TESTING SPORTS SHOES USING AN INDUSTRIAL ROBOT

Bojan Nemec, Michele Leonardi, Jozef Stefan Institute, Ljubljana, Slovenia

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INTRODUCTION: Sports shoes are a very important type of sports equipment and are subject to constant development and improvement, especially for winter sports like skiing, cross country skiing, skating, etc. Basically, the design of ski boots is based on a trial and error method, in which each prototype is tested on the outdoor terrain. This approach to development is very time-consuming and costly. Besides, it is affected by the personal judgments of the subjects. In this paper we propose new approach to sports equipment testing. It consists of two major phases: the measurement phase and the simulation phase. In the measurement phase we capture the forces and trajectories that occur during the sports activity. Along with the trajectory, video images of the sports activity are also recorded, which makes possible the identification of the sports activity during the simulation phase. In the simulation phase, we use an industrial robot that exactly repeats the captured motions. Using additional measurement equipment, various forces, tensions, vibrations, etc. can be measured in any part of the sport shoe. The main benefit of this approach is that many subjects can be measured and compared under exactly the same conditions. Additionally, the laboratory environment makes possible measurements that are very difficult or impossible to perform on the terrain [Hubbard, 93].

METHODS: The proposed approach was used for testing alpine ski boots and cross-country ski boots. Testing alpine ski boots is less complex than testing cross-country ski boots. Due to its rigidity, the ski boot allows motion only in the sagittal plane of the human body; therefore only motion in the sagittal plane of the human body must be measured. Two parameters were consequently sufficient to determine a ski boot's behavior: the skier's knee bend and the resulting flex force of the ski boot during the ski activity on the ski terrain [Nemec 96]. The flex angle was measured with a precise potentiometer attached to a special tibial under-knee brace via a bar linkage, as shown in Fig. 1.

Fig. 1. Flex angle measurement

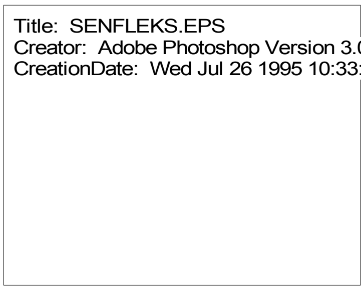


Fig 2. Flex force sensor

The flex force is measured with a special force sensor inserted between the ski boot tongue and the ski boot shell. A force sensor which consists of four strain gauges connected to a Whetstone bridge to compensate for temperature changes is presented in Fig. 2. The flex force and knee bend trajectories were captured by special microcomputers attached to the skier's belt. The measurement was synchronized with the video image recorded with the standard camcorder with timecode capability [Nemec 97]. The measurement setup is outlined in Fig 3.

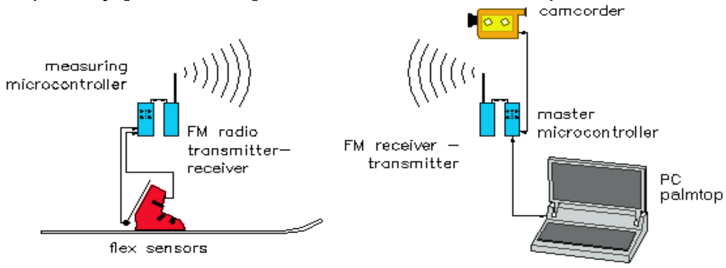


Fig 3. Ski boot flex measurement setup

In the simulation phase, the robot can simulate skiing using two modes - trajectory tracking and force tracking. Accurate simulation requires high forces, high velocities and high accelerations. These properties require powerful and therefore costly industrial robots. Therefore, we developed a special manipulator with a single degree of freedom that is capable of producing high forces (> 1000 N) at high acceleration and high motion velocities. Beside the manipulator, we developed a special control unit which can drive the manipulator in the trajectory or force tracking mode. The control unit can measure up to 8 signals from force transducers, and up to 16 analog signals from potentiometers and temperature probes and up to two angles from the incremental encoders. Along with the simulation, the control unit plays AVI video clips of simulated sports activity, synchronized with the drive trajectories. The manipulator and control unit is shown on Fig. 4.

