School of Electronics and Communication Engineering

Report on

GMSL Link Quality Analyzer

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CERTIFICATE

This is to certify that the project entitled **"GMSL Link Quality Analyzer"** is a bonafide work carried out by the student team of **Amish Bhushan Kulkarni (USN: 01FE22BEC099), Sambhram Doddamne (USN: 01FE22BEC132), Bhavani Inamdar (USN: 01FE22BEC199), Prarthana Devaraj (USN: 01FE22BEE051)**.

The project report has been approved as it satisfies the requirements with respect to the mini project work prescribed by the university curriculum for BE (V Semester) in the School of Electronics and Communication Engineering of KLE Technological University for the academic year 2024–2025.

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-The Project team

ABSTRACT

Ensuring the quality of multimedia data transmission has become crucial, especially for safety-critical automotive applications, as high-speed serial links are increasingly being used in intelligent mobility platforms. In these systems, camera and sensor data is commonly transmitted using the gigabit multi-media serial link (GMSL) standard. Creating a GMSL Link Quality Analyser is the main goal of this project in order to assess and model the behaviour of a GMSL camera system and guarantee dependable data transfer. Our analyser replicates key link characteristics under controlled conditions by using an ARDUCAM camera as a functional replacement for a GMSL source and the NVIDIA Jetson platform.

Three essential parameters [mean, standard deviation, and checksum] are used in qualitative analysis of image frames captured using the suggested methodology. The standard deviation aids in determining the variation in pixel values for evaluating sharpness, the checksum ensures the integrity of the data during transmission, and the mean intensity gives an estimate of the overall brightness of the image. Real-time classification was made possible by the definition of thresholds that distinguished between corrupt and non-corrupt frames. Statistical analyzes, including the effective frame percentage, were performed in a number of tests to confirm the robustness and consistency of the analyzer.

For multimedia link diagnostics in automotive systems, our implementation offers a scalable and reasonably priced solution. The project can be expanded for future applications that involve checksum validation on every 1,000 pixels for live sensory streams, even though it simulates a GMSL setup. It also accurately models real-world transmission characteristics. The analyzer can be integrated into automotive testing frameworks and embedded diagnostic tools, which will help to make perception systems in connected and autonomous cars more reliable.

Contents

Chapter 1

Introduction

Serial communication standards like GMSL (Gigabit Multimedia Serial Link) are widely used in the automotive and intelligent mobility industries due to the need for dependable and fast data transmission. GMSL is an essential part of ADAS (Advanced Driver Assistance Systems) and autonomous vehicle platforms because it is mainly used to send high-resolution video and sensor data over long distances with low latency. The proper operation of perception systems in such vehicles depends on the quality and integrity of data transferred over GMSL links. However, conventional link quality testing techniques frequently necessitate costly hardware configurations and are not adaptable enough to be integrated into embedded environments.

In order to replicate the behaviour of a GMSL camera system, this project presents the design and implementation of a GMSL Link Quality Analyser. It was created using an ARDUCAM camera interfaced with the NVIDIA Jetson platform. Using metrics like mean brightness, standard deviation for sharpness, and checksum for transmission integrity, the analyser evaluates the quality of the frames that are captured. The system successfully distinguishes between corrupt and non-corrupt image frames by setting thresholds for these parameters. In addition to offering a useful tool for testing, development, and research in automotive embedded systems, the project provides a low-cost, scalable solution for real-time multimedia link quality monitoring and diagnosis.

1.1 Motivation

In automotive systems, especially those that use autonomous driving and ADAS, it is very important to quickly and reliably send camera and sensor data so that the system can work safely and accurately. GMSL links are commonly used for this, but developers often forget to check the quality of the data transmission. This made us want to make a system that can mimic a GMSL camera setup and check link quality by looking at measurable image parameters. We want to learn more about and rate the performance of multimedia links in real-time settings by keeping an eye on things like frame consistency, sharpness, and data integrity.

1.2 Objectives

- To assess the simulated GMSL camera system's visual performance by analysing frame rate, pixel clarity, and motion smoothness.

- To assess image quality utilising statistical metrics like mean and standard deviation.

