Low-power Embedded System for Real-Time Correction of Fish-Eye Automotive Cameras

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***Abstract*— The design and the implementation of a flexible and cost-effective embedded system for real-time correction of fish-eye automotive cameras is presented. Nowadays many car manufacturers already introduced on-board video systems, equipped with fish-eye lens, to provide the driver a better view of the so-called blind zones. A fish-eye lens achieves a larger field of view (FOV) but, on the other hand, causes distortion, both radial and tangential, of the images projected on the image sensor. Since radial distortion is noticeable and dangerous, a real-time system for its correction is presented, whose low-power, low-cost and flexibility features are suitable for automotive applications.**

Keywords*— *Fish-eye camera, video automotive assistance systems, real-time image processing, distortion correction, radial distortion, fish-eye lens, blind zones.

I. Introduction and Review of State of the Art Fish-Eye Correction Systems

In last years the use of cameras for automotive application has increased a lot [1-3]. Nowadays many car manufacturers offer video systems on their vehicles to give to the driver a better view of the so-called "blind spots". Fish-eye lenses are commonly used for automotive applications, due to their large FOV but, on the other hand, they suffer of radial and tangential distortion. Since it is very important to give a correct view to the driver, adjustment is required for video captured by a camera equipped with a fish-eye lens. Correction of images affected by fish-eye effects has been treated in literature, but until nowadays existing solutions refer to off-line correction of a still picture with a software running on a PC. On the contrary, real-time processing is needed for automotive driver assistance. A low-power and low-cost implementing platform is also required for automotive applications characterized by large volume market and where power-efficiency is becoming a main issue. Few solutions have been proposed for real-time fish-eye correction. FPGA-based solutions have been announced by Altera [4] and Xylon [5]. Both technologies are based on volatile SRAM technology so an external non-volatile memory device is needed. Moreover these solutions implement just a fixed correction algorithm while, to adapt the solution to different types of lenses, cameras and displays, an higher level of flexibility is required. Another solution has been recently announced by Techwell [6]. More information about this solution are not available, but it is known that the system is based on proprietary and custom Intersil Image Signal Processor, specifically designed for Techwell surveillance devices, and this reduces its flexibility for other cameras with different correction requirements.

To overcome the above issues this paper presents a low-cost, flexible and real-time DSP solution for correcting video stream captured by cameras equipped with fish-eye lenses. The paper is focused on the implementation aspects while fish-eye lens theory and the used correction algorithms have been discussed and detailed in [7] and [8].

II. Fish-Eye Effect Correction

A fish-eye optic can easily reach an angular FOV wider than 180 degrees but causes image distortion effects: radial and tangential. The radial one is the most noticeable and so it is the bottleneck for the successful application of fish-eye cameras to automotive video systems. Several types of fish-eye lens exist, each differs from others for its mapping function, i.e. a mathematical formula that associates points of the image sensor to points of the scene. Let R_{fish} be the distance between the optical axis (the line that ideally goes from the center of the scene to the center of the image sensor, perpendicular to this) and the projected point on the image sensor, and let θ be the angle from a point on the scene and the optical axis. An example of mapping function is given by Eq. 1. The parameter f is the distance between the objective and the image sensor.

$$R_{fish} = 2f\sin\left(\frac{\theta}{2}\right) \qquad \text{(Eq. 1)}$$

Since the mapping function of a normal (without any distortion) lens is given by Eq. 2, it is possible to re-arrange pixels of the source distorted image to get a new target image without any noticeable distortion.

$$R_{norm} = f\tan(\theta) \qquad \text{(Eq. 2)}$$

Consider a blank image with the same resolution as the source, distorted, one. For every target pixel of the blank image (x_t, y_t) it is possible to compute the coordinates of the correct pixel (x_s, y_s) by reversing and re-arranging Eq. 1 and Eq. 2, and assuming that tangential distortion is negligible.

The results of this operation is showed in Eq. 3

$$x_s, y_s = \frac{2f\,x_t, y_t}{\sqrt{x_t^2 + y_t^2}}\sin\left[\frac{1}{2}\tan^{-1}\left(\frac{\sqrt{x_t^2 + y_t^2}}{f}\right)\right] \qquad \text{(Eq. 3)}$$

Further details about this method, called "back-mapping method", are given in [8].

