.06.009
2. Senner V, Michel FI, Lehner S et al. (2013) Technical possibilities for optimizing the ski-binding-boot functional unit to reduce knee injuries in recreational alpine skiing. *Sports Eng* 16:211–228. https://doi.org/10.1007/s12283-013-0138-7
3. Hermann A, Ostarhild J, Mirabito Y, et al. (2020) Stretchable piezoresistive vs. capacitive silicon sensors integrated into ski base layer pants for measuring the knee flexion angle. *Sports Eng* 23. https://doi.org/10.1007/s12283-020-00336-9

4. Kiefmann A, Krinninger M, Lindemann U, et al. (2006) A New Six Component Dynamometer for Measuring Ground Reaction Forces in Alpine Skiing. In: *The Engineering of Sports 6,* vol 21. Springer, New York, NY, pp 87–92
5. Hermann A, Senner V (2020) EMG-pants in Sports: Concept Validation of Textile-integrated EMG Measurements. In: Pezarat-Correia P, Vilas-Boas J, Capri J (eds) *Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support*. SCITEPRESS - Science and Technology Publications, pp 197–204
6. Hermann A, Senner V (2019) Sensing the Skier: Towards a Mechatronic Ski Binding. *23rd International Congress on Snow Sports Trauma and Safety*, Squaw Valley, California, USA
7. Fischer JF, Loureiro O, Leyvraz PF, et al. (1996) Injury mechanism of the anterior cruciate ligament in alpine skiing: Case studies. ASTM Special Technical Publication 1266