- To carry out checksum validation in order to identify transmission noise, preserve data integrity, and detect corrupt frames.

1.3 Problem statement

In automotive systems, it is very important to be able to send multimedia data over GMSL links without any problems so that people can make the right decisions and see things clearly. It is hard, though, to check the quality of these links in real time. This project aims to simulate GMSL camera system and check the quality of the link using various parameters.

Chapter 2

GMSL

The Gigabit Multimedia Serial Link (GMSL) standard is a high-speed serial communication technology that plays a critical role in the transmission of uncompressed multimedia data in real-time systems. It was primarily developed to meet the demands of modern automotive platforms, where sensors and high-resolution cameras continuously relay vital information to central computing units.

In the context of autonomous vehicles and Advanced Driver Assistance Systems (ADAS), timely and accurate transmission of visual data is essential for environment perception, decision-making, and vehicle control. Any delays, corruption, or inconsistencies in this data could lead to functional failures in safety-critical applications. Hence, evaluating the quality of data transferred over GMSL links becomes a priority.

This project presents a simulation of GMSL behavior using an ARDUCAM camera setup interfaced with an NVIDIA Jetson Orin platform. The system replicates the functional characteristics of a GMSL camera link and performs quality analysis on the received video stream using statistical metrics such as mean, standard deviation, and checksum. This approach offers a low-cost, scalable alternative for real-time multimedia link diagnostics.

2.1 About GMSL

GMSL is a point-to-point communication protocol developed by Maxim Integrated (now part of Analog Devices) for transmitting high-bandwidth multimedia data. It is capable of transferring high-definition video, audio, and control signals over a single coaxial or shielded twisted pair cable. GMSL links provide features such as:

Figure 2.1: Block Diagram of GMSL

- **High Data Rates:** Supports data transmission rates up to several gigabits per second, suitable for multiple high-resolution camera streams.
- **Power over Coax (PoC):** Allows simultaneous power and data transmission over the same cable, reducing wiring complexity.
- **Long Cable Support:** Maintains signal quality over distances up to 15 meters or more.
- **EMI Resistance:** Designed for harsh automotive environments with strong electromagnetic interference.
- **Control Channel:** Includes bi-directional control and I2C communication capabilities for sensor control and synchronization.

Two generations of GMSL exist — GMSL1 and GMSL2 — with GMSL2 offering improved features, higher bandwidth, and better integration for modern automotive systems.

2.2 Use Cases of GMSL

GMSL technology is widely adopted in both automotive and industrial sectors. Its robust data handling, reliability, and efficiency make it suitable for several high-performance, real-time applications. Key use cases include:

- **Advanced Driver Assistance Systems (ADAS):** GMSL transmits real-time camera feeds to the central processing unit for features like automatic braking, pedestrian detection, and lane departure warning.

- **Autonomous Driving Systems:** Multiple camera and sensor streams are fused to create a 360-degree understanding of the vehicle's surroundings. GMSL enables fast and reliable communication between these components.
- **Surround View and Blind Spot Monitoring:** Video feeds from various directions are stitched into a panoramic view for improved driver awareness during parking and lane changes.
- **In-Vehicle Infotainment (IVI):** High-resolution media is delivered to dashboards and rear-seat displays without latency or loss using GMSL, ensuring a seamless user experience.
- **Industrial Machine Vision:** GMSL is also employed in industrial automation for high-speed image processing tasks such as inspection, object tracking, and quality control.

These use cases highlight the critical importance of GMSL in modern intelligent systems. Its ability to deliver reliable, high-quality data in real time makes it a backbone technology for perception in connected and autonomous environments.

Chapter 3

Implementation

This chapter discusses the end-to-end implementation of the GMSL Link Quality Analyser. The system is designed to simulate the behavior of a GMSL-based camera feed and perform real-time analysis of the transmitted frames to ensure data reliability. The core goal is to detect anomalies in transmission that could arise due to link degradation, noise, or hardware faults.

