Chapter 1

Thesis Overview

1.1 Introduction

Sometimes it can be problematic to coldly answer to the most innocent question or to do the most trivial action if no further help is at hand. When anyone is inquired to judge the beauty of a piece of art, shoot at the green fuzzy teddy bear or buy half a dozen of ripe oranges (Fig. 1.1), shape is not enough to decide what to do and many cumbersome difficulties might at once rise unless color is taken into account.

Like most of other impressive abilities of human vision, color perception probably is the most astonishing since it makes the world far easier to be understood. Nonetheless, artificial vision has to work harder to take advantage of color in the same way while keeping pace of its human counterpart. If we want our machines to attain visual capabilities similar to those of the human beings someday, color must turn out to be as a handy and reliable tool to apprehend information from images as it is for us when doing the aforementioned jobs.

However, even the best panacea has some drawbacks, and color is not an exception at all. If color is supposed to be employed to identify objects, places, and situations, it is a must to have a way of putting together the diverse parts in a scene sharing the same color. The problem rises when we carefully face the crude reality and ask to it what to have *the same color* means after all, because it is a fact that color changes. For many reasons and motives, but when objectively appreciated, color perception is not as easy as pinning a label to a certain area in an image.

The color nature of objects is something really complex because many factors are in play at the same time in order to produce the light beam carrying the surficial information that is translated in a camera into a color signal. Such factors are shape and texture of surfaces, composition of light, relative position between light, object, and camera, presence of nearby objects, class of sensors, and so on. All those factors basically generate two main effects on a homogeneous surface, i.e., a dispersion of measures due to geometry and surface roughness, which induces highlights and shades, and a global change of color when light conditions vary.

As a consequence, any visual system trying to use color in a favourable manner to extract some knowledge from images must first reduce the amount

Figure 1.1: Examples of the importance of color vision.

of color variation that appears in different views of the same scene or object in order the corresponding images to be compared. Afterwards, it must also be able to extract the regions in the image with regard to their color content, which can be posteriorly used to identify objects, locations, or to retrieve images from a huge database. In Fig. 1.2 it is clearly illustrated how color in a scene changes due to a variation of the light under which these images were taken.

Such processes are identified with the classical terms of *color constancy* and *color image segmentation*, and both are critical stages for any low–level vision system. The problem derived from the variation of color is even worse in the case we are considering in this work, namely, a mobile robot moving about an indoor human–made environment, since the relative movement of objects and the unknown and changing light conditions are inherent to the sort of images which are likely provided by the visual system on an autonomous platform.

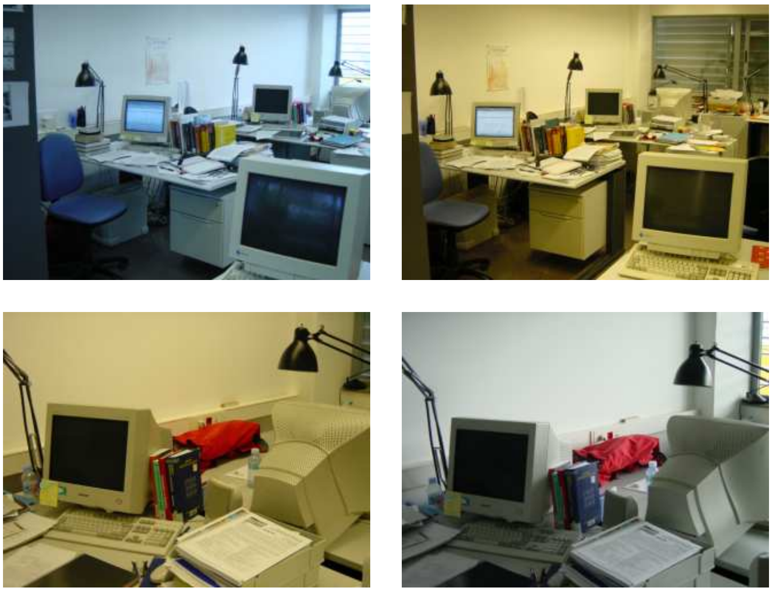

Figure 1.2: Examples of color variation due to illumination changes.

