Winning a ski competition requires not only talent but also sophisticated technologies that enable careful scrutiny and consequent improvement of technique and performance. To enhance those efforts, one group is developing a Global Navigation Satellite System–based tracking method, combined with accelerometry data, to precisely record a skier's position and speed throughout a run. Alone or coupled with videography, this information permits close analysis of a course and a skier's performance on any given run.

GNSS Hits the Slopes

Analysing Alpine Skiing with GPS–GLONASS

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Famous for its banks, watches, and chocolate, Switzerland is also known for its spectacular mountains and sport-oriented cities that welcome international tennis, golf, and ski events each year. Popular vacation destinations are spread throughout the country, with Verbier, Saas-Fee, Zermatt, and Montana topping the list of sites in the southern canton of Valais.

Proud of its landscape and exceptional sunny weather, that entire region — with the candidacy of Sion 2006 — competed to host the 2006 Winter Olympic Games. The dynamic created by this effort gave birth to many new ideas for using cutting-edge technologies in winter sports. Today, even though the Olympic Committee selected Torino, Italy (located a few hundred kilometres from Sion) as

A view from the Montana ski domain (left)

With a GPS antenna attached to his helmet, World Cup professional skier Xavier Gigandet of the Swiss Team (opposite page) races during the 6-kilometre downhill competition of Mont-Lachaux Trophy, at Crans-Montana.

the host, the enthusiasm for such projects still pulses through the country.

Couple that excitement with the fact that in Switzerland, skiing is second only to football, then you will understand why we found the temptation too great to resist. Temptation? Indeed. You can't study the latest in positioning technologies — Global Navigation Satellite Systems (GNSS) such as GPS — and work every day on sport and physiology projects without someone saying (particularly as the snow season approaches), "And what about measuring ski runs using GPS?" We finally responded with the only logical answer: "Why not?"

Forming a Championship Team

In fact, in October 1998, this question initiated a joint project between the Geodetic Laboratory of the Swiss Federal Institute of Technology of Lausanne (EPFL), directed by Professor Bertrand Merminod, and the Research Group of Applied Physiology of the University of Lausanne, led by Dr. Yves Schutz. We hoped, by combining satellite-based positioning and accelerometer data, to obtain precise information such as speed, position, and physiological parameters at a frequency of 1–10 Hz. This would enable better analyses and allow more detailed comparisons between runs than is possible with such traditional approaches as examining two intermediate times.

We knew that position and speed data would allow us to recreate each skier's run and determine where one person loses or gains time over another, with trajectory information revealing different strategic approaches to a course. In addition, lateral acceleration serves as a good indicator of a skier's technique when passing gates, with vertical acceleration helping determine when he or she bends down to pass a gate and stands up again. Plus, speed profiles facilitate the testing of different ski waxings. When we presented our project and these potential benefits to various ski clubs, we discovered such an interest and curiosity that we immediately decided to further investigate this domain.

Our project team consists of the aforementioned directors from each school, who advise us on study methodologies and the different parameters of interest, as well as Olivier Perrin, a geodetic survey engineer who participated in the first feasibility tests. At any given time, various other students and faculty from the two institutions also participated in the trials and postprocessing sessions. I (Quentin Ladetto) was in charge of managing the overall project and specifically the geodetic aspects, which also forms part of my Ph.D. work.

Before launching into this challenging project, we analysed the accuracies required to achieve our goals and discovered that we would need to use professional survey equipment. As we had no expertise in high-dynamic applications, we decided (somewhat by default) to use our high-precision GPS receivers for our initial fieldwork. We quickly discovered, though, that manufacturers hadn't thought about so-called "people" applications when they designed these devices. But, we thought, don't we always say that faith can move mountains? And it was precisely on these mountains that we planned to conduct our tests.

Heading up the Mountain

It was still dark when we left the laboratory at 6:30 am that seventh day of December 1998 — Olivier and myself piling into a small car packed with receivers, laptops, batteries, tripods, and a complete set of ski equipment. The radio announced cold, sunny

During the tests at Veysonnaz, skiers from the Ski Club Savièse carried traditional backpack GPS survey equipment backpack to track their run (above).

Quentin (right) and Vincent set the spirit level of the Montana reference station in arctic conditions.

weather and excellent snow conditions. After a two-hour ride, we reached Veysonnaz, a ski station located 10 kilometres from Sion. We opted for this station, which often organises world downhill skiing championship competitions, because of its optimal snow conditions and the gradients of its slopes.

