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Efficient Video Surveillance: Performance Evaluation in Distributed Video Surveillance Systems

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1. Introduction

The ultimate aim of performance evaluation is to improve the system efficiency. Overall efficiency of the system is a combination of three factors: system functionality, performance and cost. Whereas system functionality improvement and cost optimisation are usually well understood and implemented the third factor of system performance is usually under prioritized. The development and improvements on system functionality are naturally driven by market requirements such as new features, compliance to common standards and adaptation of new technologies. The evaluation of system functionality is available by features benchmarking, etc. The evaluation of cost might be more complex due to the fact of different criteria of system pricing and various methods of following the costs of system and system maintenance. However, the cost of the system is also usually quite well evaluated and optimised - it is naturally driven by market economics. The task of performance evaluation followed with measurements and tests are usually performed only when certain performance problems appear in a system. Additionally, the methodologies to measure and evaluate system performance are not well known and understood. We believe that this approach should be changed. The factors describing system efficiency are interleaved - the performance can affect the cost of the system (usually long term maintenance costs) also the general system functionality depends upon system performance, a system of poor performance may not be able to accommodate new functionality or expand without difficult structural changes.

2. System performance evaluation approach

Evaluation of system performance is a difficult task: there are many different factors to consider, these factors may be (and usually are) interdependent. Moreover, they belong to different categories (see technical vs. business) which make them difficult to compare. There are various approaches on how to evaluate overall system performance. Our approach is to extract performance critical areas in the system and analyse what factors play the most important role in terms of performance. The combination of these factors will be a measure of overall system performance. The performance-critical system areas include: (a) data acquisition and system intelligence, (b) system architecture, (c) user-interface and user-oriented functionality. We try to analyse performance measurements methodologies and review available methods, rules, techniques or tools. Where applicable, we address methodology accuracy, results stability and analyse errors that may affect the quality of the measurements. We aim to provide the description of performance measurement process expended with collection of ideas, theories and concepts related to performance evaluation.

3. Data acquisition and system intelligence

A well performing and intelligent surveillance system will optimize the overall performance of the system by applying variety of intelligent tools. An intelligent system is able to perform initial filtering of the data based on its relevancy before any further processing is applied. It is able to combine the data in an efficient way to optimize a system for various criteria. Some level of intelligence might exist already on the data acquisition level (on the sensor) but intelligent cooperation between system and system's sensors is essential due to the fact the sensors have limited processing power (comparing to distributed system). The analysis of data acquisition performance also involves analysis of low-level detection and processing algorithms that allows a level of filtering of incoming data. Usually, at the level of data collection, data fusion analysis is not applied. The exceptions are the situations where the node posses mutli-sensor capabilities e.g. audio activated camera and the node is able to perform some pre-filtering. Intelligent systems are able to apply automation mechanisms and they also should have learning capabilities.

3.1 Data acquisition

In context of video surveillance systems data acquisition refers to processes of gathering relevant data. In most surveillance systems data is retrieved from multiple sources of different types, such as: (a) video and image content sensors, (b) HW sensors, (c) other sensors, such as audio, or bio-metrics. Despite the fact that in many cases the identification of relevant data is rather subjective, there are good metrics available allowing the evaluation of data acquisition processes. The methodologies evaluating data acquisition systems can be divided into multiple categories. The most applicable are the mapping procedures comparing data to ground truth plus other various ways of comparing data of many different systems. Additionally, the importance of context testing should be discussed. Mapping refers to the mapping of system results against the results gathered from either reference system or ground truth data. The term ground truth refers to information that is collected "on location" and that exists "in reality". The mapping procedure is used to map the results data to ground truth data. In terms of data acquisition for surveillance system ground truth data is the data indentified manually as the relevant and interesting one. Methods relying on ground truth comparison are very well understood. They can be used for many types of sensors but they are especially efficient and commonly used for evaluation of video and image analysis. One of the reasons is the fact that ground truth data can be prepared manually with good quality as the visual information is easier to identify and classify for humans. It is the preferred method to evaluate the quality of single video or image data acquisition system despite the fact the process of identifying the data relevancy may be subjective and the process of preparing ground truth data is laborious and slow. In order to evaluate the system using these methods, the benchmarking data is usually provided together with ground data (see example (PETS, 2010)) or even with ground data and automatic tools for generating scores. Various metrics can be used to compare the output of tested data acquisition systems to ground truth data. The most common metrics include: (a) precision, (b) recall, and (c) f-measure. The system of excellent performance is characterized by high values of precicion, recall and f-measure. The precision describes amount of relevant data within all the data retrieved. The precision can be measured as a rate (see Equation 1). It can be interpreted as probability of that (randomly selected) retrieved data is relevant.

