# Using the MicroBlaze Processor to Develop Speed Sensors for F1 Racing Cars

## CEA Leti Minatec, Michelin, and EASii IC developed an accurate and real-time optical sensor prototype that calculates both speed and slip angle.

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Understanding the dynamic behavior of cars, in particular two-dimensional horizontal speed parameters (also known as the car's slip angle), is critical to optimize performance during races and improve essential equipment like tires.

You can estimate horizontal speed parameters through indirect modeling of wheel speed and yaw-angle measurements; however, this method suffers from modelling errors and other uncertainties. Some optical sensors give measurements that are, in practice, not reliable in wet conditions.

We set out to develop a compact and real-time sensor that could deliver a direct slip-angle measurement with high accuracy and flexibility in various conditions (dry, wet, humid, or snowy). In this article, we'll describe how the Xilinx® Virtex™ FPGA family, with its embedded MicroBlaze™ processors, helped us achieve our goal.

### Sensor Measurement Principles

A laser velocimeter is commonly used for taking speed measurements in the printing and textile industries. The velocimeter takes laser images of the surface and uses an autocorrelation function to compute accurate speed estimates.

We extended this approach to measure both longitudinal and transversal speed components. For our sensor, two laser diodes emit elliptical beam shapes to illuminate the road. The first front laser beam runs parallel to the longitudinal axis of the car, while the second back laser beam measures orthogonally. Two linear photodiode arrays collect the reflected light beams on the ground.

A pixel from the front photodiode array is compared to all pixels on the back photodiode array. The back pixels provide information about slip angle or transversal speed, while a corresponding time delay gives longitudinal speed estimation. Figure 1 illustrates the general optical configuration of the sensor.

We then developed an additional functionality to our sensor. Because of the laser beam shape, we inserted a standard triangulation process to measure ground height variation beneath the car. This parameter is useful for understanding the behavior of the vehicle and also improves overall system accuracy.

Finally, we developed an innovative process to avoid optical disturbances. In wet conditions, random spurious reflections disturb systems locally and corrupt the calculation of correlations. Our solution is two-fold: inclining the laser beams at a specific angle and using preprocessing to split the optical signals. We successfully tested our sensor in real time in various conditions.

## Embedded Intelligence

During the development of our sensor, we designed and validated the signal processing algorithms using a reconfigurable FPGA. Unlike other targets such as DSPs or ASICs, an FPGA allowed us to adapt routines and software architecture depending on test results and evolving specifications.

### Software Architecture

Figure 2 shows the main architecture of the sensor as proposed by Leti, the research laboratory in charge of this project. Three processes run concurrently:

- The height process calculates ground height variations.
- The speed process computes longitudinal speed and slip angle from correlations and height estimations of the car.
- The output process sends sequential outputs on a high-speed, CAN-standard automotive bus system.

These processes share variables through memory access.

Figure 2 includes some key points marked with circles. As in the example previously mentioned, signal chopping improved our ability to take measurements in wet conditions. Still other developments are essential to provide accurate measurements:

- Sampling frequency is the constant parameter that ensures accurate measurements. We controlled the acquisition frequency of diodes so that the ground sampling remained constant during vehicle displacement. A control loop adjusted the sampling frequency according to the speed estimation and prediction, part of the speed process previously described.

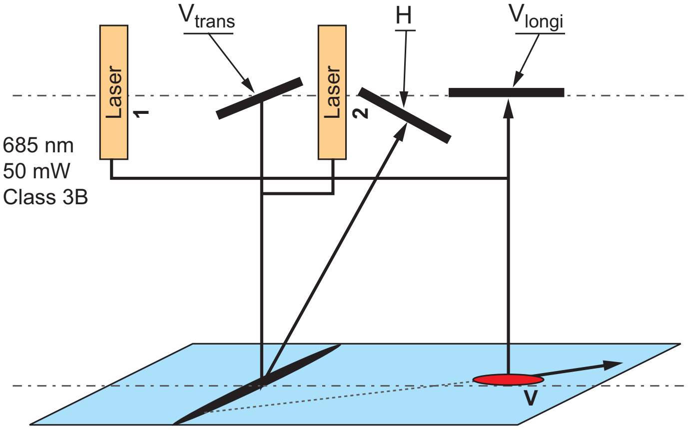

*Figure 1 – General optical configuration of a laser speed sensor. Three photodiodes arrays measure longitudinal speed, height measurement, and transversal speed*