Before beginning our actual tests, we first created a GPS-based digital terrain model (DTM) of the course to ensure we obtained the same level of precision for both planimetry and altimetry. After executing a kinematic on-the-fly initialisation, Olivier carried the antenna in a backpack and travelled the length and breadth of the slope. It took more than an hour and a half to make this first "slalom," but it provided a very good representation of the course. Because we conducted our test runs immediately upon completing the DTM, we fortunately didn't need to worry about the terrain changing because of snowfall, which could be a problem for any work conducted on two different days. In addition, studies were simultaneously conducted using differential barometry to compare level changes computed by this means and the difference of altitude given by the DTM.

Other preparatory studies had revealed satellite visibility to be optimal until 14:00, so we had more than five hours to run our tests. Under the surprised and watchful eyes of a tourist group, we installed a base station at the end of the ski run. We placed one of our two 12-channel, dual-frequency, carrier-phase GPS receivers on a tripod over a known survey marker, with the second unit to serve as our rover. Because real-time information would not significantly enhance our results, we simply set the equipment to record raw data for postprocessing. We were a little anxious using such high-precision instruments, as they were designed for typical surveying tasks and certainly not for this kind of fast-paced, somewhat hazardous navigation-related fieldwork. We nonetheless forged ahead.

To avoid any unnecessary risks to man or machine (particularly because the receivers weren't insured), Olivier did all of the skiing. We planned to do the tests in kinematic mode with a five-minute static initialisation. I stayed at the base station, maintaining radio contact with Olivier. A bad surprise came, though, when we noticed our radios were too powerful and disturbed the GPS signal reception, forcing us to reinitialise the GPS equipment after each contact. We therefore stopped all communications during runs, happy to have immediately noticed this drawback.

Computing the Course. Because data transfer to the laptop computer proved too slow, we were not able to check our results between runs. This simply added to the suspense as I watched Olivier travel down the course and (thankfully) arrive safely each time. We completed six runs, packed up our gear, and returned home, anxious to analyse the data we hoped we had collected.

Back at the office, we processed all the data, waiting impatiently for our first results. Unfortunately, only two of the six sessions had complete data sets, forcing us to more closely analyse the files. It came to the fore that the course's North orientation played a more important role than we expected. If we could lock onto seven GPS satellites at the top of the course, this optimal constellation degraded to three in the middle of the run, a situation known to cause problems computing accurate positions.

This strong visibility dependency left us a little dubious about the feasibility of this project. How could we develop and promote a new analysis tool, if it depends so heavily on time and place? The answer came in January 1999, when the Geodetic Laboratory acquired three GPS–GLONASS receivers. Because the Russian satellites are located more in the North, these units fulfilled our needs perfectly — the show could go on!

annual competition on the famous "Piste de l'Ours" of Veysonnaz. The course was designated for Super-G runs, which are commonly described as technical downhill courses, as they have several turns that slow the skier down to a mean of 80 kilometres per hour, compared with the 120–130 kilometres per hour for pure downhill runs. Timing would be provided by the professional Veysonnaz Timing Organisation, which would help us fix the run's GPS endpoint. Although the start of the course is easy to determine, the end does not correspond with where the skier stops and is therefore more difficult to localise. Precise finish-line coordinates added to the total time of the run would allow us to calculate that point.

One Sunday in Savièse

Savièse is a small village in Valais, not far from Sion but located on the opposite side of the valley from Veysonnaz and almost lost among the vineyards. As you certainly guessed, the area's speciality comes from white grapes, in particular the one called *Fendant*, which produces a savoury wine of the same registered appellation. Most people, however, still probably wouldn't have heard of this delightful area if it didn't have a ski club that is very competitive on the national level.

After numerous faxes and phone calls, the Ski Club Savièse agreed to participate in our tests during their

The VIP SA society, responsible for and proprietor of the Savièse skiing domain, offered us daily passes to access the entire facility during our tests. Naturally, as such great events always take place on Sundays, we were grateful that the satellites wouldn't be taking the day off when we needed them.

Professional Participants. That's how we found ourselves on 7 March 1999 at 2,100 metres, enjoying a nice sunny, snowy landscape. The competition or-

On you mark . . . get set . . . Corinne Héritier waits in the Veysonnaz starting block, carrying the backpack-based GPS equipment (above).

The team (left to right) — Vincent, Quentin, Simon, and Jan — take a quick photo break next to the base station at Montana.

Temperatures around –15 °C and winds at 85 kilometres per hour were not optimal conditions for the batteries, computer displays, or test participants (above).

