Advanced image processing in space applications: the new trend to increase the success rate of exploration space missions

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I. Paper abstract

Video-based navigation (VBN) is a well-studied area of computer vision spanning several application fields including robotics, unmanned vehicles and avionics. VBN is also gaining importance in space exploration missions.
Target planets of exploration missions (i.e., Moon, Mars, Venus, etc.) are hard places to reach. In fact, for example, the success rate for actually landing on the Martian surface is very low, roughly 30 percent.
In the last years, all space agencies have increased their research efforts in order to enhance the success rate of exploration missions. In particular, a hot research topic is the guided landing on planets. Future space-missions will increasingly adopt VBN systems to assist the entry, descent and landing (EDL) phase of space modules (e.g., spacecrafts), enhancing the precision of automatic EDL navigation systems. For instance, in recent space exploration missions, e.g., Spirit, Opportunity, and Curiosity, the descending trajectory and the landing point were pre-computed and fixed, guaranteeing a maximum landing point precision of 20 km. The usage of a VBN system will allow to design an autonomously guided EDL system able to reduce the landing ellipse, guaranteeing to avoid the landing in dangerous area of the target planet surface (e.g., huge craters or big stones) that could lead to the mission failure.
Basically, a VBN system is made up of a camera, mounted on the spacecraft, a data handling module, which extracts information from images, and a controller for the spacecraft actuators, to change the descending trajectory relying on the extracted information.
The data handling module executes very computationally intensive image processing algorithms. Since the VBN system has real-time constraints, it must be able to compute these algorithms at high speed. A software implementation of the data handling tasks cannot reach the required performances, thus the emerging trend is to accelerate the image processing algorithms via hardware.
In space-applications, Field Programmable Gate Arrays (FPGAs) are increasingly replacing application specific integrated circuits (ASICs). They are highly versatile, featuring dedicated carry structures to support adders, accumulators and counters, and offer cheaper cost per logic gate.
The proposed paper aims at presenting an FPGA-based IP cores library for image processing. The IP-cores included in this library are tuned to reach high timing performance and low resources usage, that are two key-factors for space-applications.
Each proposed IP-core has: (i) a parametrizable design and (ii) a standardized I/O interface. This two characteristics allow designers to freely interconnect the different modules to create a completely custom image processing system, in terms of precision (i.e., internal data parallelism) and delivered functionalities.
The library is organized in four main categories. Each category groups IP-cores that perform similar functionalities. In particular, the proposed categories are:

- *Image enhancers*: the IP-cores included in this group aim at enhancing the quality of images in terms of contrast and brightness. The image enhancement can be achieved exploiting different algorithms. Two of the most used are: *Histogram Equalization* and *Histogram Stretching*. Three IP-cores are included in this category: the *Histogram Equalizer*, the *Histogram Stretcher* and *SAFE*. The last IP-core is a self-adaptive image enhancer that is able to autonomously select the best enhancement algorithm depending on the input image characteristics.
- *Image filters*: it incorporates three IP-cores for image noise removal: the *Gaussian Filter*, the *Median Filter*, and *AIDI*. *AIDI* is an adaptive filter, that is able to self-tune its filtering parameters by estimating the level of noise that affects the input image.
- *Features extractors*: it includes IP-cores able to extracts interesting features from an image (i.e., one of the fundamental tasks behind VBN), namely: *Harris extractor*, for corners identification, and *Cannie extractor*, for edges detection.
- *Features matchers*: it contains a *Correlation-based matcher* able to match the extracted features between two consecutive images. This information is very useful to evaluate the motion of the camera, in terms of speed and position.

In the paper, different image processing systems, build exploiting the aforementioned modules, will be presented. The

main goals of these paper are: (i) highlight the flexibility provided to the designer for the development of custom image-processing systems, and (ii) show the performances improvement, achieved by the proposed IP-cores, w.r.t. the actual state-of-the-art.