To achieve this, the project uses an ARDUCAM camera as a functional substitute for a GMSL camera. The video stream is acquired via the GStreamer pipeline and processed using the OpenCV library on the NVIDIA Jetson Orin platform. Each frame undergoes statistical evaluation based on three key metrics — mean, standard deviation, and checksum. Corrupted frames are flagged based on threshold rules and visually indicated in the output window.

The output window displays both the camera feed and the calculated quality parameters in real time. This makes the analyser useful for debugging, testing, and evaluating multimedia links without the need for expensive automotive-grade hardware. The system is lightweight and can be extended to integrate with actual GMSL serializers and deserializers in future setups.

3.1 Hardware Specification

The hardware used in this project is chosen to emulate real-world GMSL conditions while keeping the system flexible and scalable for future integration. Below are the key hardware components:

- **NVIDIA Jetson Orin Developer Kit:** A high-performance edge computing platform capable of processing real-time video streams.

It features CUDA-enabled GPUs and ARM Cortex-A78AE CPUs, suitable for OpenCV-based image processing.

- **ARDUCAM 12.3MP IMX477 Camera:** A high-resolution MIPI CSI-2 camera that interfaces directly with the Jetson platform. It is used as a stand-in for GMSL cameras, producing full HD video streams at 30 FPS.
- **Monitor (HDMI Display):** Used to visualize the real-time video stream along with overlayed quality metrics and frame diagnostics.
- **Jetson-compatible Serializer/Deserializer (optional):** In advanced versions, these modules can be added to physically replicate GMSL signal behavior.
- **Power Supply and Cooling System:** Required for sustained operation of the Jetson during extended analysis.

This hardware setup ensures sufficient computational performance, sensor compatibility, and low-latency video handling required for accurate simulation and analysis.

3.2 Algorithm

The implemented algorithm performs real-time analysis of video frames by evaluating brightness, sharpness, and data consistency. Below are the detailed steps:

1. **Video Capture Initialization:**
   - Launch a GStreamer pipeline to stream live video from the ARDUCAM camera.
   - Use OpenCV's 'VideoCapture' interface to receive each frame.
2. **Preprocessing:**
   - Convert each frame from BGR to grayscale using 'cv::cvtColor'.
   - Store the grayscale image for further analysis.
3. **Mean and Standard Deviation Calculation:**
   - Calculate the average intensity (mean) to assess overall brightness.

- Compute the standard deviation to estimate image sharpness and variation.

4. **Checksum Calculation:**
   - Apply a simple XOR or additive checksum over the grayscale pixels.
   - This acts as a lightweight data integrity check.
5. **Corruption Detection:**
   - A frame is flagged as corrupt if:
     - Checksum = 0 or 255 (indicating potential loss or noise)
     - Standard deviation lesser than 2.0 (implies flat or frozen frames)
   - Maintain a counter of corrupted frames.
6. **Visualization:**
   - Overlay calculated statistics (mean, std dev, checksum, corruption count) on the frame using ‘cv::putText‘.
   - Display the processed frame using ‘cv::imshow‘.
7. **Termination:**
   - The system continues analysis until the ESC key is pressed.

This algorithm ensures that each frame is independently analyzed, and any deviation from normal quality is detected and recorded immediately. It forms the core of the link quality assessment methodology and lays the foundation for more advanced error modeling in future work.

3.3 Flowchart

Pipeline: The project uses NVIDIA Jetson Orin with an Arducam over CSI to emulate a GMSL setup. Real-time video frames are captured and analyzed using C++ and OpenCV. Metrics like Mean, Standard Deviation, Checksum, and Latency help detect frame issues. Results are shown with live overlays and logged for later analysis.

