Combined Dynamic Power- and QoS-Management in Embedded Video Surveillance Systems

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Intelligent video surveillance (IVS) offers a large spectrum of different applications that have strict quality of service (QoS)-requirements. Beside high demands in computing performance, power efficiency is another major concern in these applications. For instance, recent IVS systems need to deliver compressed video data in high quality while using devices that are partly solar- or battery-powered. Since delivering high QoS-levels usually goes along with increased power consumption, it makes sense to implement combined QoS-management and power reduction methods. However, existing IVS systems usually do have a lack of functionality in offering combined power- and QoS-management mechanisms.

In this work we present PoQoS, a novel approach for combined management of power- and quality of service (QoS) in distributed embedded video surveillance systems. PoQoS allows the implementation of hardware-tailored dynamic power management schemes for different individual QoS-levels. The proposed approach also offers an extensible model for implementing PoQoS in an overall distributed embedded video surveillance system.

We demonstrate the feasibility of PoQoS in a simple experimental setup for video surveillance. Experimental results show that the approach leads to power savings of up to about 25%.

1 Introduction

3rd generation video surveillance [1] has become an important research area over the last years due to its various different applications. Recent embedded video surveillance systems combine video sensing, data-compression and analysis as well as short- or long-term storage.
Beside high demands in computing performance, power efficiency is also of major importance in embedded surveillance systems. For instance, recent applications need to deliver compressed video data in high-level quality of service (QoS) while using devices that are solar- or battery-powered. Furthermore, safety critical applications like, e.g., traffic surveillance, typically have strict requirements in reliability that get affected if a device for instance suffers from thermal problems.

Due to the lack of available power lines in exposed positions, parts of an IVS such as cameras often are only solar- or battery-powered. In this case, the limited amount of available energy minimizes the time of operation and endangers the delivered QoS to be degraded improperly. Furthermore, power-aware system design helps to minimize size and weight of certain facilities since smaller batteries and solar cells can be used.

Low power consumption is not only important in portable but also in line powered devices. Since electric current results in waste heat, heat dissipation is another serious problem that appears. If a certain amount of power is consumed, additional cooling devices need to be installed in order to avoid thermal problems that even can lead to destruction. In safety-critical surveillance applications, none of the employed facilities may fail due to high demands on reliability. However, especially active cooling devices are an additional source of uncertainty in reliability.

Furthermore, malfunction caused by thermal problems leads to costs for maintenance and repair making power-awareness an important economical factor as well.

Another aspect that makes power-awareness important in video surveillance is image quality distortion caused by noise. Sophisticated surveillance cameras [2], [3] take use of CMOS sensors due to their high dynamic range and logarithmic behavior. These sensors are quite sensitive in high temperatures, resulting in a decreased signal-to-noise ratio. To keep the advantages of a CMOS sensor in high image quality, minimizing the power consumption is inevitable and allows that no additional cooling for the sensor needs to be used.

Furthermore, it is not always feasible to have power lines on location due to environmental or even legal aspects. Beside, low power networking devices may allow the use of recent technologies such as power over Ethernet (IEEE802.3af). Fig. 1 summarizes the main reasons that indicate the use of power-aware video surveillance.

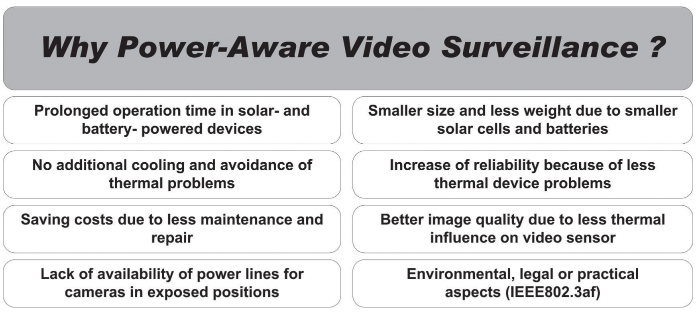

Fig.1: *Motivation for Power-Aware Video Surveillance*

2 Background

2.1 Intelligent Video Surveillance

There exist diverse application scenarios for IVS, including safety critical applications such as traffic surveillance. IVS can also deliver valuable

