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Space-variant image processing: taking advantage of data reduction and polar coordinates.

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acquisition of frames per second is accelerated since the images are very small. The frame-grabber size is also dramatically reduced. Combined, these two effects make the exploitation of differential algorithms especially interesting. Such image-processing algorithms systematically apply simple operations to the whole image, computing spatial and temporal differences. These can be computationally intensive for large images and the simultaneous storage of several frames for computing temporal differences can be a hardware challenge. Log-polar image-data reduction can therefore contribute to the effective use of differential algorithms in real applications.[7]

In addition to the selective reduction of information, another interesting advantage of log-polar representation is related to polar coordinates. In this case, approaching movement along the optical axis in the sensor plane has only a radial coordinate. This type of movement is often present with a camera on top of a mobile platform like an autonomous robot. If the machine is moving along its optical axis, the image displacement due to its own movement has only a radial component. Thus, complex image-processing algorithms are simplified and accelerated.[3,7,8] Further, the hardware reduction achieved in storing and processing images, combined with the density of programmable devices, make possible a full image-processing system on a single chip.[9] This approach is especially well suited to systems with power consumption and hardware constraints. We would argue it is the natural evolution of the reconfigurable architectures employed for autonomous robotic navigation[7] systems.

This work is supported by the Generalitat Valenciana under project CTIDIA/2002/142.

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ELECTRONIC IMAGING 14.1 JANUARY 2004

Space-variant image processing: taking advantage of data reduction and polar coordinates.

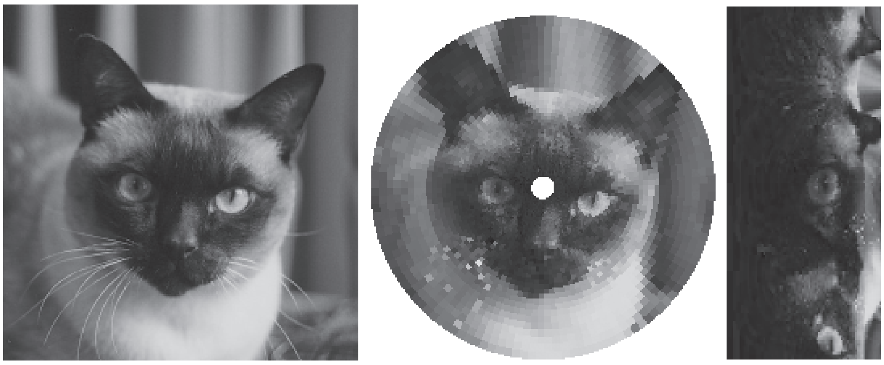

Figure 1. Left: A 440×440 Cartesian image. Center: A 128×56 log-polar image. Right: The computational image.

The human retina exhibits a non-uniform photo-receptor distribution: more resolution at the center of the image and less at the periphery. This space-variant vision emerges as an interesting image acquisition system, since there is a selective reduction of information. Moreover, the log-polar mapping—as a particular case of space-variant vision—shows interesting mathematical properties that can simplify several widely-studied image-processing algorithms.[1-4] For instance, rotations around the sensor center are converted to simple translations along the angular coordinate, and homotheties (linear transformations) with respect to the center in the sensor plane become translations along the radial coordinate.

The sensor (with the space-variant density of pixels) and computational planes are called the retinal and cortical planes, respectively. The resolution of a log-polar image is usually expressed in terms of rings and number of cells (sectors) per ring. A common problem with this transformation is how to solve the central singularity: if the log-polar equations are strictly followed, the center would contain an infinite density of pixels that cannot be achieved. This problem of the fovea (the central area with maximum resolution) can be addressed in different ways: the central blind spot model, Jurie's model,[5] and other approaches that give special transformation equations for this central area. Figure 1 shows an example of a log-polar transformation. At the left there is a Cartesian image of 440×440 pixels; at the center is the same image after a log-polar transformation with a central blind spot that gives a resolution of 56 rings with 128 cells per ring. Notice there is enough resolution at the center to perceive the cat in detail. The rest of the image is clearly worse than the Cartesian version, but this is the periphery of the image. This retinal image occupies less than 8 kB: the equivalent Cartesian image is around 189 kB (24 times larger). The computational plane of the image is shown in Figure 1 (right).

The best way to obtaining log-polar images depends on the available hardware and software. The simplest approach is to use software to transform a typical Cartesian image from a standard camera. This is done using the transformation equations between the retinal plane and the Cartesian plane. Since the transformation parameters can be tuned online, this solution is flexible. However, it can be an excessively-time-consuming effort if the computer must first process these images in order to perform another task. The other option is the purely-hardware solution: the log-polar transformation made directly from a sensor with this particular pixel distribution. An example of a log-polar sensor is a CMOS visual sensor designed with a resolution of 76 rings and 128 cells per ring.[6] The fovea is comprised of the inner 20 rings that follow a linear- (not log-) polar transformation to avoid the center singularity. This method fixes the image transformation parameters and is not flexible.

As an intermediate approach, a circuit that performs a Cartesian to log-polar image transformation can be implemented on a programmable device. This solution gives the advantage of speed while retaining flexibility: the transformation parameters can be changed on the fly. Moreover, the complexity and density of current reconfigurable devices represent a new trend in computer architecture, since it is possible to include microprocessors, DSP cores, custom hardware, and small memory blocks in a single chip.

The log-polar image data reduction has several positive consequences for the processing system. The first and most obvious is that the

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