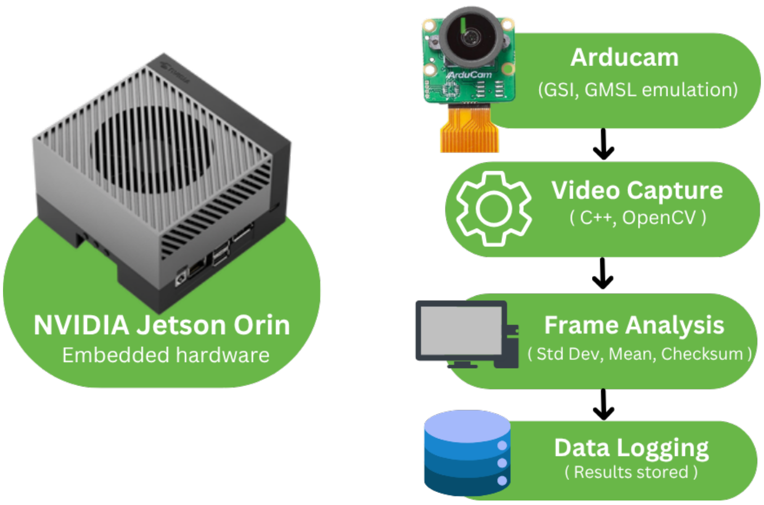

Figure 3.1: Flowchart of the proposed system

Chapter 4

Parameters

In order to assess the quality and integrity of the captured image frames, three key statistical parameters were used in this project: **mean**, **standard deviation**, and **checksum**. Each of these metrics serves a specific purpose in identifying issues such as image corruption, poor lighting, or loss of data fidelity during transmission.

These parameters are lightweight, computationally efficient, and suitable for real-time applications. By monitoring these metrics for every incoming frame, the system can instantly flag anomalies and assist in diagnosing the performance of multimedia links under simulated GMSL conditions.

4.1 Mean

The **mean** represents the average pixel intensity of a grayscale image. It provides a global indication of the image's brightness or exposure. If the mean value is too low, the image may be underexposed (too dark), and if it is too high, it may be overexposed (too bright).

$$\mu = \frac{1}{N} \sum_{i=1}^{N} I_i \tag{4.1}$$

Where:

- μ is the mean intensity
- I_i is the intensity value of the i^{th} pixel
- N is the total number of pixels

Purpose in the Project: Mean values help identify general brightness problems in the video feed. Significant deviations from expected brightness levels can suggest sensor errors, misconfiguration, or lighting issues in the environment.

4.2 Standard Deviation

Standard deviation (σ) measures the spread or variation in pixel intensity values. It indicates how sharp or flat the image is. Higher values indicate more variation (edges, texture), while lower values suggest flat, uniform regions — possibly indicating frozen or blurred frames.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(I_i - \mu)^2} \tag{4.2}$$

Where:

- σ is the standard deviation
- I_i is the intensity of each pixel
- μ is the mean intensity
- N is the total number of pixels

Purpose in the Project: If the standard deviation falls below a predefined threshold (e.g., 2.0), the frame is considered potentially corrupted or frozen. A very low standard deviation indicates lack of edge variation or complete stillness — which might be caused by a frame not updating properly.

4.3 Checksum

A **checksum** is a lightweight mathematical operation used to verify data integrity. In this project, it is calculated by applying XOR or summation over the grayscale pixel values of the frame and then taking the result modulo 256.

$$Checksum = \left(\sum_{i=1}^{N} I_i\right) \bmod 256 \tag{4.3}$$

Alternate (XOR-based) version:

$$Checksum = I_1 \oplus I_2 \oplus \cdots \oplus I_N \tag{4.4}$$

Purpose in the Project: Checksum helps identify frame-level corruption or data loss during transmission. A frame with a checksum value of 0 or 255 (extremes) may indicate uniform pixel values (i.e., frozen, blacked-out, or noise-heavy frames). Comparing checksums across consecutive frames also helps detect if the video feed is repeating or stuck — useful for frozen frame detection.

Threshold Conditions:

- **Frozen Frame:** Checksum remains unchanged for multiple frames
- **Corrupted Frame:** Checksum = 0 or 255 and standard deviation $<$ 2.0

These parameters collectively help in performing real-time, computationally efficient quality analysis for live video streams.

