Real-time Multicamera Image Processing for Localization of autonomous Robots in dynamic Environments

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1. Introduction

In order to develop a stable Robocup Small Size Vision System, there are different aspects the focus should be set on.
One of the main problems is the ability for Real-time, because of the very fast game play in this League. The Latency should be hold as small as possible to save some milliseconds in contrast to the opponent.
On the other hand industrial image processing software often set up some rules for itself making it simpler to analyze the pictures. There are special light conditions and other environment variables that have to fit. But what for possibilities exist to analyze up to 50 or more pictures per second in a Multicamerasystem with a dynamic changing environment?

2. Premise

In the Robocup Small Size League most teams are using industrial Firewire CCD cameras. The cameras that can be achieved on the market can achieve 50 frames per second and more depending on the resolution and the color format.
This work refers to the Marlin F-046C camera from Allied Vision Technologies. This camera has an output of 53 frames per second in the RAW mode. This RAW mode should be transformed in the RGB color format by using a library which can do the BAYER filtering very fast.
As result of the decision for two 53 Hz cameras, to overpeer the whole field with an acceptable resolution, there is a deadline of round about 19 milliseconds. In these 19 milliseconds the objects in both cameras must be found and the strategy software, which should run on the same computer like the vision software must be able to finish calculating the new commands for the robots. The deadline can be qualified as hard deadline, with the reason that missing a deadline means losing frames and the possibility to get a goal.

One of the most important problems, in developing a stable real time vision system, is the differentiation of colors. The Robocup Small Size League specifies, that the two different teams are labelled with the two colors yellow and blue. The ball is a usual orange golf ball. Minimum these three colors must be differentiated stable. To identify the own player and to detect the line of sight for every robot, there are more markers, according to the rules with other colors, needed. The challenge occurs because the illumination of the field is not constant over the whole sight area. The same color appears completely otherwise in different light conditions and different brightness.

3. Differentiating Colors

One of the main motivations of this works is to solve the problem of the different color appearances in different light conditions.

In view on the required real time ability this work takes the line of the least resistance and follows the basic concept of real time systems. A simple and fast algorithm with few necessary calculations is a good algorithm.

The RAW color format which is supplied from the cameras is be formatted in the RGB color format. This format has a simple structure and because of the simple additive color mixture another important feature.

The RGB color cube is shown in Figure 1. The figure shows the structure of one pixel in the RGB color format. For every pixel in the image are provided 24 bit. In these 24 bit are 8 bit for the color Red (R), 8 bit for the color Green (G) and 8 bit for the color Blue (B) reserved. The mixture of these three fundamental colors can supply over 16 million different colors. If all three values are 0 the color of the pixel is black. If all three colors have their maximum which is at 8 bit at 255 the pixel has the color white. So it is assumed, that in a different lights just the three values R, G and B change their values equal.

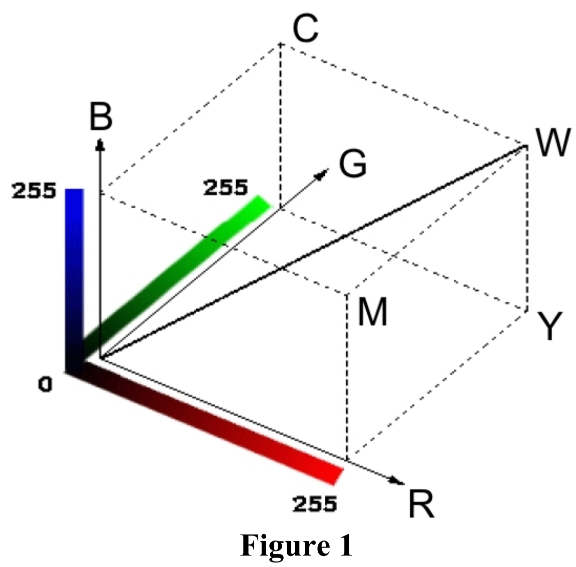

Figure 1

The different existing solutions of differ colors use these R, G and B values direct. So the color space, in which a marker or a pixel is identified as for example Yellow or Red or Blue, is defined by comparing the R, G and B value separate.
But this direct usage of the values can not compensate different brightness. The RGB color cube can be considered as 3 dimensional vector with the three dimensions Red, Green and Blue.
Two other possible distinguishing features can be set up. The method using ratios and the method using the unit vectors. Both methods base on the same fact. In changing light conditions the Red, Green and Blue values are changing but not the orientation of the resulting vector in the color space.
The method using the unit vectors is shown in Figure 2. To simplify the diagram and hold the figure clearly there are shown only two of the three dimensions in the cube. The construction in a 3 dimensional space would be analogue.