Therefore, this Thesis is completely devoted to the development of a general theoretical framework to study the mathematical basis of the color change phenomenon, as well as the proposal of methods to compensate, on the one hand, the color variation due to a change in the conditions of illumination, as well as an algorithm to segment color image fast enough for the kind of applications under account and capable of furnishing coherent and stable segmentations of usual indoor scenes, on the other hand. Additionally, some distance measures between image segmentations are suggested in order to compare images in terms of their color content. These measures will help to evaluate the color constancy step in regard to the reduction of the color discrepancy between image segmentations.

1.2 Objectives

In the same way as it is now exposed in the Introduction and as it was done some time ago in the proposal of this Thesis, the main objective of the present work is the attainment of proper segmentations of color images provided by a mobile platform so as to be used in tasks such as object recognition. To fulfill this purpose, we suggest that our work should follow two different paths at the same time, namely, the study of what causes image colors to change and some method to minimize this effect, along with the development of a fast algorithm capable of providing coherent and stable segmentations.

Thus, it seems clear that if color variation is reduced and a segmentation algorithm maintaining the structure of object regions is provided, the resulting segmentations will present the desirable features of stability and coherence, which will facilitate, as a consequence, any eventual identification process. Next, we expose in a more detailed manner the objectives proposed in our work for both color constancy and color image segmentation.

1.2.1 Color Constancy

The most important goal in this Thesis, in the context of color constancy, is to propose an effective method capable of recovering the values of color in an image that has been taken under an unknown illuminant as if it had been captured under some canonic conditions of light. This algorithm must work with the only information available in most of the tasks involving mobile robots, i.e., the pixel data of an image that is taken as the reference, and independently from an eventual image segmentation process since we think this stage should be applied before other processes.

The aim after the color constancy step is that the variation in the color nature within a set of images belonging to the same scene or object diminishes in relation to the differences between sets from dissimilar scenes or objects, which would be helpful to obtain more selective similarity measures in tasks such as object recognition or image retrieval.

In order to attain such a purpose, first we need to establish a model accounting for the color variation due to changes in light conditions. Therefore, our goal will be to develop a theoretical framework, by reformulating the usual color formation equations, that includes several former models and is able to explicitly compute the color change as accurately as possible. This model will be part of a wider study on the structure of general color mappings whose object is to determine the precision of a collection of models in terms of error at predicting the color change. Hence, it would be possible to select a certain model by knowing beforehand the amount of error that is assumed.

Nevertheless, it is not realistic to establish a general model for the color change in a way it is only possible to be explicitly computed, that is, knowing *a priori* the whole set of characteristics conforming the model. Quite the contrary, we need to develop an effective color constancy algorithm capable of calculating the aforementioned color change from the data our visual system will provide us during a promenade of the autonomous platform, i.e., images of what is seen at present and also a historic database of what has already been seen, which can be associated to a position, by the way.

Once the color constancy algorithm is applied, it will be useful to reduce the whole database of images to the set of illumination conditions given as a reference, standardizing this way the knowledge of the visual system corresponding to a certain location. For any new image, its color should be corrected before joining a particular scene set, which would prevent the posterior segmentation procedure from providing dissimilar descriptions of the same scene and would mitigate the difficulties in an eventual identification process carried out within the scene due to appearance dissimilarities.

1.2.2 Color Image Segmentation

The principal objective of this Thesis in the field of segmentation of color images is to develop a procedure capable of generating coherent segmentations in regard to real regions of homogeneous color in a given image, while keeping this segmentation as stable as possible through time in a sequence of images. Moreover, it is necessary to keep in mind that image segmentation is a capability of the visual system embedded on a mobile robotic platform, meaning that this process should be as fast as possible, a requirement that prevents us from using too time–consuming approaches.

Coherence is understood as the correspondence existing between segments and regions in an image. Two usual problems in segmentations are that there can appear more segments than actual regions (oversegmentation) or quite the contrary, that is, too few segments (undersegmentation). Our objective is to propose an algorithm capable of adjusting the number of segments as close as possible to those really present in the image, i.e., our goal would be to produce segmentation which are neither undersegmented nor oversegmented.

Moreover, as the appearance of objects in an image may change as there exists a relative movement between objects and camera, new segmentations may also generate some segments which do not completely correspond to those in previous segmentations of nearly the same view. In order to produce stable segmentations, where a given segment keeps belonging to the same actual region from the moment it appears until the point it disappears from the sequence, some kind of region tracking must be taken into account as well as a mechanism to incorporate previous segmentations to the ongoing one.

