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Log-polar mapping template design: From task-level requirements to geometry parameters ☆

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Abstract

The best parameters defining the geometry of a visual sensor generally depend on the particular visual task the sensor is intended to be used in. However, translating task requirements directly into low-level geometric parameters may be difficult, since deep knowledge of the sensor design is usually required, but end users of a sensor need not necessarily be its designers. A framework is suggested to facilitate this translation by including an intermediate layer, the design criteria, between task requirements and sensor parameters. The proposed framework is illustrated with a log-polar space-variant vision model. The motivation behind using this particular sensor is the observation that, in the literature, little attention has been paid to the proper choice of the sensor parameters, or the lack of justification of the chosen configuration. Sets of general-purpose design criteria and task specifications are provided and discussed. The process of finding the best geometric parameters for a given set of (many and/or mutually conflicting) design criteria is automated with a multi-objective genetic algorithm. Some examples are given demonstrating the feasibility and potential of the approach.

Keywords: Log-polar vision; Receptive fields; Design criteria; Genetic algorithm

1. Introduction

The computational interest of the log-polar image model [5], which has a biological inspiration [32], has been explored over about two decades by the pattern recognition [44] and the active vision [7] communities. As a practical issue in computer vision, log-polar images can be obtained through camera research prototypes [14,45,27], by software simulations [3,25,36], or with programmable hardware cards [16,12]. While log-polar images are a direct output of the visual sensor in the first case, cartesian images are required as input to the log-polar mapping procedures of the two other cases.

The design and fabrication of log-polar sensors has to deal with a number of technical and technological difficulties, but significant improvements have been achieved, including a color log-polar CMOS sensor [31]. Unlike the many obstacles and high economic cost of this option, obtaining log-polar images from cartesian images by means of software is a very flexible and cheap alternative. Unfortunately, this simplicity probably helps to explain why the proper choice of the mapping parameters has been mostly ignored in the past.

However, several reasons suggest the significance of devising adequate criteria when designing a log-polar mapping template. First of all, it is important to bear in mind that the particular log-polar geometry being used may affect the performance of some visual tasks using these images. Second, *users* of procedures to obtain log-polar would benefit from the availability of guidelines to get good mapping templates. Finally, *designers* interested in improving their log-polar sensors might follow some existing set of design criteria.

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The impact of the log-polar mapping parameters on the performance of a vergence control task was analyzed in [2]. The relevance of an appropriate parameter selection was also highlighted in [1]. Precision requirements of 3D measurements led to a choice of log-polar geometry parameters in [40]. Possibilities for foveae design were considered at length in [42], while the quality of log-polar templates were quantified in [30,31]. This summarizes the few works related to the problem of selecting the log-polar sensor parameters. All of them tend to focus on a particular visual problem or lack a more general design perspective accounting for the variety of visual tasks which are possible. In contrast, this article studies a set of general log-polar mapping template design criteria, as well as a mechanism to find the mapping parameters meeting those criteria. A general framework aimed at reducing the knowledge gap between task requirements and low-level mapping parameters is also suggested.

In this article, the problem of sensor design is formulated as an optimization problem. More specifically, a multi-objective genetic algorithm is used. A rich literature exists on parameter optimization in the context of computer vision systems. The scope of these systems may range from the design of optimal image filters [29], to finding the best parameters of a motion detection system [6]. An area of recent interest is that of discovering an optimal placement of a set of visual sensors [8,23,48], so that the total price can be minimized or the coverage can be maximized. The design of catadioptric sensors has also been considered lately [13,20,21]. The work in this article shares with these the fact that the proper configuration of a vision system is designed by means of some kind of optimization.

The work presented here is based on our preliminary efforts [37], and represents improvements in several aspects. First, the overall perspective of the work has been enhanced by including a proposal of a general design framework. Second, the design criteria have been better formalized, and the importance of having unit aspect-ratio receptive fields has been discussed more rigorously. Third, several examples illustrating the proposed approach are given. Finally, and most importantly, the optimization algorithm finding the sensor parameters from a set of design criteria is now much more general and effective. For the sake of clarity and completeness of this article, some background information from this previous paper [37], is part of Sections 1, 3, 4 and 5.

The rest of this article is organized as follows. First, a general design framework is described (Section 2). Next, the log-polar model and its basic parameters are introduced (Section 3). Then, a set of general design criteria are discussed (Section 4), and examples of task requirements are given (Section 5). Subsequently, the multi-objective genetic algorithm in charge of finding the primitive parameters best fulfilling a set of given design criteria is presented (Section 6). Illustrative examples of sensor designs found following the described procedure are then provided (Section 7). Finally, concluding remarks are given (Section 8).

2. Overview of the approach

Generally, the best configuration for a given sensor[1] depends on the particular task in which the sensor is to be used. Therefore, since sensor design is task-dependent, some procedure is required to translate task requirements into low-level sensor parameters. If this procedure is not automatic, human intervention is needed, and then the problem is that the human expert in a given task (the *user* of the sensor) may not have the needed knowledge to design/configure the sensor fitting their needs. Conversely, the human expert in the sensor technology may not have the insight in the task the sensor is intended for.

In general, the problems faced when trying to find the sensor parameters from a given set of task requirements can be categorized into these three groups:

(1) *Deep knowledge of the sensor and its parameters is required.* For instance, the number of rings and sectors of a log-polar sensor should be selected, but what do these parameters really mean? Which consequences on the overall sensor configuration will these parameters have? Will the choice affect some image processing operation? If several parameter combinations are possible, are they all equally valid?
(2) *Significant gap between task requirements and low-level sensor parameters may exist.* For example, if detecting faces with a given size and resolution is required, can good (or the best) sensor parameters be found? If so, how?
(3) *Task requirements might induce conflicting design criteria.* For instance, one might have the intuition that requiring a given number of pixels in the image and, at the same time, desiring a certain visual resolution at same region of the image, might be mutually conflicting criteria. But, can a trade-off solution be found? How can this be done?

2.1. General framework

To overcome, or diminish, these difficulties, we suggest a three-level framework, shown in Fig. 1, where the task-domain expert is in charge of translating high-level, task requirements into mid-level, design criteria. The advantage of this is that this expert need not know the low-level details of the sensor. There is an intermediate layer hiding these details and providing a suitable interface. Mid-level design criteria, in turn, need be finally translated into low-level (geometric) sensor parameters, and this can be done by a sensor-design expert.

[1] In this article, the term "sensor" is used with a lax meaning to refer to either a hardware- or software-based visual sensor or system with some configurable parameters.