A Hierarchical Approach for Energy-Aware Distributed Embedded Intelligent Video Surveillance

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Abstract

Intelligent video surveillance (IVS) offers a large spectrum of different applications that have strict requirements on quality of service (QoS) and energy-efficiency. Recent embedded IVS systems need to deliver compressed video data in high quality while using devices that are partly solar- or battery-powered.

In this paper we present PoQoS, a novel hierarchical approach for combined power- and QoS-management in distributed embedded IVS systems. PoQoS allows the implementation of both global and local power- and QoS-adaptation in order to achieve optimal energy/QoS trade-offs. Furthermore, we present a DSP-based, embedded platform that is used for IVS. It includes QoS-triggered onboard dynamic power management (DPM) that is controlled via Ethernet. We demonstrate the feasibility of PoQoS with a typical IVS-setup and present experimental results.

1. Introduction

Intelligent video surveillance (IVS) [5], [4] has become an important research area over the last years. It is mainly based on the recent development of embedded intelligent cameras [9]. These devices allow a distributed implementation of embedded IVS systems that combine video sensing and data analysis, video data compression and transmission as well as short- or long-term video data storage.

IVS is an area with widely spread different applications. In traffic surveillance it allows the recognition of dangerous situations such as accidents or lost cargo which may in turn be exploited to warn succeeding vehicles. In this IVS application, high-level video analysis algorithms are deployed to recognize various dangerous situations.

Beside high demands in computing performance, energy-efficiency is also of major importance in embedded IVS systems. In devices that are solar-powered (e.g., due to the lack of availability of power lines for devices in exposed positions), energy-aware IVS leads to prolonged time of operation and smaller device sizes.

Even in line-powered devices, energy-awareness may avoid thermal problems. Active cooling can then be avoided which helps to improve the reliability of the overall system. Recent technologies such as Power-over-Ethernet (PoE, IEEE802.3af) [8] are also deployed but have strict limitations in the amount of available energy.

In section 2, we give a brief overview on the related work and summarize the contribution of this paper. Section 3 presents PoQoS, a novel approach to control power and QoS in distributed IVS system. In section 4 we present an implementation of PoQoS on an embedded DSP platform and report some experimental results. Section 5 presents an evaluation of different PoQoS modes in a typical IVS-setup. Section 6 summarizes the paper and presents some future work.

2. Related Work

2.1. IVS Systems

An IVS system can be represented as a distributed system with various computing nodes connected by a heterogenous communication infrastructure.

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. 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 include additional hardware that

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allows image processing, analysis as well as long term storage for archiving data and scene retrieval.

2.2. QoS in IVS

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).

In IVS other parameters, such as the availability of the service are also taken into account as QoS-aspect. In case of low energy in parts of the system QoS gets seriously affected and degraded.

In a safety critical application, such as traffic surveillance, QoS is also defined through the availability and proper function of algorithms for video analysis. It is therefore necessary to distinguish between delivering proper QoS as input for intelligent algorithms or for manual surveillance by humans.

2.3. Power-Aware Systems

Minimizing the power consumption of electronic systems is an area of intense research. A commonly used online method is Dynamic Power Management (DPM) [1]. 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.

In literature, special concepts for power-aware distributed IVS systems are hard to identify. Similar power-aware distributed environments have been researched in several different projects. The work of [7] investigates in a power-aware multimedia streaming to heterogonous handheld devices. 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, [3] researches the trade-off in between image quality and power consumption. The work mainly focuses on sophisticated image compression techniques.

2.4. Contribution

Typical 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.

In this work, we present PoQoS, a novel hierarchical approach for combined power- and QoS-management in high performance, distributed embedded IVS systems. PoQoS allows the implementation of both global and local power- and QoS- adaptation in order to achieve optimal energy/QoS trade-offs. We evaluate different PoQoS modes in a typical IVS-setup that is based on an embedded DSP-platform. It includes a QoS-triggered and generic implementation of onboard DPM that can be controlled via Ethernet.