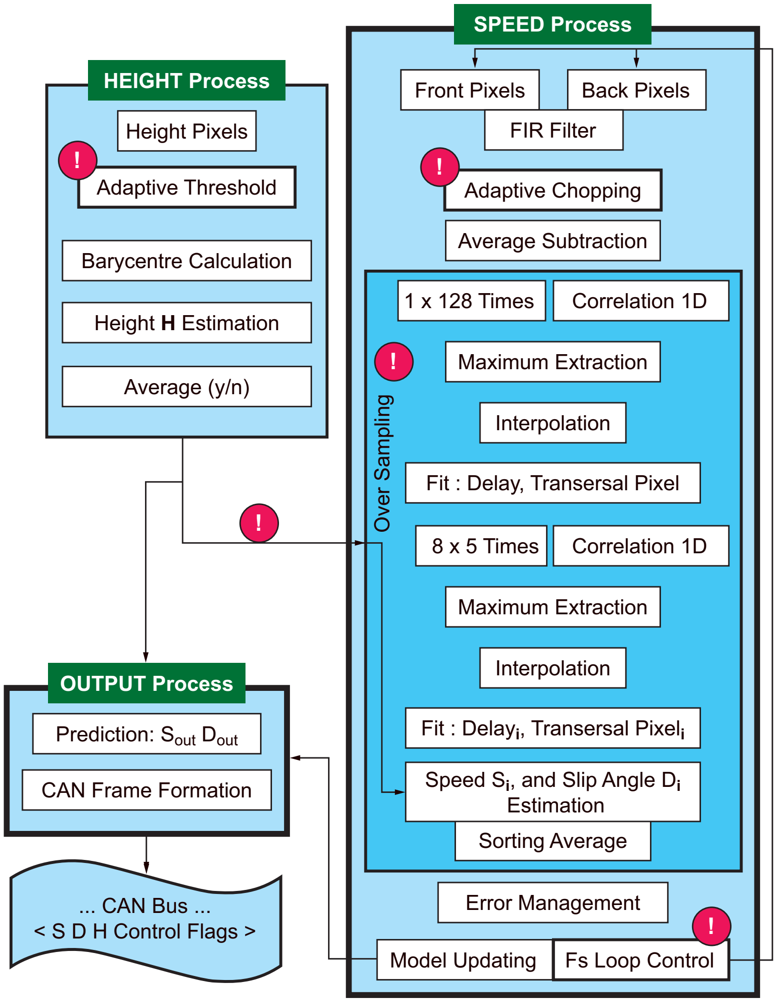

*Figure 2 – Main software architecture with key points*

We wanted a programmable embedded target that offered the possibility to accelerate software run times, used reconfigurable parameters, and facilitated evolutions of the algorithm.

- Oversampling of ground signals improved measurement accuracy, particularly for the high speeds (above 190 kilometers per hour) of F1 racing cars. At these frequencies, we encountered a technological ceiling of photodiode array integration time. Therefore, we averaged several slightly shifted measurements to improve accuracy (similar to when using very fast oscilloscopes).

  This routine additionally offered a critical way to evaluate the quality of sensor measurements. If all calculations matched, we could confidently believe in the accuracy of the measurement.

- Taking into account height estimation when calculating speed improves measurement quality; we used the car's ground height variation to refine optical parameters and added a suitable threshold to the signal to avoid sun perturbations on height calculation.