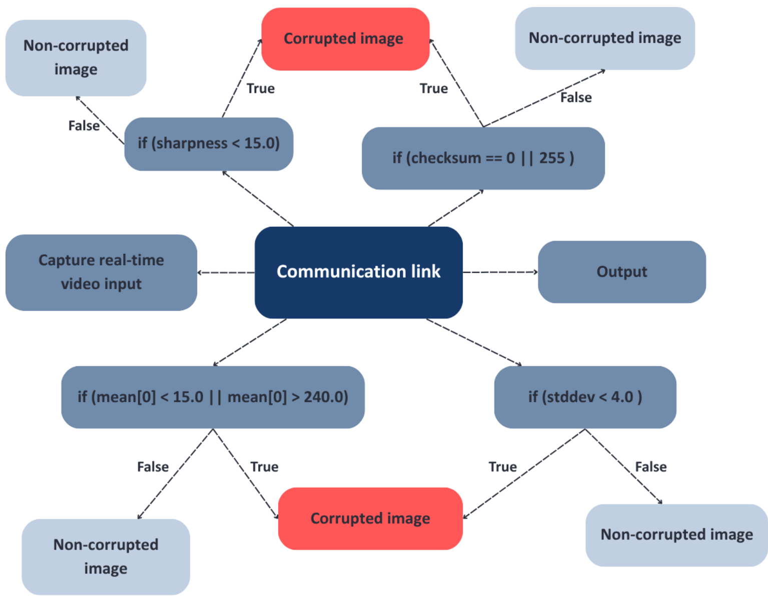

Figure 4.1: Parameters

Chapter 5

Results and Discussions

This chapter presents the outcomes observed during the implementation of the GMSL Link Quality Analyser and interprets their significance in the context of real-time multimedia transmission reliability.

5.1 Results

The system successfully captured and analyzed live video frames at 30 frames per second (FPS), evaluating each frame based on mean intensity, standard deviation, and checksum.

Key outcomes include:

- Real-time computation and display of statistical parameters on every frame.
- Accurate identification of corrupt frames using checksum anomalies and low standard deviation thresholds.
- Continuous frame monitoring for signs of freezing, brightness loss, and data inconsistency.
- Live overlay of frame diagnostics including:
  - Mean brightness level
  - Sharpness indicator (via standard deviation)
  - Checksum value
  - Count of corrupted frames

Visual testing showed that frames with checksum = 0 or very low standard deviation (< 2.0) often indicated camera stall or transmission glitch. The interface flagged such frames reliably, even in long-duration tests.

5.2 Indicators of a Corrupted Frame

Corrupted frames in a video stream can be caused by transmission errors, noise, sensor glitches, or hardware inconsistencies. In this project, specific thresholds were defined to flag potentially corrupted frames based on statistical anomalies in the image parameters.

A frame is likely considered **corrupt** when it satisfies the following conditions:

- **Mean < 15:** Indicates the frame is extremely dark or underexposed, often resulting from transmission failures or camera sensor issues.
- **Standard Deviation < 4:** Reflects very little variation in pixel intensities, suggesting a flat or blank image, possibly due to frozen frame repetition.
- **Sharpness < 15:** Implies lack of image detail, commonly associated with defocused, frozen, or blank frames.

When one or more of these conditions are detected, the frame is flagged for review and counted as a corrupted sample in the quality analysis pipeline. This rule-based approach allows lightweight yet reliable detection of anomalies in real-time environments.

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5.3 Discussions

The results validate the effectiveness of using basic statistical metrics for diagnosing multimedia link integrity. Mean and standard deviation provided real-time insight into lighting and sharpness, while checksum proved to be a lightweight yet powerful indicator of frame corruption.

While the system simulated GMSL behavior using MIPI CSI and ARDUCAM hardware, the overall architecture reflects the challenges faced in high-speed serial communication. The chosen parameters allowed the system to detect:

- **Underexposed/Overexposed Frames:** Detected via extreme mean values.
- **Frozen or Static Frames:** Identified by comparing checksum across frames.

- **Noisy or Corrupted Frames:** Recognized through irregular checksum and extremely low standard deviation.

The analyzer proved to be responsive, computationally efficient, and adaptable for embedded deployment. However, false positives might occur under highly uniform scenes or abrupt lighting shifts — areas that future enhancements can improve upon.