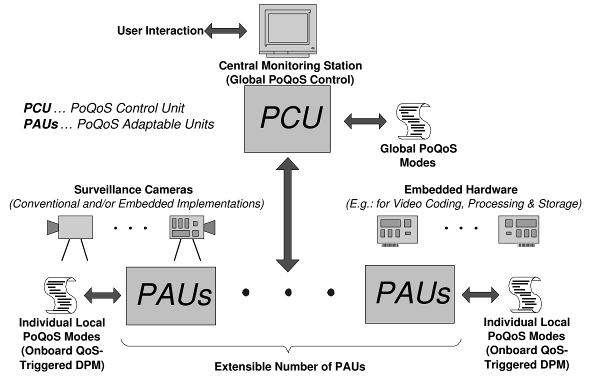

Figure 1. Architectural Concept of PoQoS.

3. Combined Management of Power- and QoS

The infrastructure of a 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 dynamically adaptable. In PoQoS, all these units are abstracted due to their use for dynamic power- and QoS-management. Fig. 1 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)*.

3.1. Global PoQoS Control

The PCU implements the interface between the user and the PAUs and is typically implemented in the central monitoring station (CMS). A set of different global PoQoS modes handles typical situations in IVS, such as the appearance of alarms or low energy in parts of the system. The global PoQoS modes trigger the individual behavior of the local PoQoS modes of the PAUs. It makes sense to define global PoQoS modes that distinguish between delivering proper QoS as input for intelligent algorithms or for manual surveillance by humans.

A global PoQoS mode that executes in medium-level QoS for instance delivers proper input data for video analysis algorithms. If an alarm has been detected by a video analysis algorithm, the QoS-levels of corresponding PAUs are then set to a maximum in order to satisfy human demands at the user interface whereas frequent user interaction typically appears. If PoQoS realizes that the remaining energy of a subsystem gets below a certain critical level, several power saving actions are applied due to user interaction or predefined policies (e.g., execute in lower power-QoS trade-offs).

3.2. Local PoQoS Control

A PAU is any device in the system (except the PCU) whose power- and/or QoS-parameters are dynamically configurable. Examples of PAUs include intelligent video sensors, processing units or network devices.

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 its 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.

3.3. IVS-Specific Communication Scheme

PoQoS uses an IVS-specific, event-driven interaction scheme. It works independently of the underlying network topology and communication protocol and is therefore to be applied upon a heterogenous network environment. Thus, it assumes little about the underlying network. In PoQoS, both global and local modes are triggered by several predefined events.

Furthermore, the PCU uses a periodic observation scheme for the PAUs recognition of malfunction or breakdown of a PAU. Like this, the overall systems reliability is increased by proper handling of the PCU for global adaptation.

4. Embedded DSP-Based Implementation

In this section, we describe an embedded, DSP-based implementation of a PAU that is used to enhance analogue video sensors for its use in IVS systems. Fig. 2 gives a functional overview of the PAU, i.e., the *'Intelligent Video Codec'* (IVC) that was designed by the *Austrian Research Centers Seibersdorf*.

The IVC captures the analogue video signal, performs MPEG-4 encoding and real-time IP-streaming. The MPEG-4 encoding is performed by the DSP in software. The network connectivity is given by a TCP/IP stack from Texas Instruments (TI), whereas real-time protocol (RTP) and multicast transmission is used.

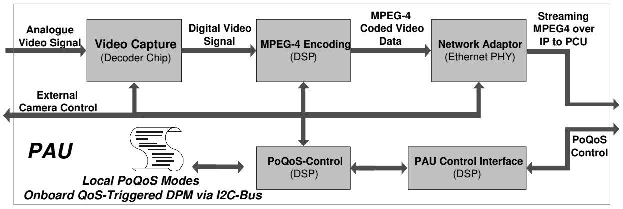

Figure 2. Functional Overview of the IVC.

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

4.1. Generic Implementation of DPM

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

We have developed a generic implementation of the PoQoS interface and of a DPM for DSP-based embedded PAUs. It allows easy porting to other DSP-based hardware platforms whose onboard components can be abstracted as power manageable components (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 at 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 has also 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 kept: *(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 recent 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.

4.2. Implemented Onboard DPM Policy

In our implementation, 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 and it can be powered-down throughout all framerates. The video decoder chip also offers a power down mode that is controlled via the onboard I^2C-bus (hosted by the DSP). In contrast to the DSP, altering the power mode of the decoder chip takes up to about 120ms and therefore cannot be neglected. Thus, it is defined in the local DPM policy of the PAU that it gets only powered down at frame rates of 5 fps and below. In this case long enough idle periods of the device are guaranteed. Several experiments showed that the PHY-device cannot be used for DPM due to setup problems with the TCP/IP stack that is used.