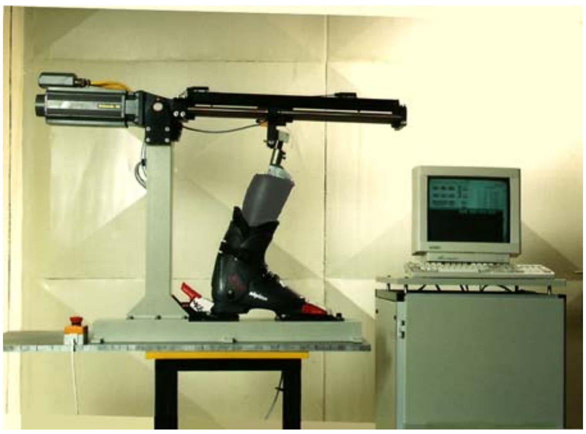


Fig 4. Manipulator for testing alpine ski boots

The measurement and simulation of cross-country ski boots is more complicated, as the cross-country ski boot is not rigid and allows motion in all three dimensions of Cartesian space. The most suitable way of capturing cross-country ski motions is by using an optical measuring system. We used two optical measuring systems: ComSport for outdoor measurement and Elite for indoor measurements. The advantage of the Elite measuring system is automatic digitalization of markers, while ComSport requires manual digitalization. Using four cameras, the measuring range was sufficient for capturing one step of sliding or skating style. With the Elite measuring system we were restricted to using roller skates, but on the other hand the measured trajectory was much more accurate [Leonardi 97]. The laboratory measurement setup and placement of the markers is presented in Fig. 5 and 6 respectively. The measured marker trajectories had to be transformed into trajectories suitable for simulation with an industrial robot. Therefore, the pure translational component in the direction of running had to be removed. This was accomplished using the following transformation:

$$\boldsymbol{a} = \frac{M_2 - M_1}{\| M_2 - M_1 \|} \qquad \boldsymbol{b} = \frac{M_3 - M_1}{\| M_3 - M_1 \|} \qquad \boldsymbol{c} = \boldsymbol{a} \times \boldsymbol{b}$$

$$\mathbf{T} = | \boldsymbol{a}\ \boldsymbol{b}\ \boldsymbol{c} | \qquad \mathbf{M}_R = \mathbf{T}\mathbf{M}_4$$

where **M** are vectors of measured three-dimensional positions of the markers, **T** is the transformation matrix from the camera coordinate system to the robot coordinate system, and $\mathbf{M}_R$ is the transformed vector of the center of the knee rotation, that is actually the tool center point of the robot, i.e., joint between the robot tool and the artificial leg. Notation of the markers is evident from Fig. 6. Two additional markers M_5 and M_6 were used to determine the leg rotation and, consequently, tool rotation of the robot.

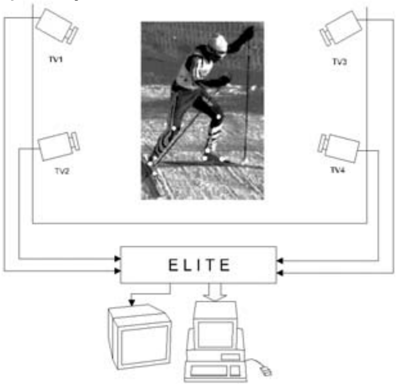


Fig. 5 Optical measurement setup

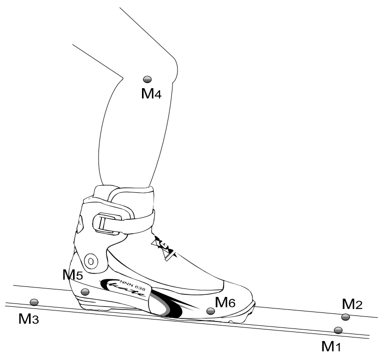
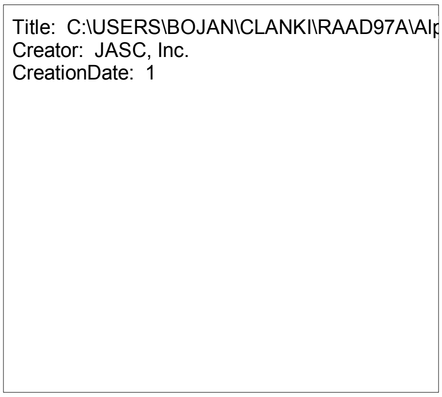
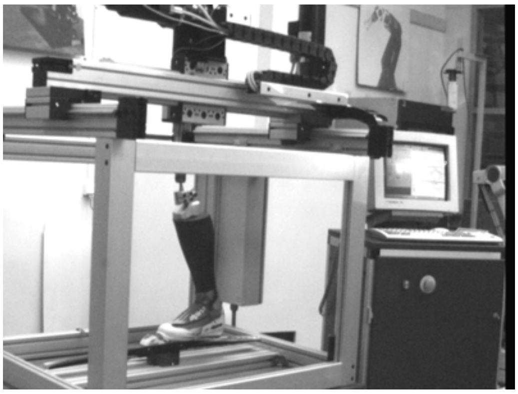