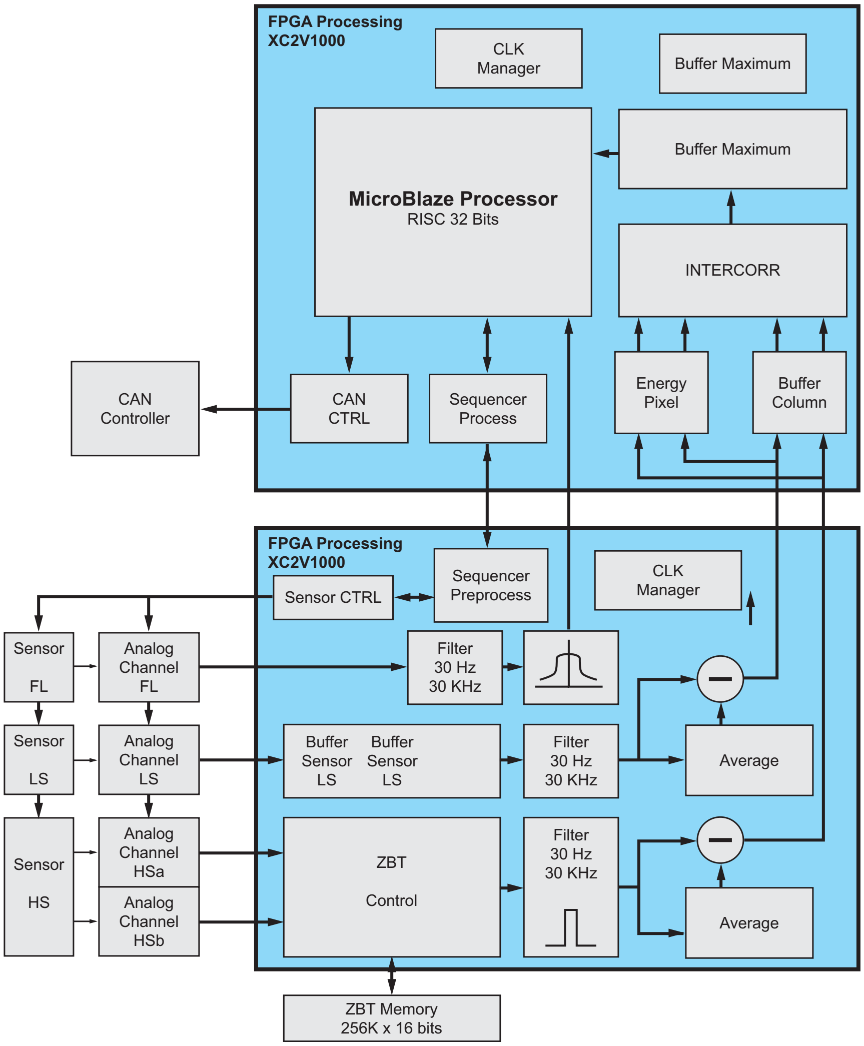

*Figure 3 – Main software architecture with four analog inputs, digital-to-analog converter timing, memory storage, calculations, timing, and output control*

Other smaller processes run in parallel. For example, a specific algorithm evaluates whether speed is equal to zero and communicates that the car is stopped.

### Hardware Architecture

We wanted a programmable embedded target that offered the possibility to accelerate software run times, used reconfigurable parameters, and facilitated evolutions of the algorithm. An FPGA had all of these features, as well as offering the potential to parallelize correlation calculations.

We used two FPGAs from the Virtex device family: one devoted to preprocessing (sensor control, digital-to-analog converter, memory, filters, averages, height processes) and one focused on the main processing.

We added a MicroBlaze embedded processor inside the second FPGA to implement our high-level algorithm. It includes mainly conditional instructions, with few mathematical calculations. Using this processor allowed us to apply mathematical functions (like trigonometric functions, for example). The soft-core processor is also more user-friendly (based on C language) and facilitates debugging.

Figure 3 shows the architecture as proposed by EASii IC, the company in charge of hardware realization.

### Component Choice

The sensor must operate through the severe conditions of F1 racing cars, which include low weights, reduced size, high vibrations, and high accelerations. We used both DC/DC converters and low dropout regulators to avoid major perturbations from the car's power supply.

The output is transmitted over a high-speed automotive CAN bus, thanks to an SJA1000 chip manufactured by NXP