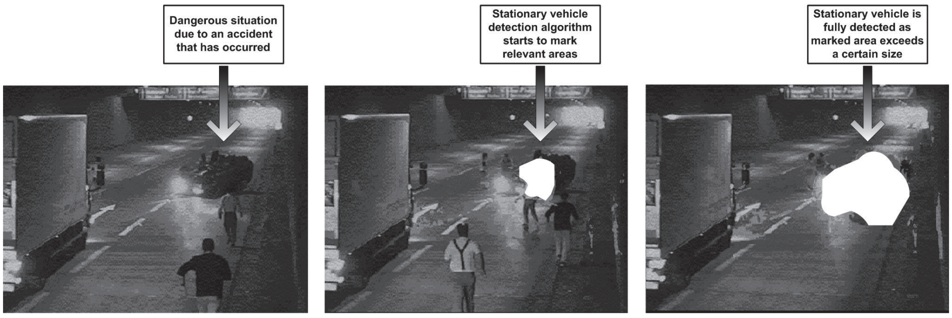

Fig.2: *Stationary Vehicle Detection in IVS Systems*

data for optimizing traffic light control in urban areas. Further applications [5] of IVS include the surveillance of buildings, persons or cargo.

In traffic surveillance, intelligent video sensors are used for better supervision of, e.g., tunnels or construction sites. This allows the recognition of dangerous situations and the generation of alarm signals to avoid consecutive endangerment of the situation. Fig. 2 shows an example for stationary vehicle detection [4] due to an accident that occurred in a tunnel.
The picture on the left side shows the dangerous situation some seconds after the accident happened. As it can be seen in this picture, a truck has also just stopped behind the car crash in this moment. The next picture in the middle shows the monitored scene some frames after the left picture. The detection algorithm starts to mark relevant areas in the monitored scene. Again, some more frames later, the algorithm has already fully detected the accident as the marked area exceeds a predefined size as shown in the right picture. However, since the truck only arrived a while after the car had already stopped, the detection algorithm did not yet detect the stop of the truck.

An IVS system can be represented as a distributed system with various computing nodes and a heterogeneous communication infrastructure. Fig. 3 depicts a typical architectural composition.

It consists of a scalable amount of sensing devices. Beside intelligent embedded cameras, analogue cameras are also used along with additional embedded devices to achieve intelligent data-processing and transmission. PTZ (i.e., Pan-Tilt-Zoom) or dome installations allow individual positioning and setting of the cameras.

Communication is typically achieved by TCP/IP based data transmission, both with wired and wireless infrastructure. Depending on the local circumstances, sensing devices are partly solar- and battery-powered.

The video data is transmitted to a central monitoring station (CMS) that also implements the user interface of the system. The CMS may also includes additional hardware that allows image processing and analysis of the captured scenes if only conventional analogue cameras are used. Long term storage is used for archiving data and scene retrieval.

2.2 QoS in Video Surveillance

Typical QoS-parameters in video surveillance are video data quality and its distortions in network transmission. Further parameters include quality metrics such as image size, data rate or blockiness or the number of frames per second (fps). However, other parameters like the availability of the service are also taken into account as QoS-aspect.

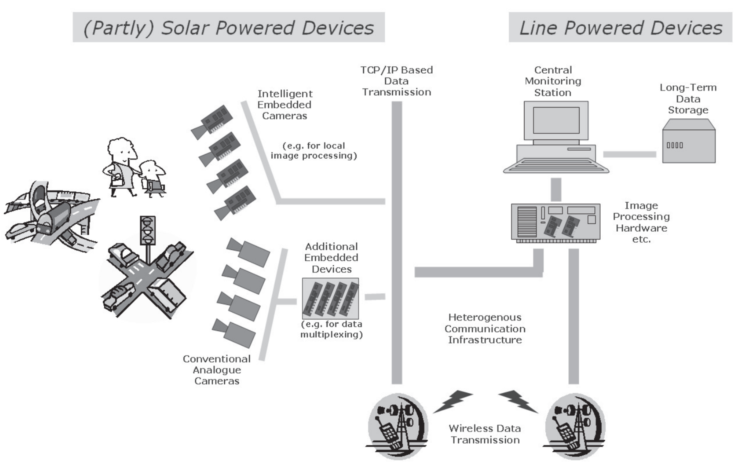

Fig.3: *Typical Architecture of an IVS System*

Thus, QoS is linked with power parameters. For instance, in case of low energy in parts of the system, the QoS gets seriously affected and degraded.