$$Precision = \frac{\{\text{retrieved relevant data}\}}{\{\text{all retrieved data}\}} \tag{1}$$

The recall describes the amount of relevant data that has been retrieved within all the existing relevant data. The recall can be measured as a rate (see Equation 2). It can be interpreted as

probability of that (randomly selected) relevant data is retrieved.

$$Recall = \frac{\{\text{retrieved relevant data}\}}{\{\text{all relevant data}\}} \tag{2}$$

The performance of data acquisition systems can be described by these two measures by use of so called precision-recall curves. Other metrics are usually combining either recall or precision and provide either a more precision-oriented or recall- oriented approach. We will briefly present the most popular metrics which could be applied for measuring data acquisition in surveillance. If single score comparison is required, then the metric of F-measure can be used. F-measure (called also F1 score or F score) measures data retrieval accuracy by combining both measures of precision and recall (see Equation 3). F-measure itself can be weighted to be more recall or more precision- centred.

$$F = 2 * \frac{\{\text{Precision}\} * \{\text{Recall}\}}{\{\text{Precision}\} + \{\text{Recall}\}} \tag{3}$$

Additionally, (Kasturi et al., 2009) lists other metrics which are applicable for data acquisition in surveillance. We consider one to be very useful - SFDA (Sequence Frame Detection Accuracy). It was developed for VACE (US Government Video Analysis and Content Extraction) program. In addition to combining of precision and recall- type of measure the metric displays spatial distance between system output object and ground-data object. The other two metrics that we considered interesting in context of data acquisition for surveillance are: MODA (Multiple Object Detection Accuracy) and MODP (Multiple Object Detection Precision). All metrics proposed by (Kasturi et al., 2009) are available as a part of CLEAR program evaluation system (see (CLEAR, 2007)). The methods listed above provide a good base for evaluation of data acquisition systems in general but might not offer a definite answer as to whether system A performs better than system B in a given context - different systems performs well using different types of benchmark data. The benchmark data should reflect the usage scenario of the system.
The benchmark data for different testing context is widely available (see (Russell et al., 2008) and (Martin, 2001)). As all data acquisition methods rely on benchmarking data - test cases should be selected carefully. (Pavlopoulou et al., 2009) proposes the criteria to identify the test cases that should be used when comparing the systems. The comparison between the two solutions should be undertaken by further testing the areas of the biggest differences between algorithms. It will allows identification the weak and strong points of given solution. The results of this research can be applied to evaluation procedures in surveillance system.

3.2 System intelligence

The performance of system intelligence is very important performance factor for all systems where intelligent decision mechanisms exist. In particular, it concerns all the surveillance systems where video content analysis is applied. The primary function of video content analysis tools is to improve the time (speed), reliability and quality of access to relevant material. The secondary function is to provide system automation to improve user quality of work. Video content analysis tools provide various system functionalities, such as: predefined scenario alerting, forensic search capabilities, statistical analysis, traffic flow control and more. Video content analysis is widely deployed in surveillance applications for urban environments, high security objects (usually for access control purposes) and commercial areas. Adding intelligent system tools should have an immediate positive effect on system performance. The system should increase probability of detection. However, the final result of applying intelligent system tools might be also negative. The system intelligence applications