Finally, another objective of this Thesis is to evaluate the impact of a color constancy stage upon the resulting segmentations, i.e., whether it is true that color constancy reduces the differences between images and so between segmentations. The case of image comparisons will be tackled in the context of the evaluation of the performance of the color constancy algorithm. However, if a similarity between segmentations must be established, it is necessary to have a set of proper measures among segmented images. We propose the content–based image retrieval approach to define a list of similarity measures between images based on their color segmentation.

1.3 Outline of the Thesis

In the next lines, a brief description of the contents in each of the Chapters embodying this Thesis is given as a fast way to locate and access to the desired issue.

CHAPTER 1 ***Thesis Overview***
This overview.

CHAPTER 2 ***State-of-the-Art Survey on Color Constancy Methods***
Summary of the most interesting approaches so far in the color constancy issue having some kind of relation with to the problem endeavoured in this Thesis of computing color mappings.

CHAPTER 3 ***State-of-the-Art Survey on Color Segment. Methods***
This Chapter deals with the problem of segmenting color images, which is illustrated with a pretty nourished list of approaches divided into three periods until presently, focusing only in color algorithms.

CHAPTER 4 ***Continuous Color Formations Model***
We propose the continuous color formation model as a mean to generalize some former physical models and to mathematically study the problem of color change due to a variation of the illumination conditions. The validity of those models, in terms of prediction errors, is also checked against that of a linear least squares fitting approach.

CHAPTER 5 ***A Color Constancy Algorithm***
We propose here an algorithm to compute color mappings from image raw information using one scene view as the canonic image. The purpose of this method is to get a set of images from the same view where color remains constant no matter the changes in illumination they could have suffered.

CHAPTER 6 ***A Color Image Segmentation Algorithm***
This Chapter describes in a precise way our color segmentation algorithm, which has been developed to attain fast segmentations of color images as well as its extension to generate stable segmentations of images in a sequence.

CHAPTER 7 ***Comparing Images by Content***
The main aim of that Chapter is to compare images on the basis of their segmentation. Several approaches and measures to compute the distance between two segmented images are studied in the context of object recognition and image indexing, as well as using them to evaluate the effects of color constancy in the segmentation of color images.

APPENDIX A ***Fredholm's Integral Equations of the First Kind***
This Appendix is devoted to the mathematical description of the IFK equations, which are used in Chapter 4 to study the color change model. It should be regarded as a reference for such class of equations.

1.4 Summary of the Thesis

Next, we briefly summarize each of the previously outlined Chapters as a small dish of cold appetizers before the lavish feast that signifies the exposition of the whole Chapters, by contrast.

1.4.1 State-of-the-Art Survey on Color Const. Methods

This Chapter describes the wide field of color constancy trying to encompass all the most interesting and important algorithms of which our knowledge have become aware. These methods are divided into several categories, namely, gray world, Retinex, gamut–mapping, Bayesian and correlation, neural networks, multiple views, and methods based on linear models. Additionally, we also consider the set of different hypotheses about the real world that have been taken into account along the time, as well as the more specific problem about the relation between color constancy and tasks such as object recognition and image indexing.

Color constancy is understood as the task of finding descriptors for the surfaces in a scene invariant to illumination changes. However, the job of correcting colors of an image can be considered as two separate stages. First, estimating the parameters of the scene illuminant, which will be used in a second stage to compute the set of *illuminant–independent* descriptors from the image pixels. Illumination–independent descriptors can be used afterwards in a wide span of problems in machine vision such as object recognition and image indexing and retrieval.

While some authors simply restrict color constancy only to the first stage, i.e., estimation of the scene illuminant, others are more interested in finding a transformation between image colors in order to keep them as resembling as possible to those under a reference light condition. These two approaches are fully interchangeable once a model of color formation and variation is specified.

The *diagonal* model is, by far, the most used model of color change in literature. This model transforms colors under an illuminant onto other colors taken under an unknown illuminant by only scaling every color channel independently. The efficiency of that restricted linear model is, in great extent, a function of the sensors in the vision system. Specifically, whether these sensors are narrow–band or their sensibility functions overlap.