The GPS–GLONASS reference station in front of the famous "Tipi-Bar" of Veysonnaz (right). The team attached a plastic plate just below the antenna to help mitigate multipath.

ganisers and participants were in a good mood, asking a lot of questions about the strange instruments we were using. We planned tests with six skiers, each one making three chronometred runs, if possible, at three different speeds. For security and the benefit of the skiers, we reminded the skiers no competition results were expected — they needn't take any risks for our purposes, nor should they feel compelled to ski aggressively (and risk damaging the equipment or themselves) to beat another skier's time.

Two skiers each carried a GPS–GLONASS, L1 receiver in a backpack, with a triaxial accelerometer attached with a Velcro belt near the base of the spinal column. The antenna was fixed on top of a rigid metal bar, interdependent with the backpack. This time, we placed the reference station in the middle of a small meadow, under the surveillance of local Indians that had installed their "Tipi-Bar" right on the course (and who also happened to be friends of mine).

All participants conducted the sessions very professionally, but unfortunately, once again, we had neglected a human parameter that caused the tests to last much longer than expected. The large number of tourists prevented us from using an intermediate ski-lift station, so we had to wait 30 minutes between two runs. Fortunately, mulled wine helped us to keep a reasonable body temperature and to exchange a few anecdotes.

Power Problems. The number one problem with fieldwork such as this, in the cold and snow, is the receivers' power supply. We brought enough batteries for the rovers and had expected three car batteries to be enough for the base station. In standard conditions, one can typically collect data for seven hours with one such unit. In the conditions we faced, we just reached five hours with the three batteries.

We computed the results using smoothed differential code algorithms. This gave positions with a sub-decimetre accuracy. We computed speed using the Doppler measurements obtained from the satellite receivers and compared those data with the measurements obtained by differentiating two positions. These two sets matched perfectly, which proved the high accuracy of our position data. In addition, according to preliminary tests and literature, the speed precision we get is of the order of a few centimetres per second.

Analysing our raw data revealed that had we used only GPS during these tests, half of the runs would have been useless. Of 15 runs, 13 showed results based on complete data, with the two lost runs having only two visible satellites during more than half of the course.

Accelerometry gave us complementary information about the propulsion force at the start of the run, the aerial phase proportion (jumps) during the whole run, and a personal signature for each gate passage. Despite the fact that gates are very close to one another on this type of course, our high-accuracy results allowed us to easily distinguish between the different skiers and thereby analyse performance on the slalom runs.

Too Fast to Track? We of course dream of some day also analysing pure downhill skiing, which achieves velocities greater than 120 kilometres per hour, but we were already encountering problems with the slalom ski speeds. Because the receivers had a sampling frequency of 1 Hz, polynomial interpolation was done to get the trajectory between epochs. We realised that because of the relatively high speeds achieved during Super-G competitions, we would need receivers with 5–20-Hz sampling rates to continue the project and provide useful results. Unfortunately, no such units were yet on the market.

Our antenna also proved a major concern as we analysed this second set of fieldwork. The lack of ergonomics together with the antenna's heavy weight forced the skier to adopt an unnatural style, on top of adding danger to an already dangerous sport. Our research wouldn't get very far using standard antennas, and although these devices were getting smaller and lighter, we needed to find something that was not only ergonomic but that we could attach to a skier's helmet, which can vary in design.

It was with this kind of preoccupations that spring came, bringing with it heat, flowers, and skis stored in the basement until the next season.

Off-Season Improvements

At this time, beginning of summer 1999, I saw the call for entries in the *GPS World* Seventh Annual Applications Contest. Feeling our project fit perfectly with all of the participation guidelines, I sent in the necessary documents. What a surprise when two months later I received an e-mail saying we were just awarded first place in this contest. This unexpected and welcome recognition allowed us to more vigorously pursue organisations that might be interested in our work, either to provide funding or add to our efforts.

One company we contacted, InMotion Technologies Ltd, has developed a product that superposes video data from two different skiers running the same course, enabling one to visually determine where one competitor performed better than another. Satellite-based continuous velocity and trajectory data are complementary information that can also be graphically integrated into the image to facilitate additional analyses, all viewable from the comfort of a living-room couch. Enthusiastic about the possibilities a joint effort held, we immediately joined forces to further pursue the project.

