HDR-ARtiSt: a FPGA-based Smart Camera for
High Dynamic Range color video from multiple exposures

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Extended summary:
Standard cameras capture only a fraction of the information that is visible to the human eye. This is specifically true for natural scenes including areas of low and high illumination due to transitions between sunlit and shaded areas. When capturing such a scene, many cameras are unable to store the full Dynamic Range (DR) resulting in low quality video where details are concealed in shadows or washed out by sunlight. High Dynamic Range (HDR) imaging techniques appear as a solution to overcome this issue by encoding digital video with higher than standard 24-bit RGB format, and then increasing the range of luminance that can be stored. For example, HDR capturing techniques are essential for outdoor security applications in which unpredictable illumination changes may affect performance algorithms [1,2]. Similarly, HDR techniques should facilitate object tracking or automotive applications [3,4] under uncontrolled illumination. Recent research programs on machine vision have clearly demonstrated the benefits of real-time HDR vision [5,6]. Finally, medical applications require high precision images and HDR lighting techniques to improve the rendering quality of imaging systems [7,8].
There are two types of imaging systems that can be used to capture the entire dynamic of a scene: high dynamic range (HDR) sensors and standard sensors. The HDR sensors are, by design, able to capture a wide dynamic range with a single capture. However, these sensors are still under development and are not suitable for embedded and low cost applications. Another technique is to use a standard low dynamic range (LDR) sensor to capture the HDR data by recording multiple acquisitions of the same scene while varying the exposure time [9, 10]. By limiting the exposure time, the image loses low-light detail in exchange for improved details in areas of high illumination. A contrario, by increasing the exposure time, the resulting image contains the details in the dark areas but none of the details in the bright areas due to pixel saturation. Complex algorithms build a single HDR image (i.e. radiance map) that covers the full dynamic range by combining the details of the successive acquisitions. However, current display technology has a very limited dynamic range, so that HDR images need to be compressed by tone mapping operators in such a way that the visual sensation of the real scene is faithfully reproduced.
This paper is a general overview of the HDR-ARtiSt project, run at Le2i between 2010 and 2014. The main goal of the HDR-ARtiSt project was to build an embedded vision system dedicated to real-time HDR video. This HDR smart camera is built around a

standard off-the-shelf LDR (Low Dynamic Range) sensor and a XILINX Virtex FPGA board. It is able to produce a real-time HDR live video color stream by recording and combining multiple acquisitions of the same scene while varying the exposure time. This technique appears as one of the most appropriate and cheapest solution to enhance the dynamic range of real-life environments. HDR-ARtiSt embeds real-time multiple captures, HDR processing, data display and transfer of a HDR color video for a full sensor resolution (1280 × 1024 pixels) at 60 frames per second.
The main contributions of the HDR-ARtiSt project are:
(1) Multiple Exposure Control (MEC) dedicated to the smart image capture from the sensor with alternating different exposure times. The MEC evaluates dynamically the adequate exposure times from frame to frame using the histograms and the number of low-level and high-level saturated pixels of each captured frame. Exposure times are evaluated according the following principle: fewer than 10% of the pixels must be saturated at high-level for the short exposure time (respectively at low-level for the long exposure time). If too many pixels are saturated, the exposure time is decreased for the subsequent short exposure captures (respectively increased for the long exposures). Finally, the middle exposure time is linearly computed from the two other exposures.
(2) Multi-streaming Memory Management Unit (MMMU) dedicated to the memory read/write operations of the three parallel video streams, corresponding to the different exposure times. This MMMU continuously manages the storage of different frames, the oldest frame being systematically replaced with the new acquired frame. The MMMU is able to capture and store the current stream of pixels from the sensor, and delivers simultaneous different pixel streams previously stored to the HDR creating process. With such a memory management, we avoid waiting for the capturing of new successive frames before computing any new HDR data. Once the initialization is done, our system is synchronized with the sensor framerate and is able to produce a new HDR frame for each new capture.
(3) HDR creating by combining the video streams using a specific hardware version of the standard HDR Devebec's technique, and Global Tone Mapping (GTM) of the HDR scene for displaying on a standard LCD monitor.

This project has produced several releases of such a smart camera. All the versions of HDR-ARtiSt share a common FPGA-based architecture but differ in the techniques used for implementing the HDR algorithms. These versions have already been described in previous papers [11-14] but always in a rather separate manner.
The goal of this paper is to provide a global presentation of these separate releases and to provide a comparative assessment of the successive versions of the HDR-ARtiSt platform. It explains in particular why these versions, which share a common hardware architecture for implementing the HDR pipeline, differ significantly in the algorithmic techniques used for achieving a high quality HDR video flow. This paper focuses on the successive HDR-ARtiSt releases by making a comparative survey with other state-of-the-art HDR imaging solutions, according to a set of criteria (performance, complexity, quality). It also gives an account of the lessons we have learned, both when dealing with these implementation issues and when using the resulting HDR smart cameras in realistic visual scenes.
The final paper will be organized as follows. Section 2 is a brief recall of the HDR techniques based on multiple exposures. Section 3 details the common principles of the HDR-ARtiSt hardware architecture, highlighting the multi-streaming memory management unit designed to address the computation capacity and memory bandwidth

limitations. Section 4 presents the successive versions of HDR-ARtiSt and the criteria to asses them. Section 5 is a brief review of related work and Section 6 concludes this paper and outlines directions for future work.

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Biography

Dominique Ginhac received his Masters Degree in Engineering (1995) followed by a PhD in Computer Vision (1999) from the Blaise Pascal Univer- sity (France). He then joined the University of Burgundy as an assistant professor (2000) and became member of Le2i UMR CNRS 6306 (Laboratory of Electronic, Computing and Imaging Sciences). In 2009, he was promoted professor and became head of the electrical engineering department until 2011. He is currently a deputy director of the Le2i laboratory. His research activities were first in the field of rapid prototyping of real-time image processing on dedicated parallel architectures. More recently, he has developed an expertise in the field of image acquisition, hardware design of smart vision systems and implementation of real-time image processing applications.