UNIVERSITY POLITÉCNICA SALESIANA

SUBJECT: COMPUTER VISION

Intercycle Integration Project

Made by:
Samuel Pardo y Jairo Salazar

Teacher:
Vladimir Robles Bykbaev

Period:
69

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I. Introduction

[h!] Nowadays, mobile applications have a significant impact on various fields of technology, especially in areas such as computer vision. Real-time image processing has enabled remarkable advances in applications ranging from security to augmented reality. This project aims to develop a mobile application capable of capturing images and processing them using advanced computer vision techniques.

To achieve this, the ESP32-CAM-MB board, which integrates the OV2640 camera, will be used as a video capture device. This board will be configured to deploy a video streaming server, allowing the mobile application to receive the images captured from the camera in real time through a WiFi connection. In the mobile application, preprocessing of the images will be performed, using techniques such as binarization, thresholding, edge detection, pixel manipulation, and the application of filters to generate visual effects in real time.

The objective of this project is to implement an efficient system for image capture, processing and visualization, taking into account the hardware limitations of the ESP32-CAM-MB board and the mobile application. In addition, the performance of the system will be evaluated, measuring parameters such as the frame rate per second (FPS), RAM usage and the bandwidth required for data transmission, which will allow analyzing the feasibility of this approach for real-time applications.

This report describes the development process of the mobile application, the streaming server and the implementation of the computer vision techniques, as well as the results obtained during the performance tests and the discussion on possible improvements and future extensions of the project.

II. Practical description and steps

II-A. First Phase: Design of the Filter for the Mobile Application

objective

The main objective of this phase was to develop and test a complex visual filter that would be subsequently applied to the images captured from the OV2640 camera on the ESP32-CAM-MB board. The filter had to be able to apply various visual effects to the images efficiently, so that they could be transmitted in real time over the Wi-Fi network and displayed on the mobile application. [1].

Filter Description

The designed filter integrates various pixel manipulation and image processing effects, among which the following stand out:

- **Glitch Effect:** This effect introduces random alterations in the rows of the image, shifting them erratically to generate a visual effect that simulates a malfunction of the image. To achieve this, the code uses a randomization in the displacement of the rows of the image, which produces a high intensity ”glitch.[ef]fect, adjustable through a control bar in the application interface. [2].
- **Random Noise:** In addition to the glitch effect, random noise was added to the images, which increases visual distortion and contributes to the creation of a retro or interference style. [3].
- **Edge Detection:** The Canny edge detection algorithm was used to identify the outlines of objects within the image. This technique converts the image to grayscale and then applies an edge filter to highlight key lines and structures in the image. [4].
- **Edge Colorization:** After edge detection, a colorization technique was applied where the detected edges are colored with a color palette. This step gives a more striking and contrasting visual effect to the edge areas, making them stand out from the original image. [5].
- **Smoothing Filters:** To ensure that edges and other effects are not too harsh, anti-aliasing filters (such as the Gaussian filter) were applied to smooth out transitions and improve the visual quality of the final result. [6].

Technical Implementation

The filter was implemented in C++ Using the library **OpenCV** [7]. Through OpenCV, operations such as converting the image to grayscale, edge detection, pixel manipulation, and applying noise and glitch effects were performed. Additionally, trackbars were configured to dynamically adjust the intensity of glitch effects, noise, and edge color changes, allowing for more precise control during testing [**?**].

The filter code was structured into several main functions:

- `applyAdvancedGlitchEffect()` : Applies the glitch effect to the image. Row offsets are randomized, and random noise is added [2].
- `applyCanny()` : Performs edge detection using the Canny algorithm [4].
- `colorizeEdges()` : Assigns colors to the edges detected in the image [5].
- `main()` : Manages the workflow for video capture, effect application, and real-time visualization [7].

