Fast prototyping platform for navigation systems with sensors fusion

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***Abstract*—The increasing demand for robust and precise navigation systems has brought-up new sensor fusion algorithms that improve system performance of such systems. However, these algorithms present two challenges: they are computation-intensive and require hybrid but tightly coupled processing resources. In this paper, we present a flexible fast prototyping platform for navigation systems with advanced sensors fusion. The platform is a complete hardware/software framework including FPGA hardware accelerators for some compute intensive parts of image and GNSS signal processing. It can be used by system designers to implement and test advanced, tightly coupled sensor fusion algorithms in representative environments while fully respecting real-time.**

keywords: sensor fusion, embedded vision, fast prototyping, geolocalization

I. Introduction

Geolocalization has become a major issue in safety for means and people, requiring precise and reliable localization from the positioning system in order to guarantee the safety and the quality of service defined by the regulations.

Modern positioning systems tend to use a combination of sensors, exploiting complementary measurements in order to improve the performance and robustness of positioning. Each sensor has its strengths and weaknesses in terms of sensing with respect to the environmental conditions and the targeted application. Building a specific real-time compatible prototype is costly and in addition thigh sensor fusion development requires to have access to the whole processing chain, even low level hardware functions. Combined to constraints on the form-factor for applications such as on drones or robots, this motivated the study of a unified, embedded prototyping platform for navigation systems with advanced sensor fusion.

The contributions of this paper are the definition of a SW and HW platform that can host multiple sensors (camera, GNSS, IMU, etc...) and real-time implementations of the related signal processing.

II. Functional requirements for the prototyping platform

Designing a flexible yet compact prototyping platform relies on a thorough requirements analysis of the different sensor applications that might be implemented by the navigation system on the platform. It turned out that 3 main categories dimension the platform: Vision, GNSS and sensor fusion.

The use of embedded cameras opens new opportunities for localization and scene perception based services. We analysed a monocular SLAM (Simultaneous Localization And Mapping) function [1] which is representative of complex vision-based localization algorithms. The analysis of the SLAM, the GNSS and the fusion functions was conducted according to the benchmarking methodology developed at CEA. It allows to extract the functional decomposition of the algorithm, the distribution of the execution time between the functions, and the hotspots of the application.

This allowed to identify processing intensive, regular parts that can take benefit of HW acceleration like Point Of Interest (POI) tracking and GNSS signal processing. The remaining parts are more irregular and of varying complexity over execution time. It is recommended to keep them on superscalar processor since they include floating point calculations and hardly parallelizable parts of the code.

On top of the sensors directly integrated on the prototype a flexible set of serial interfaces shall allow experimentation with different sensor configurations. Finally, the platform should be able to store long datasets locally in order to record of test scenarios. For tightly-coupled sensor fusion approaches, low-latency communication of the results between the sensor processing parts is crucial.

III. MIMOSA fast-prototyping platform

Based on the identified requirements, we developed the MIMOSA fast-prototyping platform for navigation systems with sensor fusion. The platform is designed for prototyping and exploration of algorithms based on inputs such as cameras, GNSS, and inertial sensors. It provides many interfaces and powerful hardware and software resources to ease the prototyping and exploration of sensor fusion algorithms.

In the following subsections, we present the hardware, software and the IPs that constitute the MIMOSA platform.

A. Hardware description

The MIMOSA hardware platform, shown in Figure 1, includes computing and storage resources, interconnection links

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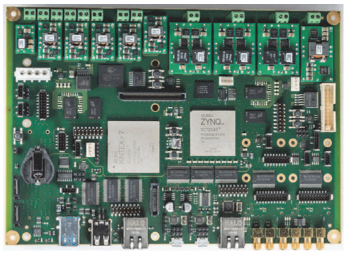

Figure 1. MIMOSA board overview

and several peripherals and sensors (see Figure 2). Cameras can be connected on standard interfaces (Ethernet/USB 3) while the GNSS functions require a analog front-end that is connected on specific ports of the platform. Some dedicated *PPSin/PPSout* links enable the synchronization of the clocks in case of redistribution to other related cards.