The implemented local DPM policy always powers down the DSP core when idle but only powers down the video decoder in framerates below 10fps. However, our generic implementation allows the specification of any DPM policy with various onboard components.

4.3. Experimental Results

The total power consumption of the IVC got measured with a digital oscilloscope (using a current probe) at several different QoS-levels that are typically used in IVS. In the 'standard' implementation (i.e., without PoQoS), the power consumption of the IVC varies from about 5.82W*(PAL)* and *5.47W(CIF)* to 5.36W*(QCIF)*. Measurements showed that these values are almost (i.e., less than 2%) 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 Table 1).

IVC Power Consumption with Onboard DPM and Power Savings in Percent

Frame Rate	PAL(5.82W w/o DPM)		CIF(5.47W w/o DPM)		QCIF(5.35W w/o DPM)	
25fps	*4.96W*	*14.7%*	*4.80W*	*12.2%*	*4.68W*	*12.5%*
20fps	*4.90W*	*15.8%*	*4.76W*	*12.9%*	*4.67W*	*12.7%*
15fps	*4.79W*	*17.7%*	*4.72W*	*13.7%*	*4.65W*	*13.0%*
10fps	*4.62W*	*20.6%*	*4.60W*	*15.9%*	*4.57W*	*14.5%*
5fps	*4.45W*	*23.5%*	*4.41W*	*19.3%*	*4.41W*	*17.5%*
3fps	*4.38W*	*24.7%*	*4.37W*	*20.1%*	*4.36W*	*18.5%*
1fps	*4.20W*	*27.8%*	*4.18W*	*23.6%*	*4.17W*	*22.0%*

Table 1. Power Savings with Onboard DPM.

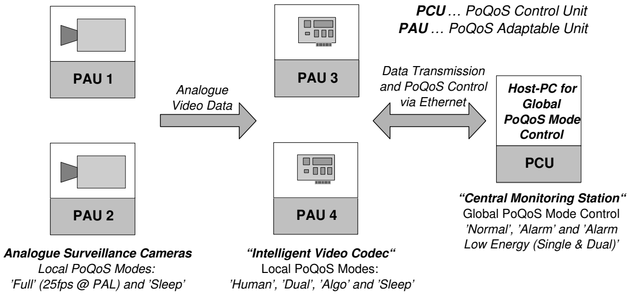

Figure 3. Experimental Setup of PoQoS.

5. Evaluation of Global PoQoS Modes

The feasibility of PoQoS has already been demonstrated in [6]. However, this previous work only focused on the implementation of PoQoS in a simple setup with a single PAU.

In contrast to that, this work provides an evaluation on the effect of different global PoQoS modes on the overall power consumption. Two analogue cameras along with two of the previously described IVC-boards as PAUs are used in order to allow IVS in a simple setup. Furthermore, we implemented an video analysis algorithm for the detection of stationary vehicles as described in [2]. Thus, the experimental setup implements intelligent video sensing, encoding and transmission.

The cameras are co-located and capture the same scenery from different perspectives. They deliver analogue video signals in full PAL resolution at 25fps ('Full'-mode and consume each about 2.35W (or 0.13W in 'Sleep'-mode, respectively).

As depicted in Fig. 3, the experimental configuration also consists of a PC that emulates the central monitoring station. We emulate the PCU on the PC by a Java application that sends PoQoS-commands entered by the user to the corresponding PAU via TCP/IP. The IVS-boards receive external control commands issued by the PCU via the PoQoS control interface implemented in the DSP-software. The interface also generates the control signals to alter a camera's operating mode ('Full' or 'Sleep').

The onboard video decoder chip of the PAU offers the possibility to receive and convert analogue video data from multiple sources via onboard multiplexing. Thus, one IVC-board can be used for, e.g., encoding the input signals of two different analogue cameras.

5.1. Applied Local PoQoS Modes

Table 2 defines the modes that are used for the IVCs along with their corresponding power consumption for this evaluation. Local PoQoS control is enabled throughout all PAU modes except in the 'Sleep'-mode whereas only about 270mW are consumed.