Testing and Results

During this phase, real-time tests were conducted on the filter applied to images captured by the device's camera. Aspects such as visual quality of effects, performance, and usability were evaluated. The tests allowed parameters to be adjusted to optimize both visual quality and performance in the future, especially in the context of the mobile application, which will need to handle processed images in real-time.

Phase Conclusions

The first phase successfully created a robust and functional visual filter that combines several advanced image manipulation effects. Once finalized, this filter is ready to be integrated into the mobile application, where it will be used to process images in real-time while capturing video from the ESP32-CAM-MB board.

II-B. Second Phase: General Application Structure

The application structure is primarily defined in the `MainActivity.java` class, which manages the user interface and native code integration. This section outlines the key aspects of the implementation.

1. Carga de la librería nativa

```
static { System.loadLibrary(.ªplicacionnativa"); }
```

1. Loading the Native Library

```
static  System.loadLibrary(.ªplicacionnativa");
```

Loading the `aplicacionnativa` library enables Java code to interact with C++ functions that implement image processing effects, such as the glitch effect. This library is compiled from native code and integrated into the Android project using the NDK (Native Development Kit) [8].

2. User Interface

In `MainActivity.java`, several user views such as `SeekBar`, `SurfaceView`, and `WebView` are defined to allow user interaction with the application:

- `SeekBars`: Allow the user to adjust the intensity of visual effects, such as glitch distortion and edge intensity.

- `SurfaceView`: Displays processed images in real-time.
- `WebView`: Loads and displays video streaming from the ESP32-CAM-MB camera, processing each frame to apply effects.

The use of these views provides a more interactive user experience, enabling real-time modification of visual effect parameters [9].

3. Continuous Image Processing

Within the `surfaceCreated()` method, a thread is started to capture frames from the `WebView`, apply visual effects, and render them on the `SurfaceView` to display the result:

```
startContinuousProcessing();
```

This processing occurs at regular 30ms intervals to ensure a continuous and smooth visualization of processed images. This optimization guarantees real-time performance even with complex image processing [10].

NATIVE CODE (C++)

The C++ code handles the implementation of visual effects, specifically the glitch effect and edge manipulation. OpenCV is used to efficiently manage the images [11].

1. Conversion Between Bitmap and Mat

The function that converts an Android `Bitmap` object into an OpenCV `Mat` object is as follows:

```
cv::Mat bitmapToMat(JNIEnv* env, jobject bitmap) {
    AndroidBitmapInfo info;
    void* pixels;
    AndroidBitmap_getInfo(env, bitmap, &info);
    AndroidBitmap_lockPixels(env, bitmap, &pixels);
    cv::Mat mat(info.height, info.width, CV_8UC4, pixels);
    return mat;
}
```

The `bitmapToMat` function converts the `Bitmap` object into an OpenCV `Mat` object to enable image manipulations. This conversion is essential as it allows images to be processed by OpenCV, which has specific functions for efficient pixel manipulation [12].

2. Applying Visual Effects

Within the C++ code, functions are implemented to apply effects such as the glitch effect and edge manipulation:

- Glitch Effect: Introduces random distortion to the image pixels to simulate a visual .erroré creating the glitch effect. This is one of the application's most prominent effects and can be adjusted using the corresponding `SeekBar` in the user interface.
- Edges: Applies a color change effect to the image edges, also adjustable via another `SeekBar`.

The C++ code uses OpenCV to apply these effects. Pixel manipulation and distortion are performed using OpenCV-specific functions that provide detailed control over the image [13].

OpenCV and NDK Integration

The native C++ code leverages OpenCV's capabilities to handle image manipulation and apply effects. Through integration with the Native Development Kit (NDK), Java code can interact with C++ functions without performing image processing directly in Android's user interface, improving performance and enabling more complex visual effects [8].

Execution Flow

The application flow is as follows:

1. The `WebView` loads the video stream from the ESP32-CAM-MB camera.
2. Each frame of the stream is captured and processed in a separate thread.
3. The frame is converted to a `Mat` format using OpenCV.
4. The selected visual effects (glitch and edges) are applied.
5. The processed frame is displayed in the `SurfaceView`.