Our good fortune continued when, in the middle of August, Patrick Lathion of GeoAstor A.G. informed us about a new 20-Hz GPS–GLONASS receiver. After a few conversations, we arranged to begin new tests in December using the equipment he offered to loan us. These particular devices offered not only the sampling rate we sought but also the opportunity to mount the antenna on the skier's helmet.

As luck would have it, two weeks before the foreseen date, I encountered Jean-Etienne Allet, alias Jeanjean, an old university friend now working for a television station. Over an excellent ristretto (strong Italian coffee, very appreciated by the author), we caught up on the past years, including a detailed description of our GNSS skiing project. When I mentioned this, Jeanjean quickly proclaimed "What a wonderful scoop!" Suddenly, I found myself proudly announcing to the project team that our next trials, this time in Montana (Switzerland), would be covered by a television crew.

Gearing Up. After our experiences during the first two trials, we decided to leave nothing to chance. Each participant carried a radio. We opted for pen-pad computers over standard laptops, as they were much more suitable for outdoor conditions. All batteries were lithium, brought in quantities three times greater than for normal applications. We placed the digital video camera that recorded images for InMotion Technologies on a heavy tripod to ensure stability, with one team member remaining with the equipment throughout the trials to initiate recording and deal with any unforeseen problems. We also brought along two high-precision, dual-frequency, 5-Hz GPS receivers to determine the coordinates of each gate along the runs. The van that left that Friday morning from EPFL definitely didn't look like a Ferrari, but all the equipment it contained could certainly have been sold to obtain one!

Vincent determines gate coordinates on the course at Montana.

Combining the practical with the pleasant, I spent the weekend in Sion, finalising some aspects of the fieldwork and visiting my family. During the afternoon, I met Patrick. He gave me the two coveted receivers and all necessary explanations about the different software I'd have to use. To cover all the necessary details, we ended up completing this short demonstration in the middle of an athletics track, under the lights of his car.

Conquering the Next Challenge

The weekend passed very quickly between kinematic proofs and postprocessing treatments in order to master this new equipment. Finally, Monday arrived with a beautiful starlit sky. The appointment was fixed with the television reporter at 7:00 at the studio. After a nice cup of lavazza (more famous Italian coffee), we left for Montana at 7:30 to join the rest of the team. We had decided not to use the Veysonnaz station this time because of the Montana course's south orientation and consequent improved satellite visibility.

Looking a bit more like an alien than a skier, Simon maneuvers about as he prepares for his run (above).

Furthermore, the existence of a permanent slalom track at Montana reduced the preparation and the mobilisation of people. This particular course is open the entire season and offers digital timing of each person's slalom run. Obtaining a chronometred ticketed for each run would greatly facilitate our efforts. The staff of the Grand Signal cable car, which would haul us and our gear to the top of the mountain, had been informed about our work. With high spirits, they helped us carry our materials to the cars.

Once at the top, we remained silent for a moment, enjoying the impressive view of the snowy Alps. As we stand here in admiration, let me present the members of this expedition. Vincent Gabaglio is a Ph.D. student at the EPFL Geodetic Laboratory. Dr. Jan Skaloud is a research scientist graduated from the University of Calgary (Alberta, Canada), where he also became a professional skier. Simon Grünig is ending his master of science studies at EPFL with thesis work addressing the use of a coupled satellite–accelerometric signal to measure ski runs. Philippe Terrier is a Ph.D. student in physiology at the University of Lausanne. And Jeanjean, of course, is our TV reporter of the day. A quick look to the thermometer indicated –15°C, not too bad. Little did we know, we had much bigger surprises ahead.

Ready, Set, Wait. The start of the slalom was located at about 500 metres from the cable car station, on a prominence well exposed to the wind. At 11:00, we were set to start the runs, with our base station in place and all participants ready to go. Unfortunately, we hadn't counted on the *bise*, that cold north wind that brings a nice open sky but at the same time, arctic temperatures. The gusts reached more than 85 kilometres per hour, carrying away GPS receiver boxes and the video camera, which Philippe thankfully saved after a spectacular run through the snow. All computer displays froze, and with a visibility approaching zero, we feared the worst. After about half an hour, miraculously, the wind suddenly stopped, giving way to a welcome sun.

Once equipment and men had warmed up, we began our tests. Simon put on the antenna-helmet and the triaxial accelerometer, while I programmed the base and rover receivers. Both had an internal flash memory of 16 MB, so if we recorded raw data at 10 Hz, with nine GPS and five GLONASS satellites, we could obtain a maximum of 30 minutes of data. Downloading the data on the pen pad being hazardous in such conditions, we decided to start both the base and the rover before each run, instead of continuous recording, to save as much memory as possible.

