Real Time Computer Vision for Multi-Agent Mobile Robot Control

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Abstract. *In this work we present our formulation, development and tests of GPU accelerated image analysis techniques for use with a computer vision based approach to control several mobile robots. The tests were realized using robots designed for the IEEE Very Small Size Robot Soccer category. In this category the robots are required to have maximum dimensions of 75 millimeters of length, width and height; the images are obtained from a single camera, positioned 2 meters above the field. The robots and the ball can be identified by their unique colors. The robots are in a dynamic environment with mobile obstacles, hence, in order for the data gathered from the image analysis for be viable to further processing and decision making, it is required a very small processing time for each frame. Using the most recent graphics processing units architectures available for the computer gaming market, we were able to obtain position and velocity estimations from images with great precision and fast processing times, enabling the use of several artificial intelligence techniques and path planning algorithm to control the movements and other actions of the robots. The position of the robots and obstacles was obtained by using color thresholding, and the velocity estimated by using a Lucas-Kanade based optical flow algorithm.*

Keywords: *Computer Vision, Real Time Image Analysis, GPU Accelerated Processing, Optical Flow*

1 INTRODUCTION

The IEEE very small size soccer is a category of robot soccer in which 2 teams composed of 3 players compete in a game with rules inspired by human soccer.

As described in the competition rules (LARC, 2008) this category utilizes a camera positioned two meters above the center of the field in order to provide images for the control systems of each team. Because of this, the rules are defined in order to facilitate the use of computer vision techniques to obtain data from the game.

The ball is an orange golf ball, and each team is identified by a colored patch (blue or yellow) which is assigned to the teams and added to the robots before the start of each game. Each individual robot can be further identified by the addition of up to two different colors to the top of its structure.

The game is played in a rectangular field of 150 by 130 centimeters with non-reflective black background. All of the lines and other points of interest are white-colored in order to provide high contrast.

The lighting condition during the game shall be fixed at around 1000 Lux. This characteristic will be important in section 2.2 in the discussion of the optical flow algorithm employed to determine the speed of the moving objects during the game.

During the development of the robot soccer team of the Computer Engineering course at the *Pontifícia Universidade Católica de Minas Gerais*, there arose the need for the determination of the approximated position and velocity of the adversary robots and the ball. This data is used by the artificial intelligence of the control system during the path planning of the robots and in establishing a tendency of move of the adversary robots.

The camera utilized by our team is capable of providing 30 frames per second with a resolution of 1920 by 1080 pixels.

2 THEORETICAL BASIS

In this section we present a brief introduction to the most important subjects which this work is based upon.

2.1 GPU Accelerated Image Analysis

Graphical Processing Units or GPUs are processors specialized in the realization of operations that are common in computer graphics and image processing. These applications require a series of similar logical and arithmetic operations, such as addition and subtraction. The operations commonly realized in a GPU are simple enough so that the processing core can be very small in both size and power requirements and therefore a very high number of these cores can be included in a single chip, hence the immense parallel processing power of a GPU.

The use of a GPU to perform general computation tasks is commonly referred to in the literature as GpGPU or general purpose graphics processing unit. The task of writing programs which can explore GPUs was simplified by the release of programming frameworks by manufacturers such as the NVidia CUDA™ and OpenCL.

In a recent work Skirnevskiy et al (2016) demonstrated that it is possible to achieve execution times up to 5.6 times faster by utilizing a GPU to run the NLM algorithm in a 210x182 pixels image. This work shows that exploring the processing power of a GPU is very beneficial to image processing applications, providing motivation to employ similar strategies in the development of the application explored in this work.

2.2 Lucas Kanade Optical Flow Algorithm

The Lucas Kanade method is a classic algorithm that calculates the optical flow between two sequential images of a scene, the optical flow being the pattern of apparent motion of objects in a scene.

In the work of Raúl Rojas (2011) it is explained that the Lucas Kanade (denoted LK from this point on) algorithm makes two important assumptions about the scene being analyzed: the first one is that the time increment between the scenes is small and the second one being that the brightness condition in the two images should be close.

Both conditions are respected by the problem which this work treats. By the rules of the category the brightness of the room in which the game is played should be constant and the time displacement between the two scenes is always constant due to the fact that the camera provides video at a 30 frames per second ratio, which results in a 33.33 ms delay between images.

The work of Raúl Rojas (2011) also explains that the LK algorithm can be used to estimate the movement of important figures in a scene. In this specific work, there are seven objects of interest to track, the first being the ball, the three robots which compose the principal team and the three robots which compose the adversary team.

2.3 OpenCV

OpenCV is an open source computer vision library, written in C and C++ and runs in Linux, Windows and Mac OS X operational systems. It was designed for computational efficiency and with a strong focus on real-time applications (Bradsky & Kaehler, 2008).