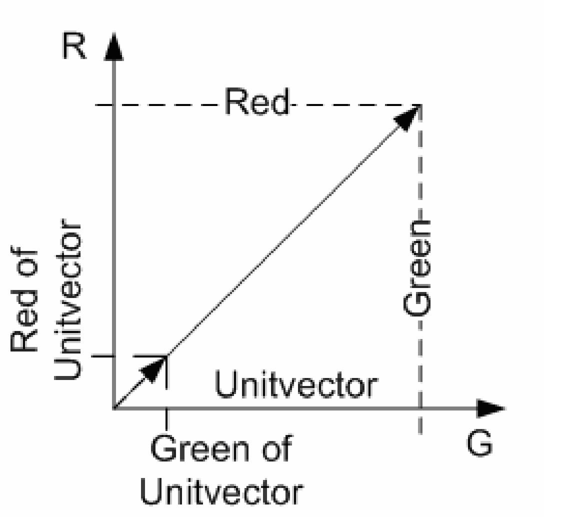

Figure 2

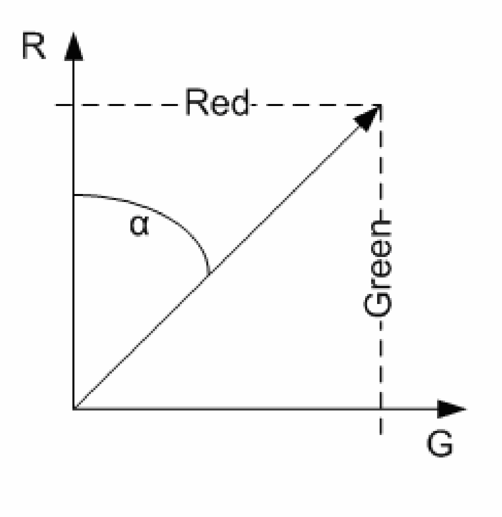

Figure 3

The Figure 2 shows the fact, that the length of the unit vectors don't change in different lights, like the Red, Green and Blue values will do.
As a result of the high computation time of the unit vectors, the method using ratios is developed. Exemplary the ratio Red/Green is shown in Figure 3. The ratios are the tangents of the angles between the vectors.
It can be expected that both methods will provide constant values.

4. Measurements

To support the theory of constant ratios an constant unit vectors, unlike to the direct comparison of Red, Green and Blue, different measurements are made.
To get comparable results, different colored round markers with a diameter of 5 cm have been placed on the field. With a dimmable lamp several brightness from 275 Lux up to 1200 Lux have been created. The markers have been recorded by the cameras and the resulting images have been researched to test the three different method. To reduce the effect of color noise, one pixel in the

center of the each marker is measured over few seconds and the average is registered.
The following Diagramm 1 shows examplary the direct taken Red, Green and Blue values of the blue colored marker against the brightness in Lux. It is assumed, that the values rise nearly linear until some values reach their maximum at 255.

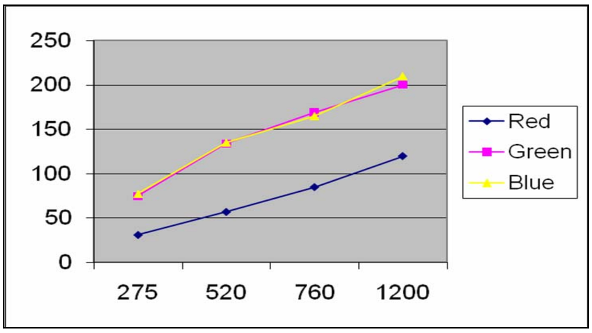

Diagramm 1

The smallest growth of a single values compared to the first value is over 260%. The next Diagramm 2 and Diagramm 3 show the taken Red/Green, Green/Blue and Blue/Red ratios and the calculated unit vectors for the same marker.