Let the Competition Begin. While Philippe recorded video of each slalom for the postprocessed superposition of images done by InMotion Technologies Ltd, Jeanjean watched for every spectacular shot that would be part of his nonconventional reporting. Our tests also allowed us to analyse several different skiing styles, after Simon, Jan, and Vincent competed in the first "Montana GPS–GLONASS Challenge."

This time, the temperature affected the video cameras' batteries more than those in the receivers. These light, portable units needed to be warmed up between shots, whereas only one car battery, isolated from snow, was necessary for the base station.

Again, all ski runs happened without incident, even if the sportsmen in us made the competition highly disputed. We also intrigued many skiers with these strange-looking people that would be presented on Swiss television as a "new kind of Martian" — the cold had caused some ice to form on the camera lens adding quite an artistic touch to the TV camera's shots of our tests.

The Data Process. We had determined the gate coordinates using the dual-frequency receivers' stop-and-go mode, placing the base station antenna for positioning the gates on the same tripod we used for the runs. We then performed a three-minute static initialisation and used a sampling frequency of 0.2 Hz, staying at each location for 30 seconds. Previous studies had shown that would produce the centimetre-level accuracies we desired.

We processed all data twice. The first time, we used the commercial software provided with the receivers. We then employed a Matlab-based program Simon developed that takes RINEX-formatted measurements as input. Positions are obtained using smoothed code algorithms and speeds by Doppler observable. By using both methods, we aimed to verify the precision of Simon's program, which was designed specifically to more easily achieve accurate and reliable results for this type of project. Our results were very encouraging. We found the difference between the two postprocessing methods to be at most a decimetre. We solved all ambiguities for each slalom, producing positions accurate to one centimetre, as we had hoped. The speed, measured again by Doppler, offered centimetre-per-second precision. These results are very promising, particularly with ambiguity resolution for such applications always proving more delicate than differential GPS.

We then exported all these computed coordinates to the Matlab software, in which analyses are easier to execute. We compared trajectories and speeds along the runs using a 10-Hz data rate. We studied the results directly in World Geodetic System of 1984 (WGS 84), rather than change the ellipsoid or projection to a local one. This choice stemmed from the fact that once the ambiguities are solved for each satellite, coordinate precision cannot be improved in this particular application, even if one used a DTM to revise altimetry.

Analysis and Assessment. Additional analyses revealed that the tridimensional accelerometrical signal, once filtered, shows features that can be directly connected to its movements through the use of the synchronised video sequences. This further enabled us to analyse the different skiers' performance. (For those curious about the Montana Challenge outcome, Jan passed the closest to the gates and made the fastest run!) As we had hoped, a plot of the lateral acceleration data reveals the course design (Figure 1) as well as the skier's technique passing gates (Figure 2). We could also analyse the skier's up-and-down movement around gates by viewing the vertical acceleration data (Figure 3).

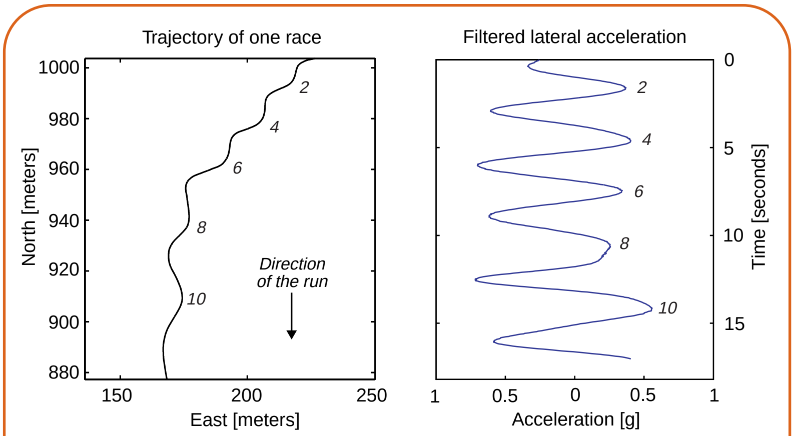

Figure 1. The lateral acceleration data from a skier reflects quite well the design of the track.

As expected, the system's weak point remained the antenna. Although receiver miniaturisation is no more a problem, finding a profiled antenna that can be easily adapted to different helmets remains difficult. To help us develop such a dream antenna, we have contacted various laboratories within EPFL, presenting us all with an interesting multidisciplinary challenge. We of course also welcome any outside input or collaboration relative to this effort.