Color constancy algorithms can also be classified as a function of the total number of recovered parameters. Most algorithms try recovering two or three parameters, accordingly to the kind of color coordinates used in the approach. When considering the estimation of the camera response, it is natural to try to appraise the RGB color of the illumination. Nevertheless, we are usually more interested in the illuminant chromaticity than in its magnitude, discarding the intensity information. Other authors even endeavour the recovery of its spectral power distribution.

From the great number of approaches reviewed so far in this state of the art, a conclusion that can be drawn is that the best methods are those based on correlation and gamut–mapping, whose notions have been kept in mind during the development of our color constancy algorithm.

1.4.2 State-of-the-Art-Survey on Color Segm. Methods

Not until recently segmentation techniques were mainly proposed for gray–level images. The reason is that, although color information permits a more complete representation of images and more reliable segmentations, processing color images requires computational times considerably larger than those needed for gray–level images. Nevertheless, this is no longer a major problem due to the increasing speed and decreasing costs of computation. Besides, relatively inexpensive color cameras are easily available nowadays.

Accordingly, there has been a remarkable growth in the number of algorithms for segmentation of color images in the last decade. Most of the times, these are kind of *dimensional extensions* of former techniques originally devised for gray–level images. Thus, they exploit the well–established background laid down in that field. In other cases, they are *ad hoc* techniques tailored on the particular nature of color information and on the physics driving the interaction between light and colored materials.

On the other hand, image segmentation is an essential but critical component of any image analysis and/or pattern recognition system. Besides, it is one of the most difficult tasks in image processing and determines the quality of the final result of the image analysis. In short, segmentation is defined as the process of partitioning an image into disjoint and homogeneous regions. This task is equivalently achieved by finding the boundaries between image regions.

The desirable characteristics that a good image segmentation should exhibit with reference to gray–level images are as follows. Regions should be uniform and homogeneous with respect to some characteristics such as gray tone, texture, or color. The interior of regions should be simple and without many small holes. Adjacent regions of a segmentation should have significantly different values with respect to the characteristic on which they are uniform. Boundaries of each segment should be simple, not ragged, and spatially accurate.

Moreover, a more precise definition of segmentation is given in the following way. Image segmentation is a process of dividing an image into different regions such that each region is homogeneous, but not the union of any two adjacent regions. Nevertheless, the image segmentation problem is basically one of psychophysical perception, and therefore not susceptible to a purely analytical solution.

This Chapter is completely devoted to the review of the most important algorithms of color image segmentation. Owing to the extremely wide extension of this issue, it is nearly impossible to refer here to all the works found and read. Therefore, on behalf of a clearer exposition, this Chapter is divided into three periods, namely, *early*, *middle*, and *recent* stages. Methods within each period are split into several categories, namely, pixel–based, area–based, contour–based and physics–based methods. Some interesting conclusions about the issue are summarized at the end.

1.4.3 Continuous Color Formations Model

Our main endeavour in this Chapter is the study from a theoretical point of view of the nature of the transformations driving the color change in the appearance of objects due to a variation of the light conditions under which two images of a same scene are taken. A precise knowledge of the kind of applications involved in the process of color change is an *a priori* stage in the treatment of the color constancy issue, which will be more specifically tackled in the next Chapter.

To this purpose a framework is suggested undertaking, both analytically and numerically, that question as a natural generalization of usual color formation equations. This formulation is able to describe the formation of multispectral color signals by means of a continuous expression that can be discretized as needed in order to attain handier formulations. Such a reformulation of the color formation equations presents some advantages over the habitual discrete equations, e.g., sound mathematical foundations, independence on the particular discretization employed, and it also embodies other previous well–known physical models of the color formation phenomenon.

The continuous color formation equation turns out to be identified as a *Fredholm's Integral Equation of the First Kind* (IFK), which is helpful to establish the least theoretical conditions for the solution to exist, be unique, and numerically well–behaved, as it is more deeply explained in Appendix A. We also propose an analytical solution to both the spectral recovery and the color mapping computation form where more useful numerical schemes are derived. The theoretical framework gives an inner insight on what is involved in the color change problem, besides being an interesting starting point to other matters such as the numerical stability or what sort of constraints should be fulfilled in order a proper solution to exist.