This flow repeats continuously, ensuring a real-time image processing experience [10].

III. Implementing the Filter

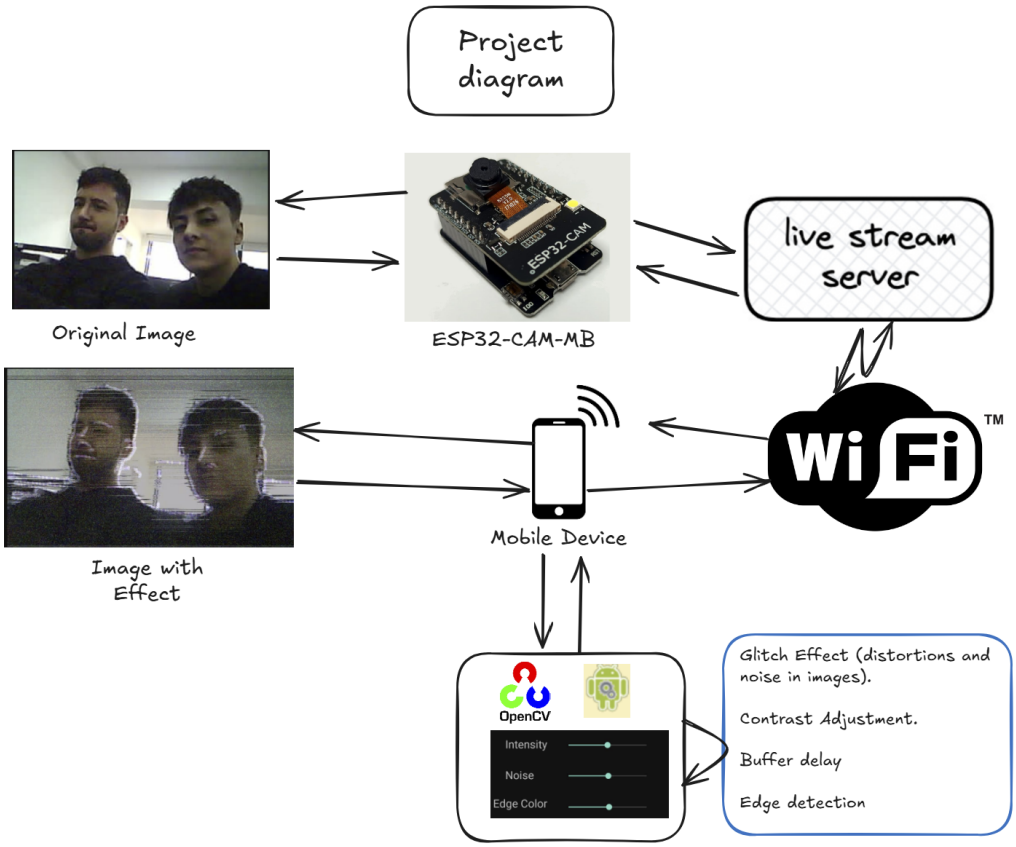

Figura 1: Project Diagram

```cpp
cv::Mat applyAdvancedGlitchEffect(const cv::Mat& input, int glitchIntensity, int noiseAmount) {
    if (input.empty()) {
        LOGE("La imagen de entrada está vacía en applyAdvancedGlitchEffect.");
        return input;
    }

    cv::Mat output = input.clone();
    int rows = output.rows;
    int cols = output.cols;

    for (int i = 0; i < rows; i++) {
        if (rand() % 100 < glitchIntensity) {
            int shift = rand() % 30;
            if (rand() % 2 == 0) {
                output.row(i).copyTo(output.row((i + shift) % rows));
            } else {
                output.row(i).copyTo(output.row((i - shift + rows) % rows));
            }
        }
    }

    cv::Mat noise = cv::Mat::zeros(output.size(), output.type());
    randn(noise, 0, noiseAmount);
    output += noise;

    cv::min(output, 255, output);
    cv::max(output, 0, output);

    return output;
}
```