We presented our results to professional skiers, showing the numerous parameters we were able to compute and how they can be used as a new training methodology (see Figure 4). We received a response resounding with even more enthusiasm than our initial contacts had generated. Our most recent tests at Montana, during the international downhill competition called the Trophee du Mont Lachaux, proved that even at high speed (a measured maximum of 126 kilometres per hour) and over quite long distances (6.2 kilometres), satellite positioning technologies can still provide accurate information. At present, research is focusing on dead-reckoning techniques to maintain the positioning data stream even when satellite lock is lost. In addition, we continue to integrate and synchronise all of this information with the video images we obtained.

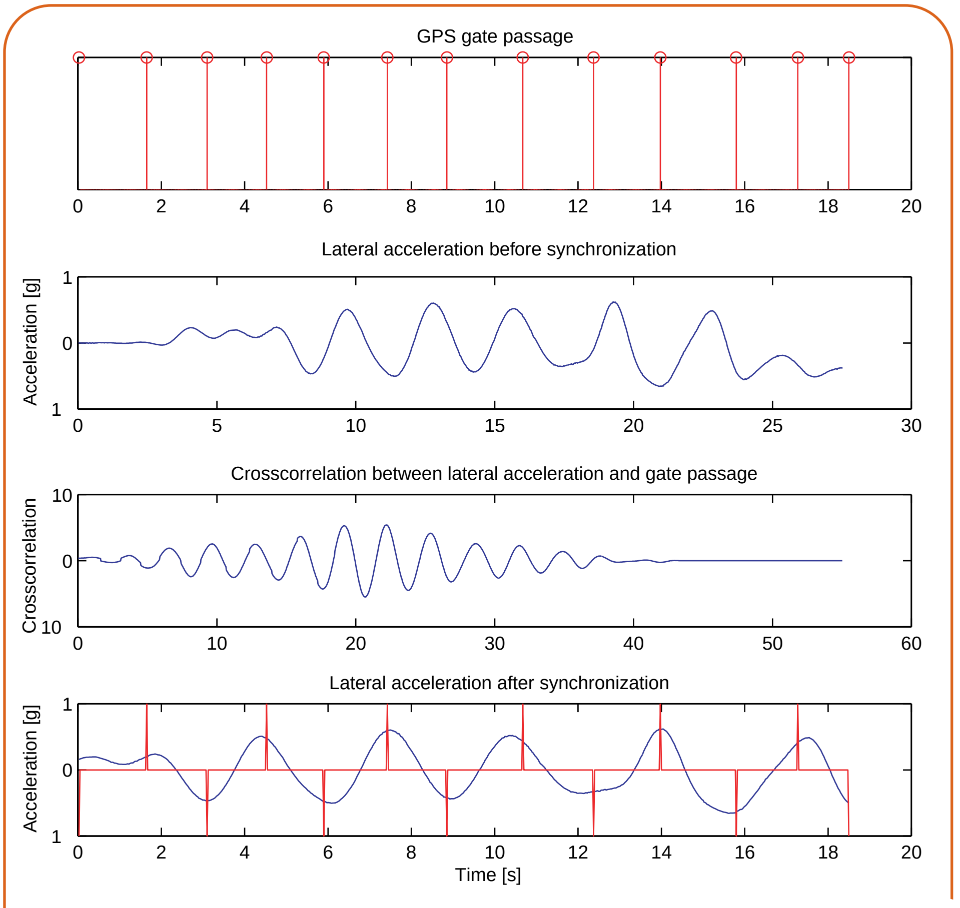

Figure 2. Lateral acceleration serves as a good indicator of a skier's gate-passing technique. The bottom graph shows that, for right turns, the maximal acceleration tends to be before the gate passage, whereas the opposite seems true for left turns.

Descending the Mountain

Of course, our adventures during the Montana fieldwork didn't end with the last skier's run, nor did the most important lesson we learned during our tests. By the time we had packed everything up, it was 14:00 and we were all very ready to hop in the cable car back to the station for a much-awaited lunch.