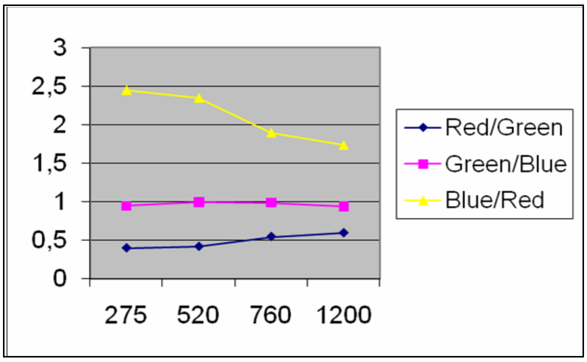

Diagramm 2

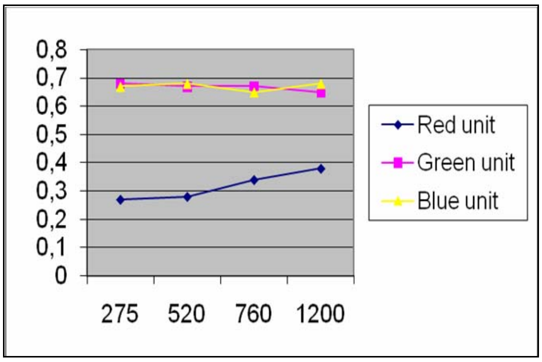

Diagramm 3

The biggest change of the ratios is round about 150%. In case of the unit vectors this value is about 140%. Compared to the old method, the biggest recorded changing in the new methods is still significant smaller than the smallest one of the direct taken values.
With the measurements the theory of constant ratios and unit vectors can be validated. The methods come to failures if one value either Red, Green or Blue come to the maximum of 255.

5. Implementations

Basing on the theoretical work and the measurements, which assist the presumptions, a complete vision software has been implemented. The software should show if the whole system would work as expected.

By using the two different methods, of differentiate colors, the software goes through the predicted areas, where the objects are estimated to be found and identifies the color for a single pixel. After a pixel is identified as possible own player, opponent or ball the neighbourhood pixels are tested. If minimum 3 of 4 tested pixels match with the right color, the software assumes that there is a colored marker and spanes a square around the first identified pixel. The size of the square is the size of the potential object to be identified plus a safety distance. The fact that the ball and team markers must have a minimum distance helps to avoid problems that the squares would overlap each other. After searching the square and checking every single pixel for the estimated color, the software checks the size and dimensions of the marker. When all checks are complete and the marker has the right size, enough associated pixels have been found and the marker is a round one, the center of gravity is calculated. All identified pixels are deleted to avoid double detection.

After searching both camera pictures by using this method, around all own player markers, in the area of the radius of the players, the colored markers to identify the robots and to detect the line of view are searched by a similar method.

For both cameras now a number of markers are available. To avoid problems in further handling, some simple safety tests can be made. These tests contain if two team markers, own players and opponents, have a minimum distance of two roboter radius. The correction of as ball identified objects, caused by similar markers on the robots, must proceed here. Otherwise problems in merging can occur, because the ball and the robots have different heights.

The next step should be to merge the marker coordinates of both cameras. By using the developed deskew function the radial deformation, caused by the wide angle objectives of the cameras, is correct. After correcting the failure resulting from height of the objects the pictures are merged on the level of coordinates. Therefore two measuring points are determined that are in an area that is recorded from both cameras. Starting from these points the torsion and the relative adjustment of the two cameras against each other can be corrected.

When merging is correct the intelligence of the vision systems starts to work. This intelligence is independence from the previous way of finding and identifying markers. The so built modular construction is very flexible by choosing different color formats or algorithms to identify the markers.

The intelligence of the vision system is able to research the markers for own players. In the next step the opponents and the ball is identified.

By using the linear tracking, the determined positions of all objects can be checked. If any failure occurs, caused by single not found markers on the robots, the tracking is used to correct the position of the objects. The correction takes effect when a robot was found in the last frames and suddenly disappears or the distance between the last frames is too big, so it is assumed, that a wrong identification was made. The two stepped tracking first calculates the estimated

position, checks if determined position is possibly wrong. If this occurs the system searches for a team marker near the estimated position. If no marker is found, the robot is tracked for a predefined time.
To speed up the system the search spaces where for own players, opponents and ball is searched is scalled down under usage of the tracking system. Before searching the whole picture the estimated positions are calculated and a search space with the size of the area of the objects plus a safety distance is clamped. Only this space is searched, before searching the whole picture, for the relevant objects. If all objects could have been detected, it is not necessary to go through all pixels.

6. Results

As the result, a reliable Vision System for a Robocup Small Size Team could have been developed. The implemented software has been applied on many Robocup tournaments like the European Championships 2006 and the World Championships 2006. The Software worked as expected and even in dynamic changing light conditions all objects could have been found with high reliability. So both methods of differentiating colors, the method of using unit vectors and the method of using ratios, are working correct and safer than the method of direct comparison of the Red, Green and Blue values. It is preferred to use the ratios because of the fewer needed computing time.

7. Literature

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