operations are scenario- specific, dependent on data context and their efficiency relies on configuration efforts. (Desurmont et al., 2004) reviews the challenges of video content analysis deployment, (Ashani, 2009) evaluates the deployment cases of video content analysis for urban environment applications, (Finn, 2004) addresses the problems related to intelligent surveillance in public transport, and (Lipton et al., 2004) presents video content analysis tools deployment for forensics application. Despite of the fact the video content analysis is well popularized and widely researched, the deployment of the video analytics is considered as one of the most risky areas in surveillance business. It is worth to mention that video content analysis tools should not only have positive impact on system performance but also should have minimum impact on remaining system efficiency factors - cost level and general system features. These facts are major motivations towards introducing pre-deployment performance evaluation. The performance of system intelligence mechanisms in general level can be measured by the same metrics and methodologies as the ones proposed for data acquisition systems. In context of intelligent systems one also can use other metrics (combining the same values as precision and recall): (a) the frequency bias, (b) the proportion of correct, (c) probability of detection and (d) false alarm ratio. Especially two last ones are commonly used to describe overall system performance when it comes to the process of identifying the relevant data. The performance is good for systems with high POD -probability of detection (see Equation 4) also known as a hit rate (HR) and low ratio of false alarms (FAR) (see Equation 5). Both metrics could be calculated as follows:

$$POD = \frac{\{\text{identified relevant data}\}}{\{\text{all relevant data}\}} \tag{4}$$

$$FAR = \frac{\{\text{data misinterpreted as relevant}\}}{\{\text{all identified data}\}} \tag{5}$$

One should be treating with caution the interpretation of the results of system performance as they depend on the context of the captured data. A good example of such interpretation is precision and recall values. In general, the highest are the scores the better is the performance. However, achieving high scores for both precision and recall can be problematic and not always optimum from system performance point of view. There are several situations, where low precision is better (refer to (Menzies, 2007)): (a) when the cost of missing the target is expensive (mission critical applications), (b) when only a small fraction of the data is retrieved (selective sensors), (c) where there is little or no cost in checking false alarms. They should be considered when interpreting the performance measures for surveillance systems.

4. Evaluation of architectural performance

The evaluation of architectural performance is crucial for all surveillance systems. The architectural design defines a systems ability to grow, scale and accommodate new functionality . Architecture defines the basic structure of the distribution of live and recorded media or data streams, communication patterns within the system and its components, etc. It should handle challenges, such as heterogeneous inputs, encoding, distribution and storage. Architectural performance can be evaluated from different perspectives. Evaluation of HW and computation architecture allows improvements in system efficiency aspects, such as: usage of energy and system resources. Evaluation of SW and communication architecture aims to provide system support for scalability, as well as functional and physical development of the surveillance system. It has a big impact on system efficiency by providing the base for expansion and development.