Available Local PAU Modes of the IVCs				
PAU Mode	QoS-Level	One Channel	Two Channels	Global Use
'Human'	*25fps@PAL*	*4,96W*	*n.a.*	Alarm Mode
'Dual'	*15fps@PAL*	*n.a.*	*5,12W*	Alarm Low Energy
'Algo'	*5fps@CIF*	*4,61W*	*n.a.*	Normal Mode
'Sleep'	*n.a.*	*0.27mW*	*0.27mW*	Off Mode

Table 2. PAU Modes for Global Evaluation.

5.2. Applied Global PoQoS Modes

In the experimental setup, four different global PoQoS modes are defined for evaluation.

Normal @ 13.92W This mode forces the cameras PAU1 and PAU2 to execute in their 'Full' mode. Both PAU3 and PAU4 execute in the 'Algo' mode. In this mode, setting automatic detection of stationary vehicles is achieved.

Alarm @ 14.62W The alarm mode is entered after a stationary vehicle is detected by one of the IVCs. It sets the cameras PAU1 and PAU2 in their 'Full' mode. PAU3 and PAU4 enter their 'Human' mode in order to deliver video data in best QoS-level for user surveillance of a dangerous situation.

Alarm Low Energy (Single) @ 7.71W This mode handles an alarm situation in energy constrained situations. Therefore, PAU1 executes in 'Full' mode while PAU3 is in its 'Human' mode. Both PAU2 and PAU4 get switched to their 'Sleep' modes.

Alarm Low Energy (Dual) @ 10.09W In this mode both cameras PAU1 and PAU2 are in their 'Full' mode. PAU3 is forced to enter its 'Dual' mode for encoding both video inputs in good quality by onboard multiplexing of the input signals. PAU4 enters its 'Sleep' mode.

The overall consumed power varies on the executed global PoQoS modes. Especially for alarm situations, the experiments show significant differences depending on the power-aware configuration. Even in energy constrained situations, the system still keeps on delivering video data.

6. Conclusion

In this paper we presented PoQoS, a novel hierarchical approach for combined power- and QoS-management in distributed embedded intelligent video surveillance systems. PoQoS allows the implementation of both global and local power- and QoS-adaptation in order to achieve optimal energy/QoS trade-offs. We presented an implementation of PoQoS in an experimental IVS-setup and report some experimental results of the evaluation of different PoQoS modes.

Future work includes an evaluation of transition times for changing global PoQoS modes in order to handle real-time constraints given by certain applications. Furthermore, we will focus on an user-friendly implementation of a human interface for the PCU that allows the possibility for dynamic configuration and modification of individual PoQoS modes.

References

[1] A. Bogliolo, L. Benini, and G. D. Micheli. A Survey of Design Techniques for System-Level Dynamic Power Management. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, 8(3), Jun 2000.

[2] M. Bramberger, J. Brunner, B. Rinner, and H. Schwabach. Real-Time Video Analysis on an Embedded Smart Camera for Traffic Surveillance. In *Proceedings of the 10th IEEE Real-Time and Embedded Technology and Applications Symposium, Toronto, Canada*, 2004.

[3] C. Chiasserini and E. Magli. Energy Consumption and Image Quality in Wireless Video-Surveillance Networks. In *Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2002.

[4] G. L. Foresti, P. Mähönen, and C. S. Regazzoni, editors. *Multimedia Video-Based Surveillance Systems*. Kluwer Academic Publishers, Boston, 2000.

[5] G. L. Foresti, V. Ramesh, and C. S. Regazzoni. Special Issue on Video Communications, Processing and Understanding for Third Generation Surveillance Systems. *Proceedings of the IEEE*, 89(10):1355–1367, Oct 2001.

[6] A. Maier, B. Rinner, H. Schwabach, and T.Trathnigg. Combined Management of Power- and Quality of Service in Distributed Embedded Video Surveillance Systems. In *Proceedings of the First Workshop on Power-Aware Real-Time Computing, Pisa, Italy*, 2004.

[7] S. Mohapatra, R. Cornea, N. Dutt, A. Nicolau, and N. Venkatasubramanian. Integrated Power Management for Video Streaming to Mobile Handheld Devices. In *Proceedings of the ACM Multimedia SIGMM-03), California*, 2003.

[8] I. Standard. Approved Standard for Power over Ethernet IEEE 802.3af. *Institute of Electrical and Electronic Engineers (IEEE)*, 2003.

[9] W. Wolf, B. Ozer, and T. Lv. Smart Cameras as Embedded Systems. *IEEE Computer*, pages 48–53, 2002.