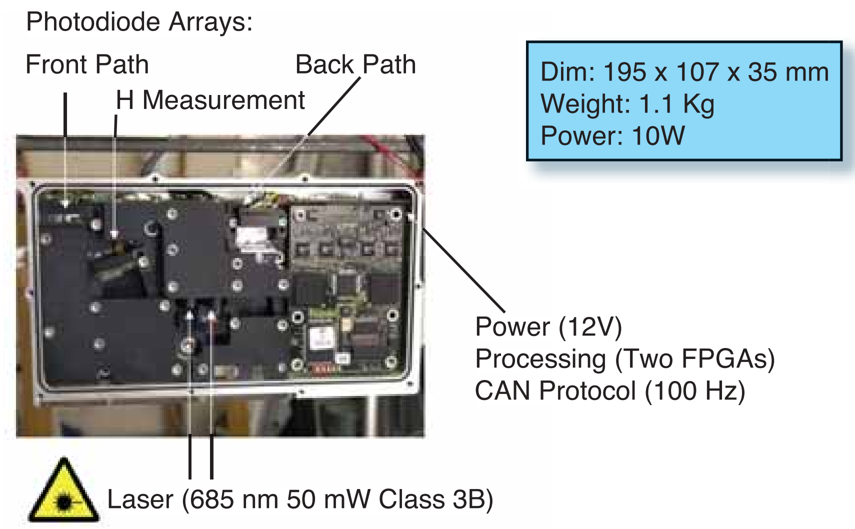

*Figure 4 – Sensor photography and main parameters*

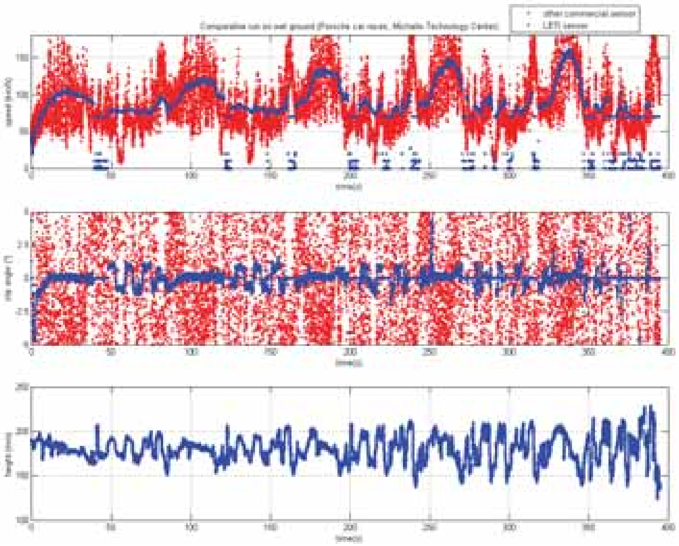

*Figure 5 – Comparative result on wet surfaces (LETI sensor in blue, other commercial sensor in red) showing speed (top), slip angle (middle), and height output (bottom)*

Semiconductors. To improve the heat transfer of the most consuming components (such as the analog-to-digital converter), we added a thermal paste, which facilitated thermal exchanges with the metal packaging. Additionally, a thermal sensor gives the temperature of the sensor to prevent overheating.

To avoid connection failure and stress breakdowns, we added glue to the largest electronic modules. Most of the basic components of our system are off-the-shelf, which means that further optimization is possible if we applied our system to a specific design. The total power consumption of the sensor is ~10W. The total size (195 mm x 107 mm x 35 mm, including both electronic and optical elements) facilitates rapid mounting on the car, either on the keel for racing cars or anywhere on the chassis.

## Performance

We set up and calibrated our prototype at the Michelin Technology Centre, our partner in this project and the eventual end user of the sensor. They have a dedicated tool for simulating high-speed and slip-angle variations. The sensor is designed to work with velocities from 2 to 400 kilometers per hour and can calculate slip angles from -10° to +10°. We reported relative errors of 0.5% on speed, 0.3 mm on ground height variation, and less than 0.1° on slip angle.

We have conducted more than 50 trials since 2003 at the Michelin Technology Centre and with F1 partner teams. These measurements allowed us to significantly improve sensor performance and validate its use under a wide variety of conditions.

Figure 4 presents experimental results in wet conditions. Outputs of the other commercial speed sensor are irrelevant because it was very disturbed by the behavior of water on asphalt. Our prototype presents more robustness; F1 car experts consider these results fully functional.

## Conclusion

Various experiments have shown that our prototype addresses the accuracy and robustness necessary for F1 race cars. We assume that these results show the engineering maturity of our sensor, especially with its innovative ability to operate on wet surfaces – a key challenge for non-contact speed sensors.

The simplicity of the global architecture (which includes electronic devices as well as optical parts) makes us confident that our optical speed sensor prototype could be implemented at a low cost. We have already studied a new hardware design that fully exploits the available space between optical elements, reducing package volume by a third.

Future works may include an image sensor to simplify the optical part and fusion with other data (such as accelerometer measurements) to enhance sensor functionalities.

For more information, visit Leti (*www-leti.cea.fr*) or EASii IC (*www.easii-ic.com*) or e-mail *viviane.cattin@cea.fr.*

*We wish to acknowledge Sébastien Dauvé, Bruno Flament, William Foucault, Jean-Michel Ittel, Philipe Peltié, and Jean-Charles Vidal from Leti research laboratories and Jean-Baptiste Monnard from EASii IC for their contributions to this project.*