4.1 HW and computation architecture

The design of HW and computational architecture is extremely important for performance of all real-time systems. The topic is well reviewed by international research. The majority of the research concerns topics, such as power consumption optimization for embedded platforms or the techniques for utilization of processing power. The ultimate goal is to provide the rules and evaluation tools to design energy-efficient architecture, applications, and processing. In the case of surveillance systems, the problem of HW architecture performance mainly concerns camera site sensors (cameras, encoders and others). IP cameras, encoders and other camera site devices are critical components of a surveillance system. The performance of camera site devices defines system support for performance-exhausting functions such as video compression or content processing. Moreover, it also defines structure of the system in terms of an applicable intelligent solution. The more intelligence that can be applied on camera site, the more efficient the system is in terms of transmission, energy usage or resource management. Special attention should be given to the design of intelligent heterogeneous sensors where multiple sensing functions are interconnected to intelligently deliver relevant data into the system, e.g. IP cameras with audio, video, IR imaging, PTZ data functions. Fortunately, the task of performance evaluation is currently an integral part of embedded systems design. It is also well supported by developer tools for performance evaluation. The metrics for the performance are well known and cover a wide selection of parameters related to: (a) processing speed (latency and throughput), (b) power consumption parameters, (c) quality and type of output data. (Northern at al., 2007), (Lieverse et al., 2001) and (Lefftz et al., 2010) present the methodologies and metrics for performance analysis of signal processing devices and (Zrida et al., 2009) describes evaluation framework for H.264 multiprocessor video encoders. Above reviews provide a good database of methods applicable for evaluation of camera site embedded devices. When considering HW and computational performance for large scale surveillance system we have identified also other potentially problematic areas of which the evaluation should not be omitted: (a) storage solutions (b) export of data from the system. (Ruwart, 2000) reviews the evaluation methods for variety of storage technologies. (Gang et al., 2000) proposes evaluation methods for storage of network attached disks. (Widmann & Baumann, 1999) reviews multiple performance evaluation methods available for database systems. (Tyagi at al., 2008) addresses the challenges efficient data transfer in distributed systems and presents the examples of how to measure their performance. It is worth to underline here that the context of performance evaluation has a major importance. Therefore, hardware (HW) and software (SW) are usually evaluated together.

4.2 SW and communication architecture

Software performance depends on the architecture and software implementation- a poorly designed SW architecture may be unable to support the future development of the SW whilst supporting the required quality and performance. The same can be stated about communication architecture. The communication architecture determines the basic structure of communication between SW components. If the communication patterns are not well thought in terms of system scalability they will affect greatly the performance of the system when future expansion is required.

The SW (architecture) quality can be described in terms of reliability, scalability, modifiability, absence of SW bugs, or fault tolerance. (Olabiyisi et al., 2010), (Sharma et al., 2005), and also (Jun-Tao & Xiao-Yuan, 2009), (Hauck et al., 2009), and (Woodside at al., 2007) provide a good review of the methods for general analysis of the software quality. The main performance metrics to be considered in context of SW architecture assessment are: throughput, response time and resource utilization (refer to (Olabiyisi et al., 2010)). In general, the evaluation of SW architecture performance should respond to questions, such as: how the expansion of the system affects particular performance metrics (e.g. system response time and throughput

when increasing the number of clients) and what are the system limits and bottlenecks; how to allocate SW components within the structure of HW architecture; how to scale the system up and also down (see (Sharma et al., 2005)) The usual motivations towards introducing the performance assesment in the process of creating SW are related to various software performance issues in a system. However, the earlier the assessment is performed in the software life cycle the less expensive and faster it is to identify potential risks and apply solutions to reduce or eliminate these risks. (Williams &Smith, 1998) discusses the advantages of early performance assessment and gives the examples of methods of performance assessments applicable for distributed systems.
(Woodside at al., 2007) distincts two approaches for SW performance evaluation: (a) an early-cycle predictive model-based, and (b) late-cycle measurement-based. It is recommended to combine these approaches to maintain the target performance within entire development cycle.
Typically, the first step towards SW architecture evaluation is architecture modelling. It allows simplifying the complexity of SW by splitting the SW into multiple functional layers. Classical approach to modelling of architecture to is represented by e.g. (Sharma et al., 2005) and (Jun-Tao & Xiao-Yuan, 2009). (Sharma et al., 2005) presents layered approach to evaluating the performance architecture where performance of analysis can be generalized to following steps: (a) layered model for system architecture is proposed, (b) environment is modelled (e.g. queuing network models parameters), (c) the limitations are modelled (e.g. thread limitations), (d) performance model solution and its outputs are proposed (performance factors). (Jun-Tao & Xiao-Yuan, 2009) proposes performance evaluation models, based on UML collaboration and sequence diagram. Additionally, (Inverardi et al., 1998) uses a method which automatically derives a performance evaluation model from a software architecture specification. The approach, is interesting but cannot be applied to surveillance systems.
(Hauck et al., 2009) challenges the evaluation methods based by architectural modelling. The modelling methods (especially for early evaluation) have tendency to be one-dimensional as their main purpose is to avoid implementing systems with poor quality. The current modelling methods do not reflect complexity and multi-dimensionality of environments, e.g. complexity of operating systems and virtual machines (being a base of SW component applications). (Hauck et al., 2009) presents extension to âĂIJmonolithic architecture modelâĂİ to enable accurate performance modelling and prediction for systems in modern complex environments which use disk arrays, virtual machines, and application servers. (Olabiyisi et al., 2010) proposes multiple evaluation models to approach different aspects of performance evaluation.
Both studies are well applicable in context of modern surveillance systems.
(Woodside at al., 2007) and (Olabiyisi et al., 2010) provide an excellent review of current state and future trends of software performance engineering. They conclude the human factors, such as end users demands and customer requirements have growing impact on SW development, whereas they are usually omitted at the model level. The topic of human impact on system performance is elaborated in next chapter.