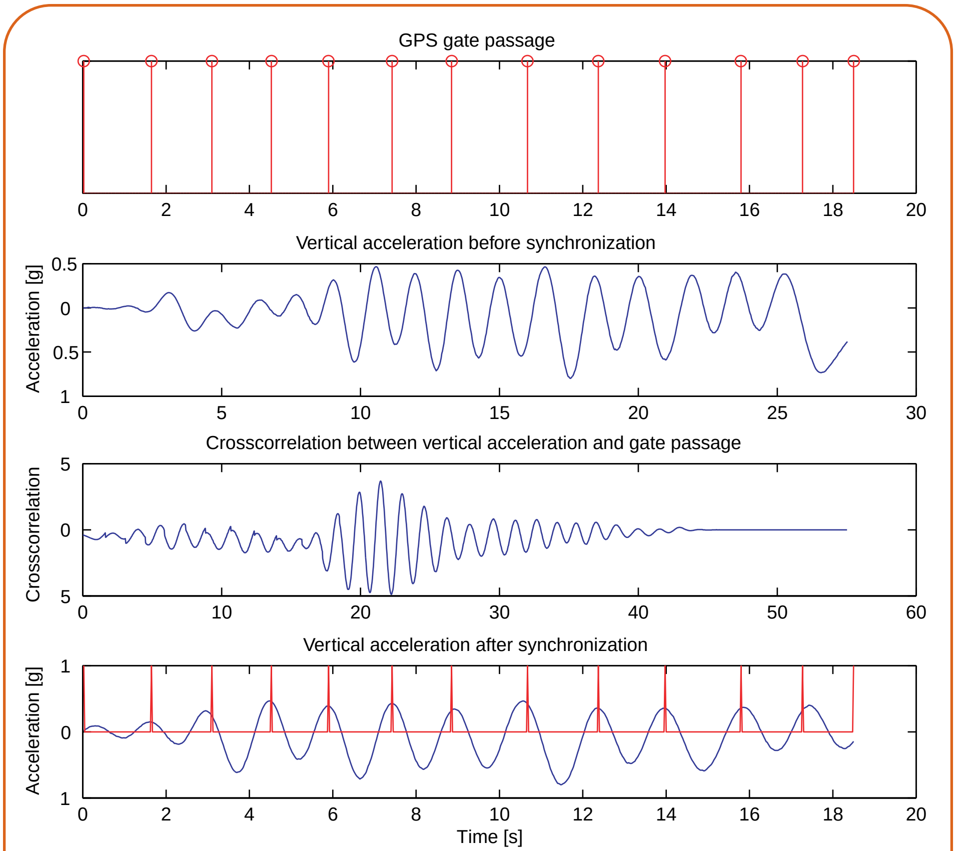

Figure 3. The vertical acceleration helps determine at which moment the skier bends down to pass a gate and when he or she stands up again. Coupling this information with InMotion Technologies's video shots provides a powerful and complete tool for run analysis.

Hardly had we reached the intermediate station with half of the material, when a short circuit, certainly caused by the cold , deprived the city of Montana of electricity. Immediately, the spare generator provided the necessary current to evacuate all people from the cable-car cabins, and simultaneously, the first half of the material to the main station. The problem now was how to pick up the other half. The spare power supply was quite limited, and no one could predict how long the outage would last. We had planned to return to the summit and retrieve the remaining equipment, but that was now out of the question.

Fortunately, the neighbouring ski domain of Montana–Crans still had a operating cable cars. Unfortunately, no more lifts would be made up to that run. It was already 15:30, and all operations stopped at 16:00. Philippe and Jeanjean were still at the top of the mountain, but on foot (no skis) and expecting us to return to help with the gear. We hoped everyone still had their radios switched on and hurriedly attempted to contact them. It was quite a relief when I heard him saying with a slow, suspenseful voice, "Hello! We're coming down right now on the blue cabin car . . . with all the material!" It was 16:30; they closed the installation just after their car arrived.

For the whole team, this would remain a wonderful, eventful day. It has shown us that even though such projects seem quite simple to realise, you'll always have to deal with unexpected situations. The Alps are very beautiful, but conditions can change so quickly that seemingly peaceful tests can rapidly turn into a reckless adventure.

We were all happy to be safely down the mountain, and even more pleased thinking about all of the high-quality data we had just collected. As we heaved a collective sigh of relief, we suddenly realised, we still hadn't had lunch! We decided to savour a local speciality — a Fondue aux Tomates. The exact recipe is kept secret; all we know is that the fondue's combination of mixed cheeses and tomato sauce spread on hot, flattened potatoes was only topped by the warm friendly ambience we enjoyed along with a nice bottle of Fendant.

InMotion Technologies's software synchronises separate video sequences of an event and displays them together, showing at each instance of the race the competitors' relative positions on a single integrated image.