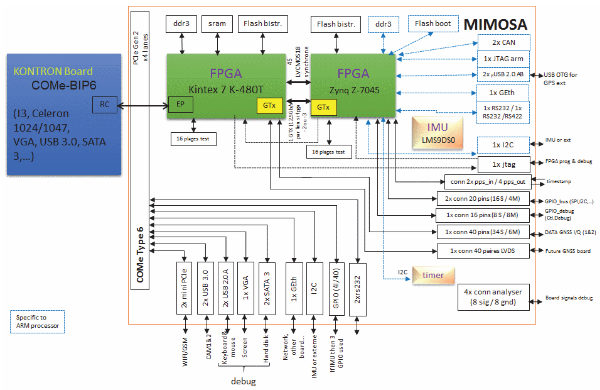

Figure 2. MIMOSA hardware architecture overview

The Xilinx family 7 has been chosen to allow the designers the possibility to automatically generate HW IPs from the software code for the FPGA using the HLS (High Level Synthesis) tool [2] from Xilinx.

B. Software description

The MIMOSA prototyping board is dedicated to sensor fusion algorithm developers that need to quickly test their software directly on the target hardware without handling the control complexity of the peripherals and sensors. Therefore, MIMOSA platform provides 2 levels of software support: low-level drivers for the peripherals (USB, GNSS receiver, IMU on I2C, onboard PCIe), and a high-level, multithreaded C/C++ software framework for application development.

The software framework can be configured in 3 modes: Acquisition mode, Replay mode or Live mode.

C. IP description

One of the added values of the platform is to enable real-time operation of HW accelerated sensor processing functions II thanks to FPGA resources. To exploit this possibility the platform provides an modular infrastructure (buses, interfaces, memories) and some generic functional IP to speed-up development. So far, we have developed a POI (Point of Interest) Tracker and a GNSS receiver.

The POI Tracker implements in hardware the POI detection, POI description and POI matching, accelerates by 10 the tracking phase compared to a SW implementation on PC. A latency of less then 15 ms can be reached for an VGA image while using only 15% of a Kintex 7480T.

The GNSS receiver IP is provided by M3Systems and is synthesized on the Zynq-7045 FPGA. It implements the digital part of the multiconstellation GNSS receiver using custom HW IPs and a soft CPU.

IV. Case study: Vision+Odometer fusion

MIMOSA platform can be used for various types of navigation systems using sensor fusion. As a simple example, we have used it for evaluating fusion of visual localization and odometer. In this configuration, we use the HW tracker (see section III-C) to accelerate the SLAM algorithm (Figure 3 shows the output trajectories compared to ground truth and a simple GNSS).

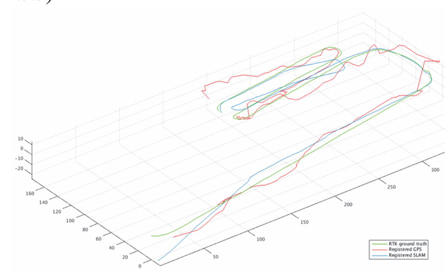

Figure 3. GNSS and SLAM+Odometer trajectories example [3]

In this configuration, thanks to the HW acceleration, the real-time constraints have been met without difficulty (30 fps) which is mandatory to maintain the continuity of the vision based localization.

V. Conclusion and Future Works

This paper has presented a fast prototyping platform for navigation systems with advanced sensors fusion. It includes a complete hardware, software, and FPGA framework allowing fast, real-time prototyping sensor fusion algorithms that take into account a large variety of sensors. In the future the framework will be extended by an additional offer of HW and SW IPs further extending its reach as a platform of choice for prototyping complex navigation applications.

Acknowledgment

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