In a safety critical application like the surveillance of traffic, QoS is also defined through the availability and proper function of algorithms for video analysis. For instance, QoS-demands may not be satisfied if the algorithm fails to detect during the capturing of an accident.
Therefore, it is necessary to distinguish between delivering proper QoS as input for intelligent algorithms or for manual surveillance by humans.

2.3 Power Reduction Approaches

If video data is processed, the time of computing activity of the processing unit and therefore its consumed power typically depends on the quality parameters like the size or the frame rate of the video data. Minimizing the power consumption of electronic systems is an area of intense research. A lot of different power reduction approaches have been described in the literature [6].

A commonly used online method is Dynamic Power Management (DPM) [7], [8]. DPM is based on the observation that a lot of power is wasted because of system components that are fully powered up even if they are not in use.

Thus, the basic idea behind DPM is that individual components can be switched to different operating states (like ‚work', ‚idle', ‚sleep' etc.) during runtime. Each operating state is characterized by a different set of power- and performance-parameters.

The commands to change a component's operational state are typically issued by a central power manager. The commands are issued due to a corresponding power management policy. In order to decide which command to issue the power manager must have individual knowledge about the system's workload behavior. It also must taken into account that changing a components operational state takes a specific time.

2.4 Power-Aware Distributed Environments

Power-awareness in distributed environments has been described in literature by several different projects. In [9], a power-aware, distributed wireless ground sensor network is investigated. It focuses on local-node and network wide global DPM with a power-aware control middleware.

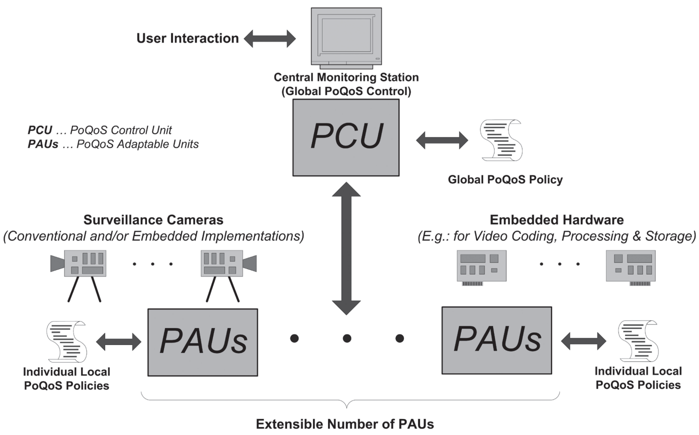

Fig.4: *Architectural Concept of PoQoS*

In [10], power-aware multimedia streaming to heterogonous handheld devices is applied. A unified framework for DPM of the CPU and memory is implemented. Further power savings are achieved by user acceptable QoS-degradation. Similar to that, [11] researches the trade-off in between image quality and power consumption. It mainly focuses on sophisticated image compression techniques.

2.5 Contribution

Existing implementations of IVS systems lack in special control schemes for combined management of power- and QoS. Furthermore, the computing performance in these systems remains low due to moderate QoS-demands.

PoQoS, a novel hierarchical approach for combined power- and QoS-management in high performance, distributed embedded IVS systems is presented. PoQoS allows the implementation of both global and local power- and QoS-adaptation in order to achieve optimal energy/QoS trade-offs.

In addition, we present a DSP-based, embedded platform (Single Channel Codec (SCC)) that is used for intelligent video surveillance. It includes QoS-triggered onboard DPM that can be controlled via Ethernet. Our measurements show that the power efficiency of the SCC-board gets improved by up to about 25%.

3 Combined Management of Power- and QoS (PoQoS)

As mentioned before, the sole adaptation of QoS does not inevitably result in power savings due to remaining idle processing activity. Furthermore, optimal power reduction is only achieved if target-specific power reduction policies are used to allow hardware tailored DPM. Thus, we focus on applying hardware tailored DPM policies for all individual QoS-levels.

Our proposed scheme of combined dynamic power- and QoS-management (PoQoS) also offers an extensible model for its implementation in distributed embedded video surveillance systems. The approach is based on some ideas presented in [12] and is described more detailed in [13].