As said before, a numerical version of the aforementioned IFK approach is given as a way to make practical computations along with the type of data commonly available in this kind of research. The continuous equation has to be discretized and this can not be done in a unkindly manner, as sometimes it is the case. In Appendix A some helpful examples of discretization methods are considered. This way, the IFK model is related with several widely known physical models of color formation.

In the results Section of that Chapter two problems are numerically studied, namely, the spectral recovery of reflectance functions from sensor measures and the explicit computation of color mappings applying the previous group of physical models. Our aim is that of comparing the results obtained using the IFK model with those generated by the alternative models as a mean to evaluate their mutual performance in the two experiments. Independently, a least squares fitting of the maps accounting for the color change is also undergone.

The goal of these approaches is to discern whether or not actual data really fulfill linear transformations as the physical models suggest and to what extent. Results show the accuracy of both the linear hypothesis and the physical models considered so far. Accordingly, some simplifications can be established to the general linear model to ease an eventual the color constancy algorithm,as that in the coming Chapter.

1.4.4 A Color Constancy Algorithm

As explained earlier, a major problem faced in computer vision in the context of mobile robotics is that, when a place is revisited, the illumination over the scene may have changed from the last time the robot was there or from the one existing during the capture of images for the database. Besides the fact that objects may have changed their position, the whole room may be viewed under a completely different light. Therefore, it is a hard task the comparison of what is seen at a given moment with what was recorded in prior visits. Then, a preliminary step when using color must be to remove the pernicious effect of a varying illumination by means of a color constancy stage to provide stability to the color of surfaces.

Generally, color constancy is envisaged as the recovery of a *descriptor* for each surface in a scene as it would be seen by the camera under a canonic illuminant taken as a reference. This is similar to pose the color constancy problem as that of recovering an estimate of the color of the scene light from an image taken under an unknown illumination. It is relatively straightforward to map image colors into illuminant independent descriptors afterwards. Therefore, finding both a color map and the color of the scene illuminant are equivalent problems.

Taking advantage of the properties of algorithms based on the computation of mappings between color gamuts and on a probabilistic framework, we propose in this Chapter a new color constancy algorithm that computes the histogram of feasible mappings. The goal of this algorithm is to be used in tasks involved in mobile robotics, where color and its stability are important issues. Thus, we constrain this approach to work only on the data present in the image pixels, besides employing as little *a priori* knowledge about illumination as possible, since the lack of such information is the quotidian case.

As it is illustrated in the results, our algorithm is capable of recovering a mapping that changes image colors as if they were seen under a canonic light by means of a single canonic image picturing a similar view of the scene as the sole source of information. The algorithm is compared to the Finlayson's 2D gamut–mapping method, which is the closest approach among other existing algorithms, that gets clearly outperformed by our results.

1.4.5 A Color Image Segmentation Algorithm

Image segmentation is an essential but critical component in low–level vision, image analysis, pattern recognition, and now in robotic systems. Besides, it is one of the most difficult and challenging tasks in image processing, and determines the quality of the final result of analysis. As said, image segmentation is defined as the process of dividing an image into different regions such that each region is homogeneous while not the union of any two adjacent regions. The hope would be that these regions had some correspondence to the real homogeneous regions belonging to the objects in the scene, besides being stable along a sequence of images.

We select the graph–theoretical approach to cope with image segmentation because of its sound mathematical basements and the fact that the segmentation problem can be easily translated into a graph–partitioning problem, which has lots of different methods to be solved. On the other hand, the worst disadvantage of these algorithms is that they are heavy time–consuming, which should prevent us from their use in (nearly) real–time applications. Nevertheless, for this reason we chose among the subset of greedy graph–partitioning algorithms, faster than any other of the kind.

In this Chapter we present a color image segmentation algorithm capable of working on diverse color spaces and metrics. This approach has a nearly linear computational complexity and is based on the maximum spanning tree along with a set of improvements, both theoretical and practical, which amend the lacks detected in former results. This algorithm has been applied to segmenting both static images and sequences, where some further enhancements were introduced to achieve more coherent and stabler segmentations of sequences.