Fig. 6. Marker placement

During the simulation, the reactive forces were measured using a universal force sensor, mounted under the ski bindings. The simulation setup with a 5 d.o.f. industrial robot is outlined in Fig. 7. In order to reduce the cost of the simulation setup, we constructed special 3.d.o.f manipulators, which can produce forces, velocities and accelerations similar to those of the human knee. The fourth degree of freedom is implemented in the artificial leg using pneumatic muscles.

RESULTS: Figure 8 shows the typical measured responses of flex forces and ski boot sole reaction forces for parallel turns in alpine skiing and skating style for cross country skiing. When the simulation was carried out with different ski boots, the resulting measured reaction forces clearly show differences among various ski boot models. Measured responses give valuable information on how and where to change ski boots in order to achieve the behavior of an ideal ski boot. Additionally, with a long-term test we can identify the weak points of the ski boots and consequently improve the durability and reduce the weight of the tested boot.

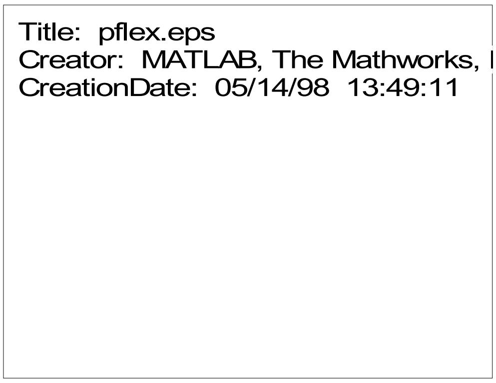




Using different test

Fig 7. Industrial robot and dedicated test manipulator in ski boot test

trajectories we built a database of patterns for alpine skiing and cross country skiing, classified according to skier experience, snow conditions, ski disciplines, etc.



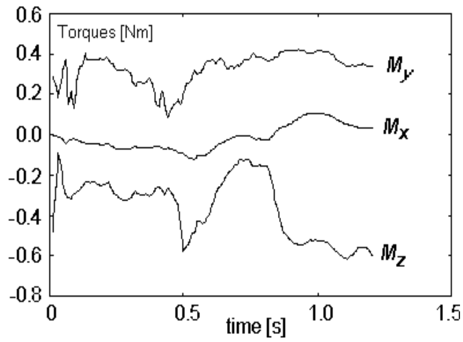


Fig 8. Example of measured trajectories - alpine ski boot flex and cross-country reactive torques

CONCLUSIONS: The proposed approach has been used for testing alpine ski boots and cross-country ski boots. The measurement results allow comparisons among different types of ski boots. Our system for alpine ski boot testing has been used for ski boot design by one of the world's leading ski equipment manufacturers.

REFERENCES:

Hubbard, M. (1993). Computer Simulation in Sport and Industry. *Int. J. Biomechanics* **26**.

Leonardi, M., Jeraj J., Nemec B. (1997). A New Approach for Testing Sports Shoes Using Industrial Robot. 6th Workshop on Robotics in Alpe-adria-Danube Region, Casino, Italy.

Nemec, B. (1997). A System for Measuring Ground Reaction Forces in Alpine Skiing. *Coaching and Sport Science Journal* **2**.

Nemec, B., Leonardi, J.(1996). A Simulator for Testing Alpine Ski Boots. 6.th Workshop on Robotics in Alpe-adria-Danube Region, Budapest, Hungary.