3.1 Architectural Concept

The infrastructure of an video surveillance system typically consists of a central monitoring station that is connected to a various number of system devices whose power- and QoS-level is adaptable dynamically. In PoQoS, all these units get abstracted due to their use for dynamic power- and QoS-management.

Fig. 4 illustrates the architectural concept of PoQoS that mainly consists of a single PoQoS Controller Unit (PCU) and a variable number of PoQoS Adaptable Units (PAUs).

3.2 PoQoS Controller Unit (PCU) for Global Control

The PCU implements the interface in between the user and the PoQoS Adaptable Units (PAUs). There exist several global PoQoS policies for different operation modes of the system. For instance, in alarm situations (e.g., due to an accident in traffic surveillance) the global policy of the PCU forces corresponding PAUs to deliver video data at best possible QoS.

Thus, the global PoQoS policies trigger the individual behavior of the local PoQoS modes of the PAUs. A simple global policy specification for, e.g., low-energy operation when the amount of energy gets critical, forces corresponding PAUs to alter their local policies in order to maximize power savings.

3.3 PoQoS Adaptable Units (PAUs) for Local Control

A PAU is any device in the system whose PoQoS parameters are dynamically configurable. Examples of PAUs include video sensors, processing units or network devices. Since a PAU's operation in a lower QoS-level usually leads to longer idle periods of its components, it makes sense to apply DPM as well. In PoQoS, each PAU employs its individual device specific implementation of DPM. Thus, a PAU contains its locally stored individual DPM policies for corresponding QoS-levels, i.e., it has its individual local PoQoS policies.

The PAU also delivers on demand status information to the PCU to execute the PoQoS control commands issued by the PCU. The PAU executes the PoQoS control commands issued by the PCU. In PoQoS, each PAU employs its individual device specific implementation of DPM. Thus, a PAU contains its locally stored individual DPM policies for corresponding QoS-levels (‚Onboard QoS-triggered DPM'). Furthermore, power state transition times of onboard components are taken into account by the local power manager.

A PAU therefore contains a local lookup table with a set of is predefined power- and QoS-levels. It lists the individual power consumption of each QoS-level. Its purpose is to provide on demand information for the PCU. Obviously, the more PoQoS levels a PAU has, the better it is adaptable to actual requirements.

3.4 Surveillance-Specific Communication Scheme

PoQoS uses a video surveillance-specific, event-driven interaction scheme. It works independent of the underlying network topology and communication protocol and is specified to be applied upon a heterogeneous network environment. Thus, it assumes as little as possible about the underlying network. In PoQoS, both global and local policies are triggered by several predefined events.

For instance, if a PAU (e.g., an intelligent camera) recognizes an accident, an accordant event message to the PCU is generated. The PCU then triggers the corresponding PAUs to alter its local policies due to the global policy for handling alarm situations (that means, e.g., maximum possible QoS delivery and minimum power savings).

Furthermore, the PCU uses a time-driven observation scheme for the PAUs in order to recognize malfunction or breakdown of a single unit.

4 Feasibility Study of PoQoS

We evaluate the feasibility of PoQoS with a simple experimental setup that implements video sensing, encoding and transmission. As depicted

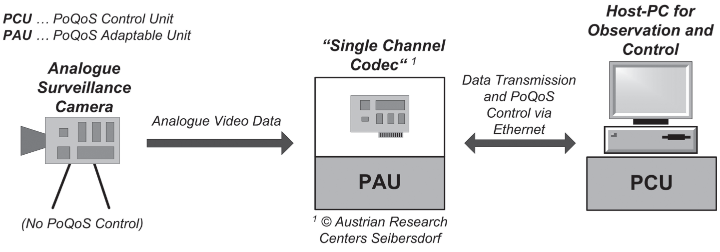

Fig. 5: Experimental Setup of PoQoS

in fig. 5, the experimental configuration only consists of a single PAU. However, it adequately demonstrates the effect of PoQoS.

The setup contains a camera that delivers an analogue video signal in full PAL resolution at 25fps. It is directly connected to a DSP-based hardware MPEG-4 compliant. Fig. 6 gives a functional overview on the ‚Single Channel Codec' (SCC, designed by the Austrian Research Centers Seibersdorf) that is used as PAU. However, the camera cannot change its PoQoS parameters and therefore it is not used as PAU in this setup.