Results have been compared to those attained by the original algorithm – improving them – and also to those obtained by the a version of the unsupervised clustering *Expectation Maximization* (EM) algorithm. EM is one of the most successful clustering methods of recent years, and the version used here to compare is completely unsupervised, avoiding the problem of selecting the number of components and that of a careful initialization. Besides, it overcomes the possibility of convergence toward a singular estimate, a serious problem in other EM–like algorithms. We show that our segmentations are fully comparable to those of the Figueiredo's EM algorithm, but at the same time and more importantly, our algorithm is far faster.

1.4.6 Comparing Images by Content

In this Chapter, our aim is that of comparing images on the basis of their region segmentation. The necessity for this arises not only from well–established tasks such as object recognition, image indexing and retrieval, but also from problems related with the color constancy of images, since we are interested in the effects of such methods on the segmentation of images.

Comparing image segmentations can be seen as an object recognition problem. Nevertheless, our situation here is slightly wider and bounds are less defined than these of classical object recognition, since these techniques usually rely on a clean segmentation of objects from the rest of the image or very often are designed for fixed and well–known geometric objects such as machinery parts. Neither of those constraints habitually hold in the case of natural images, where shape, size, and color of objects are quite variable and segmentations are most of the times imperfect.

Our impression is that a more flexible framework is needed in the present case. We need a way to compare segmented images despite the segmentation process is perfect or not. Furthermore, it is important to make clear that some of the tasks that use segmentation, such as finding an object in an environment, matching a given object or scene to a set of previously learnt objects or scenes, come together with the fact that a given image must be searched in a probably rather large image database, which should be done as fast and efficiently as possible.

As a mean to attack this problem our interest heeds the set of techniques known as *Content–Based Image Retrieval* (CBIR), since those techniques develop measures among images based on their content to effectively indexing and searching in large–scale image databases. More precisely, the CBIR approach consists of a set of methods for retrieving semantically–relevant images from an image database on automatically–derived image features.

Furthermore, similarity measures employed in those approaches are also a good tool to objectively compare segmentations in the sense that two similar images should generate similar segmentations whose closeness could be numerically grasped by way of these similarity measures. It is in this last sense that comparing segmentations gains meaning as a way to evaluate the effects of color constancy upon segmentations.

Consequently, once a proper similarity is established from a list of possibilities, we evaluate the effect of the color constancy stage by computing such similarity measures before and after its application. This way, the performance of color constancy in terms of similarity between segmentations is shown, which might help to improve object recognition and image retrieval methods in front of variations of the light conditions.

1.5 Contributions of the Thesis

We summarize here the set of contributions that has been attained by this Thesis

- The problem of defining a mathematical transformation for the colors of an image between two different light conditions is studied. We propose to reformulate the color formation process by means of a continuous color equation. From this expression, the issues of spectral recovery along with that of computation of color mappings are derived. This approach has also been related with a set of former color models that now can be obtained from the continuous equation. Moreover, the linear nature of the color transformation has been indirectly checked by a list of experiments involving least squares fitting. Experiments on both spectral recovery and explicit computation of color mappings have been carried out for all the physical models considered as a way to investigate their mutual performance, as well as to compare them with the linear regression. Results support both the linear hypothesis and the suitability of a continuous color formation equation to tackle the color change issue.

- We propose a color constancy algorithm recovering a color mapping that renders colors of an image onto those under a canonical illumination. The algorithm computes an estimation by means of a histogram of the distributions of those mappings and assigns a measure of likelihood to each of them. These values, which take into account both the frequency of the transform and its effectiveness to render back colors, are used to select the most suitable among those mappings. Results, in comparison to the gamut–mapping algorithm, show that our algorithm outperforms it and attains similar results to the color–by–correlation approach.

- An algorithm for segmenting color images based on the greedy partition of the minimum spanning tree is suggested. This is driven by an energy function that estimates the probability over joining components attending to their inner properties. Results obtained with this algorithm show comparable segmentations in terms of coherence with those achieved by an unsupervised version of the EM algorithm, but rather being far faster than the latter. Additionally, this algorithm has been extended in order to get stabler segmentations with images from sequences.

- A substantial group of distances based on the content of images are proposed and tested in tasks such as image retrieval and object recognition. Those measures are defined in the frame of the IRM distance and employ multivariate Gaussian distributions to describe color in image regions. The best two distances are also been used to study the effect of color constancy in the segmentation of color images, focusing on how this process reduces the distance amid images within a category more than the mean distance between images from different categories. This way, content–based distances become more selective and insensitive to color changes due to a variation in the light conditions.