Acknowledgments

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Manufacturers

For preliminary tests, the authors used two **Leica** (Heerbrugg, Switzerland) System 200 receivers and Leica Ski (Survey and Kinematic software) for post-

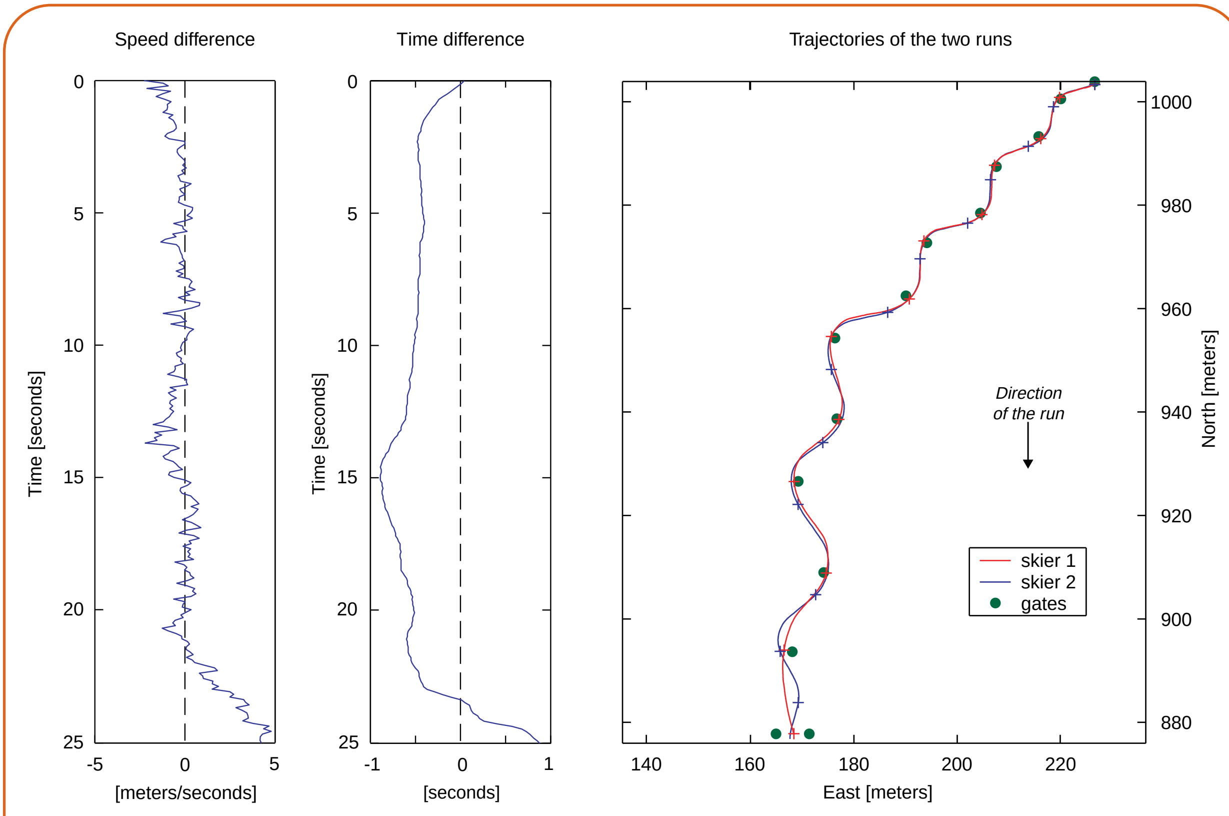

Figure 4. This continuous analysis of two runs shows, on the left, the speed difference between the two skiers. The centre plot shows the time-delay evolution of one competitor over the other during the whole run. Identical positions for time comparison are obtained after projecting one run on the other. The illustration on the right graphically shows positions for both skiers when skier one passes the gates. These graphs clearly show that skier two lead the majority of the race and lost his advance in the last few seconds.

processing. Tests in Veysonnaz were conducted using **Magellan** (Santa Clara, California) Ashtech GG RTK receivers and AOS (Ashtech Open Survey) data processing software. They computed the digital terrain module using Microstation Site Works from **Bentley Systems, Incorporated** (Exton, Pennsylvania). The tests in Montana involved Legacy GPS–GLONASS receivers manufactured by **Javad Positioning Systems** (JPS, San Jose, California) and Legant antennas as well as Leica System 500 receivers. Data were processed using JPS Pinnacle software and Leica's SkiPro program. They also used **Fujitsu** Pen-Pad computers and a **Physilog** triaxial accelerometer. All analyses were done using **Matlab** software.

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