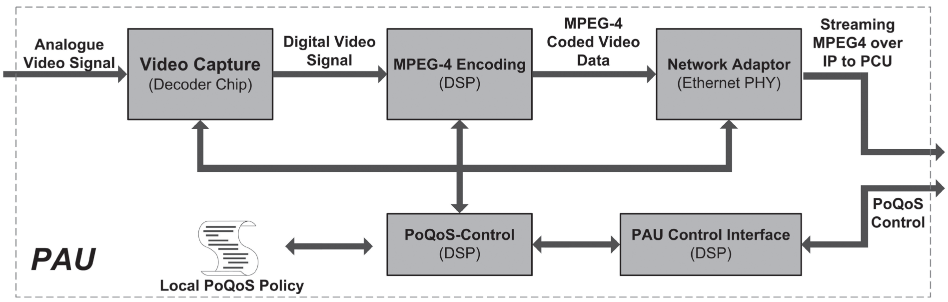

Fig. 6: Functional Overview of the PAU

The SCC captures the analogue video signal, performs MPEG-4 encoding (simple profile) and real-time IP-streaming. The MPEG-4 encoding is performed by the DSP in software (ATEME). The network connectivity is given by a TCP/IP stack from Texas Instruments, whereas real-time protocol (RTP) and multicast transmission is used. In our setup, the network bandwidth is reduced to a maximum of about 1.5MB/s (in PAL resolution with 25fps).

The SCC contains a video decoder chip and is capable of using composite video as input. Its main part is a TMS320DM642 DSP from Texas Instruments (TI) that also provides an internal Ethernet media access controller (EMAC). Thus, the PHY-transceiver gets directly connected to the DSP.

The DSP powers-down its processor core by register control and gets woken up by predefined interrupt sources. Measurements showed that changing the DSP-core's power mode usually takes less than 15ns. Thus, the effect of latency is negligible for the DSP. The video decoder chip also offers a power down mode that is controlled via I2C (hosted by the DSP). In contrast to the DSP, altering its power mode takes up to about 120ms which cannot be neglected. Thus, it is defined in the local policy of the PAU that it gets only powered down in frame rates below 10fps when long enough idle periods of the device are guaranteed. In addition, measurements showed that the PHY-device cannot be used for PoQoS due to setup problems with the TCP/IP stack that is used.

We applied a generic implementation of PoQoS for DSP-based embedded PAUs in order to allow easy porting to other DSP-based hardware platforms whose onboard components can be abstracted as PMCs. The RTOS (‚DSP/BIOS') of the C6000 series from TI provides so called ‚hooks' that are called upon specific events such as task switches. In the given application, the local power manager is called upon every task switch by the hook. The power manager maintains a data structure for each individual task, containing data about all corresponding PMCs that are used by the task.

Each PMC also has several associated additional elements, including its DPM policy, its actual power state and a mechanism for changing the power state. The implementation has no limitations in terms of the use of static or adaptive DPM-policies or the number of power states of each power manageable components (PMCs).

Furthermore, a data structure containing the following elements is (1) a task-enter callback function (its return value determines the next power state of the PMC); (2) a task-leave callback function (its return value determines the next power state of the PMC); (3) a pointer to an arbitrary policy data structure. Upon each task switch, the power manager determines the set of PMCs that have been used by the last task and those that will be used by the next task. Furthermore, the power manager collects data about busy and idle periods and to decide upon the appropriate power state of the PMC for the next idle/busy period.

5 Experimental Results

The total power consumption of the SCC is measured by a digital oscilloscope using a current probe. In the ‚standard'-implementation (i.e., without PoQoS), the power consumption of the SCC varies from about 5.82W (PAL) and 5.47W (CIF) to 5.36W (QCIF). Measurements showed that these values are independent of the frame rate due to idle clocking activity of the DSP core and the video decoder. The power consumption is also measured under different PoQoS-levels (i.e., with different DPM policies for each QoS-level) leading to power savings of up to about 25% (as depicted in fig. 7).