Figura 2: Glitch Filter Method

```cpp
Mat applyCanny(const Mat& input) {
    Mat gray, edges;

    cvtColor(input, gray, COLOR_BGR2GRAY);

    Canny(gray, edges, 100, 200, 3);

    GaussianBlur(edges, edges, Size(5, 5), 0);
    return edges;
}
```

Figura 3: Canny's method

```cpp
Mat colorizeEdges(const Mat& edges, int edgeColorChange) {
    Mat coloredEdges = Mat::zeros(edges.size(), CV_8UC3);

    for (int y = 0; y < edges.rows; ++y) {
        for (int x = 0; x < edges.cols; ++x) {
            if (edges.at<uchar>(y, x) > 0) {
                int intensity = edges.at<uchar>(y, x);

                int amplifiedChange = edgeColorChange * 10;

                coloredEdges.at<Vec3b>(y, x) = Vec3b(
                        (intensity * amplifiedChange) % 256,
                        (intensity * amplifiedChange / 2) % 256,
                        (intensity + amplifiedChange) % 256
                );
            }
        }
    }
    return coloredEdges;
}
```

Figura 4: Method for colorizing edges

IV. RESULTS

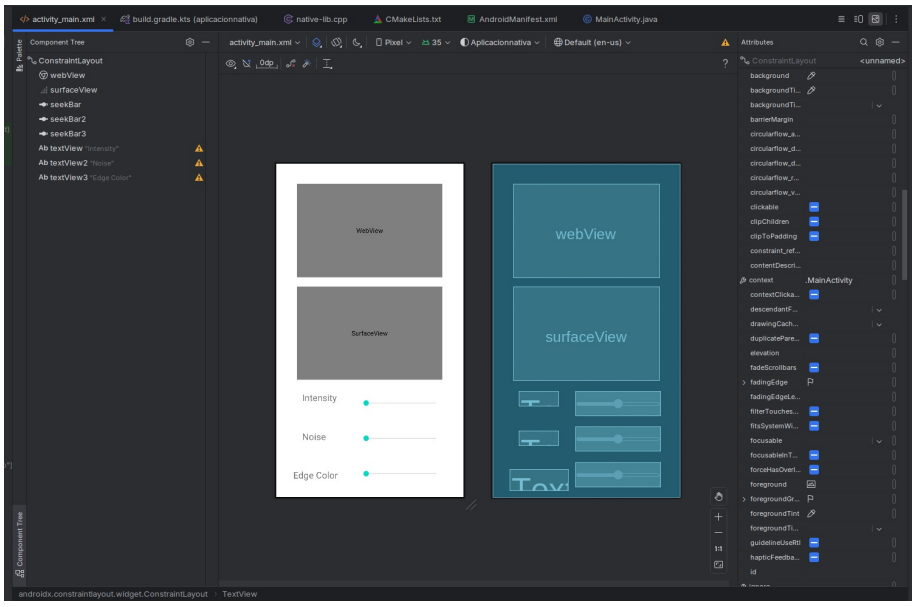

Figura 5: App XML

Figura 6: Application

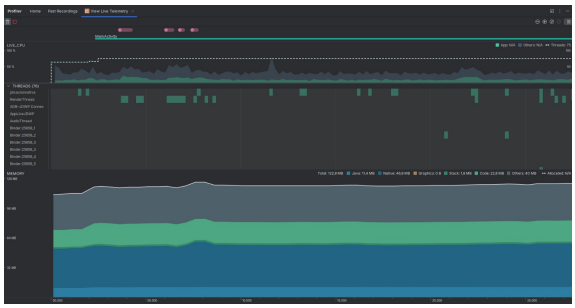

Figura 7: CPU Performance and Memory Test

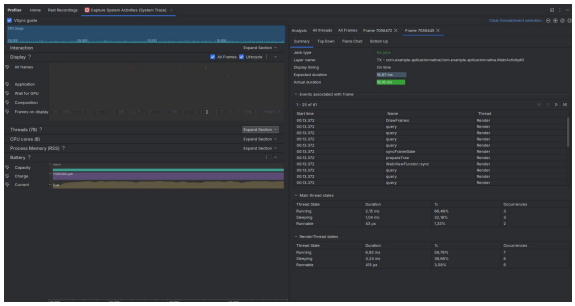

Figura 8: Frame Performance

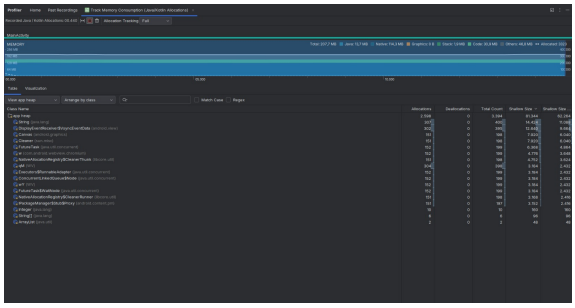

Figura 9: Memory Activity

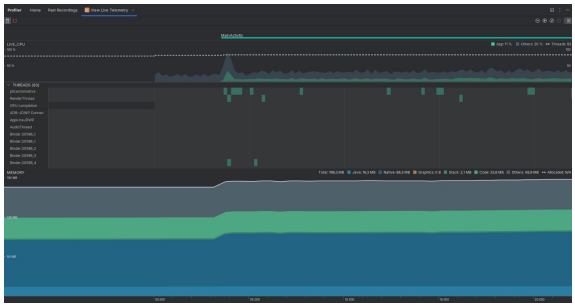

Figura 10: CPU Performance and Memory Test 2

IV-A. Application Performance Analysis

During the development of the mobile application, the **Android Profiler** tool was used to analyze real-time performance. Below is a description of the most relevant aspects monitored:

IV-A1. CPU Usage: The top graph illustrates the percentage of CPU usage (*LIVE_CPU*) during application execution. The results show that the processor remains below 50 % utilization, with occasional spikes likely linked to intensive tasks such as image processing or applying visual effects. The dashed line represents the expected average limit, highlighting a moderate use of resources.