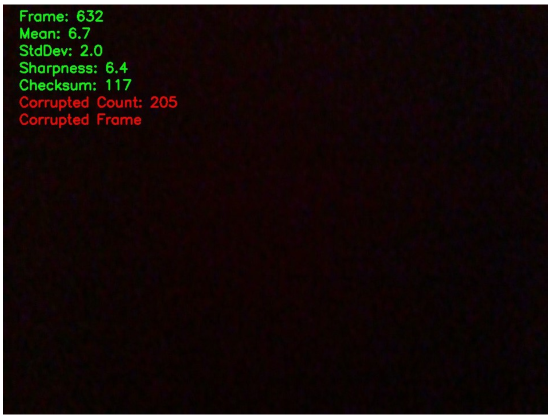

Figure 5.1: Example of a corrupted video frame

Explanation for Corrupt Frame:
This frame is classified as corrupt due to abnormal parameter values: the mean is less than 15, the standard deviation is below 4, and the sharpness is also below 15. These characteristics indicate poor lighting or static/noisy content, confirming frame corruption.

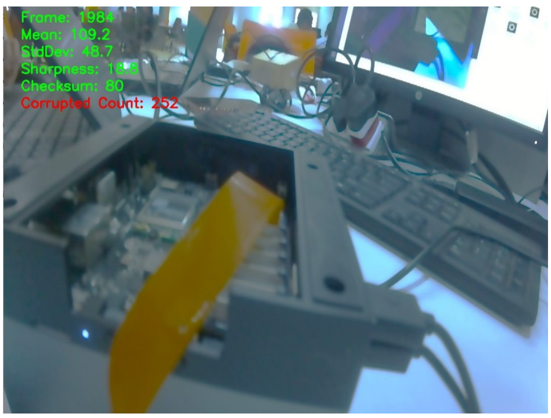

Figure 5.2: Example of a clean (non-corrupted) video frame

Explanation for Non-Corrupt Frame:
This frame is identified as non-corrupt based on valid parameter thresholds:

the mean lies between 15 and 240, the standard deviation is greater than 4, and sharpness exceeds 15. Additionally, the checksum is valid (not equal to 0 or 255), indicating data integrity.

Test no.	**Total Frames Captured**	**Corrupted**	**Frozen**
1	653	7	2
2	7323	28	58

Table 5.1: Frame analysis across different test scenarios

Quality analysis calculations:
Test 1: Effective frame % = $\frac{653-9}{653} \times 100 = 98.6\%$

Test 2: Effective frame % = $\frac{7323-86}{7323} \times 100 = 98.826\%$

Chapter 6

Conclusion and Future Scope

This chapter summarizes the outcomes of the project and outlines potential directions for enhancement and application in future work.

6.1 Conclusion

The GMSL Link Quality Analyser successfully demonstrated a reliable method for assessing the quality of real-time image transmission in automotive and embedded systems. By evaluating statistical parameters such as mean, standard deviation, and checksum, the system was able to detect corrupted and degraded frames without relying on complex image recognition models.

The simulation using ARDUCAM and Jetson Orin allowed us to replicate a GMSL-like setup in a scalable and cost-effective manner. The implementation met all core objectives:

- Continuous monitoring of image stream quality
- Detection of corrupted, frozen, or noisy frames
- Real-time visualization of parameter overlays

The project provides a strong foundation for diagnostics in safety-critical multimedia links where data integrity and consistency are essential.

6.2 Future Scope

While the current implementation provides real-time feedback and accurate detection, several improvements and extensions can be considered:

- **Frame Classification Model:** Integrating machine learning to classify types of corruption (noise, blur, freeze) more intelligently.

- **Hardware Integration:** Incorporate actual GMSL serializers and deserializers to analyze physical link behavior.
- **Temporal Tracking:** Track parameter trends over time to detect intermittent faults or slow degradation.
- **Extended Metrics:** Include histogram entropy, edge density, or PSNR as additional quality indicators.
- **Web Interface:** Real-time streaming and diagnostics accessible remotely via a browser.

This project can serve as a diagnostic layer in real-time perception pipelines for autonomous vehicles, contributing to improved safety and reliability in future mobility systems.

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