1.6 List of Publications

This thesis has generated, among other things, the next list of publications

- J. Vergés–Llahí and A. Sanfeliu, "Evaluation of Distances Between Color Image Segmentations", accepted in *the* 2^{nd} *International Conference on Image Analysis and Recognition, ICIAR'05*, Toronto, Canada, September 2005.
- J. Vergés–Llahí and A. Sanfeliu, "A New Color Constancy Algorithm Based on the Histogram of Feasible Mappings", accepted in *the* 2^{nd} *International Conference on Image Analysis and Recognition, ICIAR'05*, Toronto, Canada, September 2005.
- J. Vergés–Llahí and A. Sanfeliu, "Evaluation of Distances Between Color Image Segmentations", accepted in *the* 2^{nd} *Iberian Conference on Pattern Recognition and Image Analysis, IbPRIA'05*, Estoril, Portugal, June 2005.
- J. Vergés–Llahí and A. Sanfeliu, "A Color Constancy Algorithm for the Robust Description of Images Collected from a Mobile Robot", Progress in Pattern Recognition, Image Analysis and Applications, in *Proc. of the* 9^{th} *Iberoamerican Congress on Pattern Recognition, CIARP'04*, Puebla, Mexico, October, 2004, Lecture Notes in Computer Science, Ed. Springer, vol. 3287, pp. 232-239.
- J. Vergés–Llahí, J.Aranda, and A. Sanfeliu, "Visual Tracking System for A Mobile Robot Using Colour Histograms", in *Proc. of the* 5^{th} *IFAC–EURON Symposium on Intelligent Autonomous Vehicles, IAV'04*, Lisbon, Portugal, July 2004, CD format[1].
- J. Vergés–Llahí and A. Sanfeliu, "A Colour Constancy Algorithm Based on the Histogram of Feasible Colour Mappings", Progress in Pattern Recognition, Speech and Image Analysis, in *Proc. of the* 8^{th} *Iberoamerican Congress on Pattern Recognition, CIARP'03*, Havana, Cuba, November 2003, Lecture Notes on Computer Science, Ed. Springer, vol. 2905, pp. 171-179.
- J. Vergés–Llahí and A.Sanfeliu, "Colour Constancy Algorithm Based on Colour Histogram Distance Minimization", Pattern Recognition and Image Analysis, in *Proc. of the* 1^{st} *Iberian Conference on Pattern Recognition and Image Analysis, IbPRIA'05*, Port d'Andratx, Mallorca, Spain, June 2003, Lecture Notes on Computer Science, Ed. Springer, vol. 2652, pp. 1066-1073.
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- A. Sanfeliu, R. Alquézar, J. Andrade, J.Climent, F. Serratosa, J. Vergés–Llahí, "Graph–Based Representations and Techniques for Image Processing and Image Analysis", *Pattern Recognition*, 2002, vol. 35, pp.639-650.

[1]Proceedings, published by Elsevier, will be ready by May 2005.

- J. Vergés–Llahí, J.Aranda, and A. Sanfeliu, "Object Tracking System Using Colour Histograms", in *Proc.* 9th *Spanish National Symposium on Pattern Recognition and Image Analysis, SNRFAI'01*, Benicàssim, Spain, May 2001, vol. 2, pp. 225-230.

- A. Sanfeliu, J. Andrade, R. Alquézar, J. Aranda, J. Climent, A. Grau, F. Serratosa, and J. Vergés–Llahí, "MARCO: A Mobile Robot With Learning Capabilities to Perceive and Interact with Its Environment", in *Proc.* 9th *Spanish National Symposium on Pattern Recognition and Image Analysis, SNRFAI'01*, Benicàssim, Spain, May 2001, vol. 2, pp. 219-224.

- J. Vergés–Llahí, J. Climent, and A. Sanfeliu, "Colour Image Segmentation Solving Hard–Constraints on Graph–Partitioning Greedy Algorithm", in *Proc.* 15th *Int'l Conf. on Pattern Recognition, ICPR'00*, Barcelona, Spain, September 2000, vol. 3, pp. 629-632.