This library is utilized in this work in order to provide good implementations of the LK algorithm, that are already tested and ready to use in several GPUs and processors architectures.

3 THE DEVELOPED ROBOTS

In this section, a brief description of the robots that constitute the robot soccer team is provided.

The robots were built using 3D printing technology. The body was printed with PLA plastic and accomodates and protects the wheels, batteries, motors and electronics circuits that are needed in the robot.

The wheels have a diameter of 60 millimeters and at full speed spin at 600 revolutions per minute, resulting in a top speed of 1,885 meters per second. This speed was a design requirement, created so that the robot can go through the largest diagonal of the field in 2 seconds.

Each robot contains a Arduino Pro Mini development board, connected to a H Bridge circuit that drives the two motors of the robot. Communication was implemented in a mesh toplogy using the NRF24L01 radio wireless modules.

The robot power source are three 14500 lithium ion batteries, connect to a boost voltage regulator that maintains a constant 12V input voltage to the electronics and motors of the robot.

4 THE UTILIZED STRATEGIES

To speed up the execution of the LK algorithm, one of the possible solutions is to reduce the size in pixels of the image being analyzed. This is possible by utilizing the decimation of an image, which reduces its resolution.

As the reduction of the resolution of an image can lead to loss of detail, and therefore prejudice the precision of the optical flow algorithm, this technique was not adopted in this work.

By cropping the areas of interest in the image it is possible to reduce the area in which the optical flow needs to be calculated without any loss of detail. The limitation of this area is done by utilizing the last known position and speed of the object being tracked, a rectangular cropping box centered in the last known position and with size equal to two times the last known speed multiplied by the time displacement between the video frames is created and the original image reduced to the size of this box, then the determination of the optical flow is done only in the cropped section of the image.

This reduction in the size of the image improves the execution time of the LK algorithm due to significantly smaller size in comparison with the full image. Further improvements are possible due to the fact that is possible to utilize the GPU to determine the optical flow for each tracked object in parallel, resulting in a very small total execution time.

The only problem in applying this technique, is that the previous position and speed of the objects should always be known and this is not possible in the first frame of the video. This is solved by determining the position of the objects in the first frame and considering that all the objects in the start of the game have speed equal to zero.

As the robots are differentiated by the use of colors. A simple thresholding utilizing the color of the object being tracked is realized and the resulting region is determined by finding the largest remaining area in the resulting image.

A great increase in the execution speed of the LK algorithm was also achieved by the use of the GPU to execute this algorithm.

5 RESULT ANALYSIS

To ensure the veracity of the results, all the tests were realized 100 times and the average and standard deviation of the execution time are shown in table 1.

The tests were executed in a computer containing a Core 2 Quad Q8400 processor (4 cores and 4 threads), with 8 gigabytes of DDR2 RAM memory, a NVidia GTX 1050 Ti with 4 gigabytes of GDDR5 memory graphics board and a Kingston SSD for storage.

Table 1: Experimental Results Obtained

Technique	Image Size (Pixels)	Average Execution Time (ms)	Standard Deviation
LK in CPU	1920x1080	54182.6927	9.4288
LK in GPU	1920x1080	977.9446	1.0851
LK in GPU	256x170	31.5333	0.6147

As shown in the table 1 the reduction of the execution time simply from using the GPU to calculate the optical flow between two images of the same resolution (1920 x 1080 pixels in this case) are very significant, this can be easily explained, since the utilized GPU has 768 processing cores, competing against 4 of the utilized CPU.

Further improvements were obtained with the use of a smaller size immage, allowing for the better exploration of the graphics processor resources and a even smaller exection time.

In the work of Shukla and Patel (2013) a similar strategie to the one described in this paper was adopted in order to determine the speed of moving vehicles, however the images in their work had a resolution of only 120 by 160 pixels and a 15 frames per second sample rate. In this work we obtained a similar result with a much higher resolution and doubled sample rate. In addition, it was not necessary to reduce the resolution of the images so that the processing could be carried out in real time, which allows a greater degree of detail in the images.

The reduction in size of the image further increased the execution speed and allowed for the execution in parallel of the tracking of all the features important to the application.

6 CONCLUSION AND FUTURE WORK

The technique described in section 4 proved to be very useful for the extraction of information from the images of the game. Also the use of a GPU to perform the image analysis related tasks has reduced the consumption of processor time and memory, leaving more resources for the development of the artificial intelligence needed in the control system of our robot soccer team.

Although the strategy presented in this paper was able to solve the problems presented by the specific instance of the IEEE Very Small Size Soccer, it is still necessary to do an evaluation of this technique in other scenarios to determine if it is viable for the solution of more general problems.

Also, further research is necessary to determine if the addition of more graphical processing units can further reduce the execution times of the image analysis techniques applied in this work.

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