5. Human factors in evaluation of system performance

We claim that system performance is not only a set of measurable and comparable performance metrics describing technical measures of hardware, SW applications, communication networks, etc. The performance of each system is greatly affected by multiple human factors, such as development decisions or user requirements. Moreover, the evaluation process itself has an ultimate target of providing a system value towards client, end users and customers. The assessment showing the impact of human factors on system performance is rather reactive than proactive- the performance evaluation is usually performed when the

system, application or certain process needs to be adjusted to reflect the certain needs or problem.
Different perspectives of human impact on systems and software are investigated in various publications, such as: (Olabiyisi et al., 2010), (Chen et al., 2007), (Duis & Johnson, 1990) and others.
The estimation of impact of human factors on system performance is difficult to quantify. They have rather qualitative than quantitative value, which make them difficult or impossible to measure and compare. However, , we can analyse the impact of human factors on system performance by identifying the important performance objectives and identifying the performance metrics which are or might be meaningful in the context. Some performance indicators and objectives (such as system responsiveness) have an impact on user satisfaction and perceived system quality.
(Olabiyisi et al., 2010) presents a good review of the problem and identifies a need to develop performance modelling techniques that are capable of capturing human- related variables. (Chen et al., 2007) provides a survey of human performance issues and suggests some mitigation solutions.
We have identified multiple major areas, where objective related to human factors are important and therefore have major (however indirect) impact on overall system performance. They are: (a) software development process, (b) user interface design and system support of user work flow.

5.1 Software development process

The problem of human impact on system performance is visible at all stages of the system development. The topic has been well described by (Olabiyisi et al., 2010). It identified multiple decision variables having an impact on the final shape of system development. They include items such as: commitment of the staff, IT literacy level of operations staff, adequacy of user requirement specification and representation, communication between users and software developers, technical knowhow and the level of system training for operators, etc. (Olabiyisi et al., 2010) identified the problem with current system architecture modelling phase claiming they are machine-driven. The general solution for above problem would be creating a model which incorporates different decision variables (with the focus upon system user). It would complement the existing performance evaluation methods and make performance evaluation more user oriented.

5.2 Performance of user interface

The performance of user interface is one of the most important factors in every surveillance system.
The user interface is a system presentation layer. A well designed and well performing interface can provide the user with a good experience of the system whereas a poor performing user interface might discourage user from using the system. Additionally, the end-users role has an impact on the user interface performance, by making performance evaluation more user oriented with the introduction of the valued end-user local knowledge element. (Nielsen, 1993) discuss the importance of end user knowledge by proposing user testing based approach to performance evaluation of user interface quality. The case studies revealed great improvement of user interface quality when redesign of user interfaces was driven by user testing. (Chen et al., 2007) reviews the end users impact of performance problems , such as: insufficient bandwidth, time lags, etc. It proposes user interface improvements to address these problems, including multimodal interfaces, and various predicative and decision support systems.

