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Bachelor Thesis

Development and Evaluation of a Manufacturer-Independent Synchronization Framework for GenICam Industrial Cameras

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Matriculation Number: 465977

Berlin, January 22, 2025

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Abstract

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Declaration of Authorship

I hereby declare that I have prepared this Bachelor's thesis independently, without external assistance, and have used no sources or aids other than those indicated. All passages taken literally or in substance from other sources are clearly identified as such.

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1 Introduction

1.1 Background

With the growing need for optimization in manufacturing—particularly in labor-intensive processes like sorting and classification—machine vision emerged in the late 20th century as a technology that revolutionized industrial automation.

In its early stages, machine vision was primarily hardware-based. High-resolution cameras capture images under carefully predefined conditions, including lighting, object positioning, and camera angles. Deterministic algorithms then processed these frames to determine outcomes, such as approving or rejecting a product during quality inspection. However, with recent advancements in machine learning—machine vision being no exception—the field has shifted increasingly toward software-driven solutions. Deep learning models, in particular, are now used to perform process control and quality assurance tasks. Consequently, machine vision has evolved into a key enabler of computer vision, offering capabilities including image recognition, object detection, and semantic segmentation.

The rapid expansion of machine vision applications has also triggered significant shifts in the camera manufacturing industry. The global market for industrial cameras continues to grow [1], prompting an increase in industrial camera manufacturers. To address this diversification, standards such as GenICam [2], developed by the European Machine Vision Association (EMVA [3]), have been introduced. These standards aim to regulate and streamline the operation of cross-manufacturer cameras, thereby reducing integration costs and simplifying implementation for both users and developers.

1.2 Problem Statement

As machine vision evolves into computer vision, unlocking capabilities for more dynamic settings introduces several challenges.

One primary challenge is the reliance on machine learning models. While traditional machine vision systems employ deterministic algorithms to process predefined inputs, the integration of artificial intelligence requires large, diverse datasets to handle real-world variability effectively. For example, in fault detection, 3D data provides significantly greater accuracy than grayscale 2D data. However, acquiring 3D images—for instance, through contact 3D scanners—can be prohibitively expensive [4].

As a passive, non-contact 3D scanning method, stereoscopy offers a viable alternative for capturing different perspectives, but a multi-camera setup adds more complexity. One issue is integrating multiple cameras from various manufacturers into a single system. Although standardization efforts like GenICam strive to improve cross-manufacturer compatibility, many vendors still rely on proprietary software tied to their hardware, hindering seamless integration.

Another concern involves synchronizing frames from more than one camera. In many machine vision applications—such as industrial inspection and robotic guidance—perfect timing is crucial to avoid artifacts caused by motion, lighting inconsistencies, or other environmental factors. Even slight delays can lead to errors or missed defects, which can be particularly costly in high-speed manufacturing contexts. These scenarios introduce strict timing constraints, requiring precise synchronization across all sensors and cameras.

1.3 Goal and Scope

This thesis proposes a manufacturer-independent solution for configuring and controlling a synchronized multi-camera setup. The approach will involve evaluating hardware and software options for camera synchronization and implementing the chosen method(s) in a unified framework. This framework will enable users to easily configure and trigger synchronized recordings across up to six cameras.

The primary goal is to prevent hardware from becoming a bottleneck in various industrial applications. To this end, the project will leverage the GenICam standard alongside existing timestamps synchronization technologies. It will develop a scalable synchronization method and create an intuitive graphical user interface (GUI). This GUI will simplify the configuration and operation of the synchronization system, making it more accessible and straightforward for end users.

Beyond the scope of this thesis are tasks for synchronizing additional hardware (e.g., lighting or external sensors) and supporting non-GenICam-compliant devices. This work does not address data processing tasks, machine learning integration, advanced object detection algorithms, or real-time data analysis. While these areas are critical for specific applications, they fall outside the immediate focus of this project, which is primarily concerned with camera synchronization and user interface development.

These expected outcomes can be summarized as follows:

- **Evaluation of existing camera synchronization methods:** Includes an in-depth review of both hardware-based and software-based synchronization mechanisms. The evaluation will also focus on the key advantages and drawbacks of the different approaches, considering factors like integration, scalability, and costs.
- **Requirements specification and concept definition:** Outlines the hardware and software dependencies, including network specifications. It also identifies performance metrics for timing accuracy, sets latency thresholds, and defines constraints related to network bandwidth. The resulting specification ensures the system is scalable and compatible with industrial standards.
- **Implementation of a multi-camera synchronization solution:** Builds a software layer for synchronous acquisition-triggering and frame-timestamping of a multi-camera setup.
- **Development of a GenICam-based graphical user interface (GUI):** Streamline a GUI for the configuration and management of the camera setup, offering options for camera recognition, features control, and synchronous acquisition triggering.
- **Testing and evaluation:** Validates the proposed solution's functionality, reliability, and performance. The tests ensure that the system meets specified requirements and can be integrated effectively into industrial environments.

1.4 Outline

This thesis follows the outlined structure:

Chapter 2: Defines fundamental terms and technologies (GenICam, Synchronization, PTP..) and compares current implementations.

Chapter 3: Introduces the software, hardware, and network requirements.

Chapter 4: Outlines the design of the proposed solution, explaining and justifying design choices.

Chapter 5: Describes the implementation results and final product.

Chapter 6: Evaluates the results, detailing testing methodologies and validation criteria.

Chapter 7: Concludes the thesis by summarizing primary findings and highlighting encountered challenges.