Fig. 8 shows the effect of PoQoS on the profile of the total power consumption of the SCC. At less than 10 fps, another policy gets used that

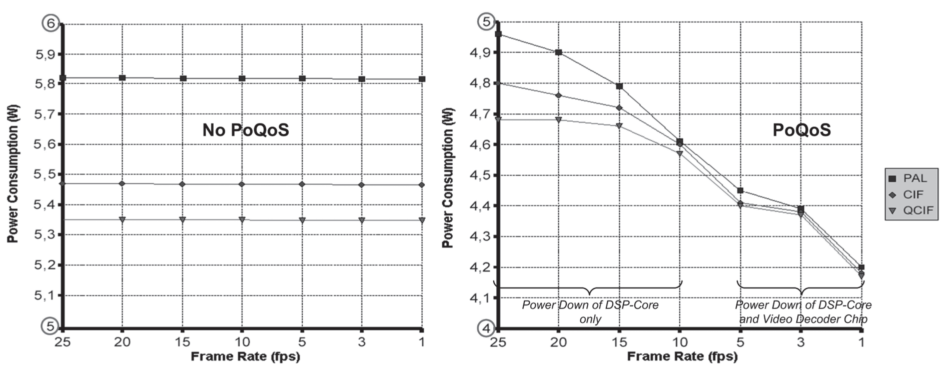

Fig. 7: Power Consumption of the SCC

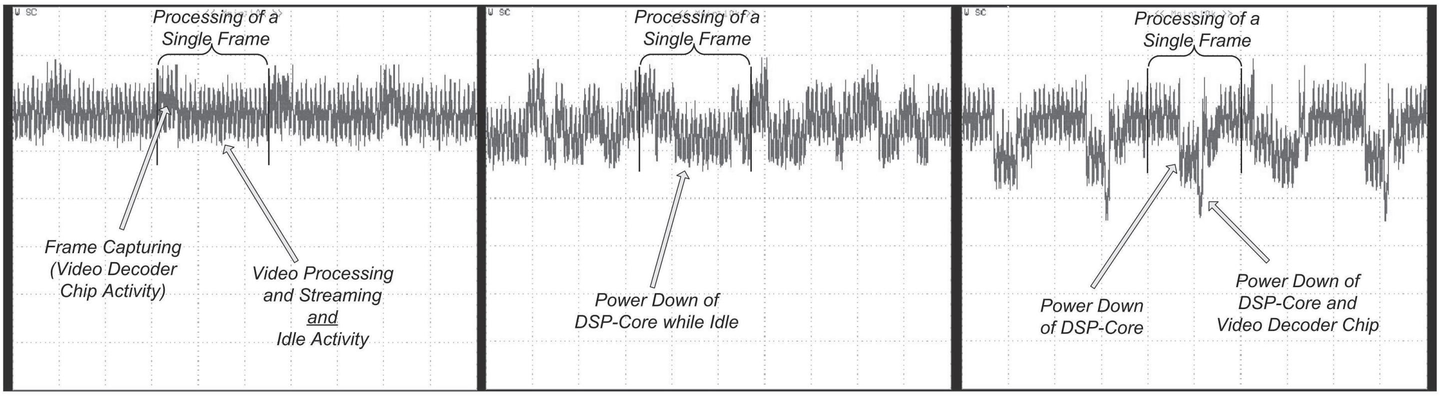

Fig.8: *Profile of Total Power Consumption*

also powers down the video decoder chip for a longer period of time without risking latency effects due to its previously described behavior.

6 Conclusion and Future Work

In this paper we have presented PoQoS, a novel hierarchical approach for combined power- and QoS-management in distributed video surveillance systems. We have demonstrated the feasibility of our approach on a simple experimental setup containing an embedded DSP-platform. Experimental results indicated power savings of up to about 25%.

Future work includes an implementation of QoS-triggered DPM in a heterogeneous multiprocessor platform for high performance intelligent video sensing (the SmartCam+ [14]). In addition, we aim in continuing the experimental evaluation of PoQoS for distributed IVS systems that include several different embedded platforms (e.g., with the SmartCam+) as PAUs.

Furthermore, we will focus on an user-friendly implementation of a human interface for the PCU. The human interface will also offer the possibility for dynamic configuration and modification of both global and local PoQoS-policies.

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