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III. LOW-COST AND LOW-POWER EMBEDDED SYSTEM FOR REAL-TIME FISH-EYE CORRECTION

An affordable and cost-effective video correction system for automotive applications must have at least: flexibility to be adapted to several resolutions, different colour spaces and arbitrary lens (i.e. a given mapping function); low cost and low power consumption; computational performance enough for video processing up to 30 frames per second (fps). Since microcontroller solutions do not provide enough computing power and HDL coding on FPGA, once configured the device, does not allow the required flexibility, the solution has been based on a DSP computing core. A real-time software solution has been developed on the Spectrum Digital EVMDM642 evaluation board based on the Texas Instruments TMS320DM642 video and imaging fixed-point processor, 720 MHz version [9]. As introduced in previous section the back-mapping method is used to perform the real-time correction. First initialization step computes data needed for the remap operation and stores them in a Look-Up Table (LUT); this contains addresses of the source buffer in which are stored the right pixels to be taken for the remap; then the algorithm performs a real-time remapping (pixel by pixel) on every captured frame. The memory requirements can be easily faced by means of a small and affordable RAM module, for instance 32 Mb. No other memory module is required for the remap operations. The LUT is computed on start-up so there is no necessity to load it beforehand on RAM. Moreover changing the initial parameters drives to compute a different LUT, suitable for another type of fish-eye lens. Hence the developed system has the possibility to perform real-time radial distortion correction of fish-eye lens with a given remap function without the need of factory customization, by simply choosing the desired configuration before start-up. It's possible to use the same system with different types of camera by simply introducing on the board some custom selector (e.g. dip-switches) which lets the OEM choose among the pre-compiled features of the system, for example standard of input and output (e.g. NTSC, PAL), resolution, colour space (e.g. RGB, Composite and YCbCr), remapping function to be used for the correction and, basically, no-correction of the video. This gives to the OEM the highest flexibility in order to adapt the system to a very large number of different cameras and displays. The complexity profiling on the EVMDM642 platform allowed to easily select a low-complex DSP core on which retargeting the application. To this aim the TI TMS320DM335 [10] has been selected since it allows real-time performance at minimal power consumption and cost. TMS320DM335 is a 90 nm CMOS ARM926EJ-based Digital Media System-On-Chip, up to 216 MHz clock rate. It is equipped with 16 Kb instruction cache, 8 Kb data cache, 32 Kb RAM and 8 Kb ROM, the core must be supplied with 1.3 V. This processor allows for a power consumption less than 100 mW. The cost of the TMS320DM335 processor for large volume market is in the order of few dollars. Such values are very interesting for the automotive market if compared to state-of-art solutions based on FPGA devices plus off-chip non-volatile memories. An example of the achievable results are presented in Fig.1 which shows a typical parking situation: a car is running backwards to a park line. The raw video captured from the fish-eye camera (Fig. 2a) shows the stationary car as if it is frontal. This misunderstanding can be the cause of an accident. Instead the processed image (Fig. 2b) shows the correct angular orientation of the view, so the exact proportion between distances behind the car.

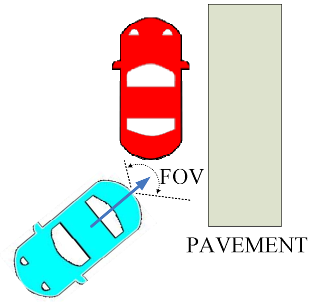

Figure 1. Example of a parking situation

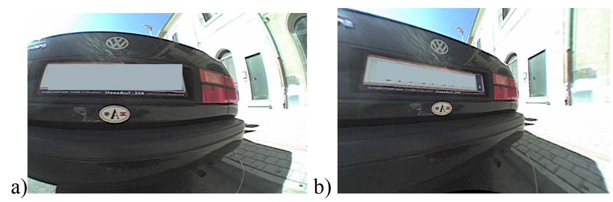

Figure 2. Example results of respectively a) captured and b) corrected image

The pictures were captured with the MT9V125 CMOS camera by Micron Aptina operating at 30 fps with a resolution of 720x480 pixels per frame and equipped with a fish-eye lens. Several advantages are obtained vs. the state-of-art solutions based on FPGA: being correction LUTs calculated during the initial transient phases no extra non-volatile memories are required; during the correction process it is possible to adaptively change the used correction LUT and hence the applied correction effect

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