IV-A2. Execution Threads: The application uses 75 active threads, including tasks such as background processing, graphical rendering, and network communication. Key threads include:

- **pilaConativa**: Related to native libraries like OpenCV for image processing.
- **RenderThread**: Responsible for handling graphics and UI rendering.
- **Binder**: Used for inter-process communication in Android.

The proper distribution of tasks among threads ensures system efficiency.

IV-A3. Memory Usage: Memory analysis indicates a total consumption of **122.9 MB**, distributed as follows:

- **Java:** 11.4 MB, used for managing objects in the Java heap.
- **Native:** 46.9 MB, associated with native libraries like OpenCV.
- **Code:** 22.8 MB, corresponding to executable code.
- **Others:** 40 MB, utilized for textures and buffers.

The graph shows a gradual increase in memory usage, likely due to the accumulation of processed data. This behavior suggests the need to release unused resources to avoid overloading.

V. Conclusions

The analysis reveals efficient CPU usage with a proper task distribution among threads.The application is designed to provide an interactive experience where the user can apply real-time visual effects on images captured from the ESP32-CAM-MB camera. The integration between Java and C++ through the use of NDK and OpenCV ensures efficient and fluid processing of the images. The use of `SeekBar` to adjust the intensity of the visual effects allows for a high degree of customization of the results.

VI. links

Link video:https://drive.google.com/file/d/1iA6Ftuaf_ARdKmZ1_D_xYZJZ-oOchAA1/view?usp=sharing

Link Code Repository: https://github.com/spardoc/AppVision.git

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