Multiple metrics can be applied to measure the system performance in context of end-user interface. The most important are interface responsiveness and system (and user interface) support for users workflow.
(Duis & Johnson, 1990) discusses the value of the user interface responsiveness in context of system performance and proposes the techniques for improving it by means of parallel processing, adaptive resource allocation and pre-computing solutions.
The performance of the user interface can be also measured by its ability to support user workflow. This type of performance evaluation is very important in scenarios where the surveillance system is integrated with other systems, such as telephony and intercom systems, access control systems, traffic control systems, security systems, and others.
Almost all modern surveillance systems are workflow systems where the user interface requirements are highly tailored. The general idea for the evaluation of user work flow system support is to evaluate how well the system is supporting the user in performing individual tasks and consecutive actions in terms of user ergonomics, intuitiveness of interface and system response parameters (accuracy and speed) . The performance evaluation of such system is addressed by multiple publications, such as (Zuoxian et al., 2009), (Tay & Cockburn., 1996) and (Kwang-Hoon & Dong-Soo, 2001). However, it should be stressed that the applicability of performance evaluation methods proposed in above articles is very individual and should not be generalized - they should serve as examples of performance evaluation.
(Zuoxian et al., 2009) discusses the time performance metrics for workflow systems and proposes concepts of active transition and active pattern, these were proposed to estimate time performance and build efficient performance analysis algorithm. Same metrics can be used in the process of evaluation of modern surveillance systems.
(Kwang-Hoon & Dong-Soo, 2001) proposes performance analysis model for distributed system based on server-client architecture. It makes the research findings applicable for video surveillance systems. It addresses the typical problems of such systems such as complexity of the development affected by various decisions and requirements

6. Summary

This work addresses the problem of improving general efficiency of the system by evaluating and improving its performance. Whereas a majority most of current research concerns the performance characteristics of individual system components or system functionality, our aim is to analyse overall system performance by identifying the most critical areas. We review different perspectives of performance starting from technical aspects, such as; performance of data retrieval, analysis and fusion, ending with more subjective, such as quality of user interface. We focus on distributed, heterogeneous and multi-sensor systems where the primary function is video surveillance. We believe in the case of these systems the effect of performance optimisation will be visible due to the fact the optimisation techniques are not usually applied. We define areas critical for improved system performance and for each of these areas we review techniques and methodologies for measuring the performance and propose the most applicable. We identify types of systems where given performance-critical areas are important. The study is highly important for future video system development, design and deployment as it addresses the efficiency problems of modern complex video networks.

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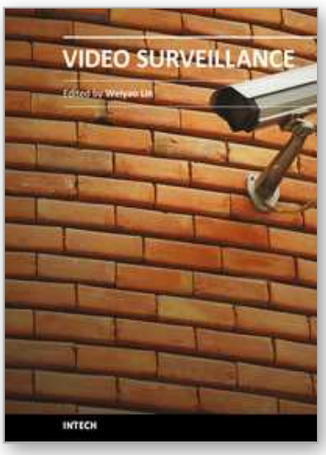
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Video Surveillance
Edited by Prof. Weiyao Lin

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This book presents the latest achievements and developments in the field of video surveillance. The chapters selected for this book comprise a cross-section of topics that reflect a variety of perspectives and disciplinary backgrounds. Besides the introduction of new achievements in video surveillance, this book also presents some good overviews of the state-of-the-art technologies as well as some interesting advanced topics related to video surveillance. Summing up the wide range of issues presented in the book, it can be addressed to a quite broad audience, including both academic researchers and practitioners in halls of industries interested in scheduling theory and its applications. I believe this book can provide a clear picture of the current research status in the area of video surveillance and can also encourage the development of new achievements in this field.

How to reference
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