Towards Pervasive Smart Cameras

Wolfgang Schriebl, Thomas Winkler, and Bernhard Rinner (Advisor)
Institute of Networked and Embedded Systems, Pervasive Computing Group
Klagenfurt University, 9020 Klagenfurt, AUSTRIA
Email: {wolfgang.schriebl,thomas.winkler,bernhard.rinner}@uni-klu.ac.at

Abstract — *This paper presents application scenarios along with a potential architecture for wireless, pervasive smart cameras. The intention of such a system is to allow simple, ad-hoc deployment of networked cameras at locations where static infrastructure either is not feasible, too expensive or can not keep up with the high dynamics of the observed phenomena. The proposed architecture is based on a two layer wireless network divided into special purpose camera nodes and general purpose nodes providing data aggregation and network services.*
This work currently is at very early stages. The individual research topics of the participants within this area are to be defined within the first phase of the project.

I. Introduction and Motivation

Intelligent camera systems, like the SmartCam [1], have proven to be a promising field of research where real world applications are starting to emerge. A key concept of smart cameras is that image processing and analysis is done locally on the camera contrary to conventional systems employing a centralized processing architecture. Many of the proposed camera systems rely on a fixed infrastructure for power supply and network connectivity. Moreover, such systems typically are deployed in a static manner where cameras are installed and calibrated by experts.

With advances in the field of wireless networking [2], it is becoming feasible to apply the concepts of smart cameras to wireless sensor networks. In addition to sensors that measure environmental values such as air pressure or temperature, nodes can be equipped with cameras capturing and analyzing the environment. While existing smart cameras typically also offer video streaming capabilities, the concept of wireless, pervasive smart cameras is focused towards in-network processing of image data such that only detected events are reported. In resource constraint wireless networks, this approach can help to considerably reduce the network load. For visual verification, occasional single images or selected image regions can be transmitted. While typical wireless sensor networks are designed to be operational for timeframes of up to several years by offering very limited computational capabilities, the envisioned system is expected to offer higher computing power and hence targets for lifespans of up to several weeks with a single battery load.

II. Application Scenarios

Typical scenarios for deploying traditional smart cameras are applications for long-term monitoring in well-defined environments, like traffic surveillance [3] or access control in buildings. Installation and calibration of cameras is expensive in terms of time, manpower and money. Furthermore, infrastructure for power supply, networking, and mounting is required, making observation of transient phenomena hardly possible.

Such short-term phenomena, taking place at varying locations or at a non-regular basis are ideal application scenarios for wireless pervasive smart cameras. In such cases, fixed infrastructure might not be available or simply too costly and too inconvenient to deploy. Scenarios might be crowd monitoring at sports events or habitat monitoring where no infrastructure can be deployed.

By combining technologies from wireless sensor networks with high-performance smart cameras, the goal is to solve many of the infrastructure problems of existing smart camera systems.

In many applications the sensor nodes will be deployed exploiting the environment of the monitored phenomenon. In habitat monitoring for example, cameras are attached to trees or poles at positions that might be difficult to reach and therefore only allowing for rough manual calibration. Self-calibration functionalities of pervasive smart cameras can help to compensate this handicap. The ad-hoc self-calibration capability of the envisioned system could also make it applicable for low cost applications like home entertainment, augmented reality applications or elderly care. In these scenarios, users could self-deploy such a system without the need to deal with complex setup and calibration procedures.

III. Proposed System Architecture

For the described application domains, we propose the following, preliminary architecture (see figure 1). The system is based on a two layer wireless network. The first layer is equipped with camera nodes using low-power SIMD or DSP processors for image acquisition and processing. The results of the analysis process are made available to the second layer of the network in terms of messages describing the detected events. First and second layer are coupled using a low-power, low-range wireless network.

The second layer is made up of nodes offering general purpose processing capabilities as well as more powerful wireless transmission technologies. Compared to the first layer, the number of nodes in this layer is considerably lower. Consequently, each node in this wireless backbone will be responsible for multiple camera nodes of the first layer in terms of providing networking connectivity and standardized services. This implicit formation of clusters is expected to enhance the manageability of the overall setup as well as reducing the communication efforts and thereby saving energy of individual nodes. The general purpose processing units at the second layer can be used to aggregate and combine information from several cameras to provide a more complete view of the surrounding area. This information, in turn, can be consumed by the actual applications which therefore are relieved from the need to collect and combine information from several individual cameras in the first layer.

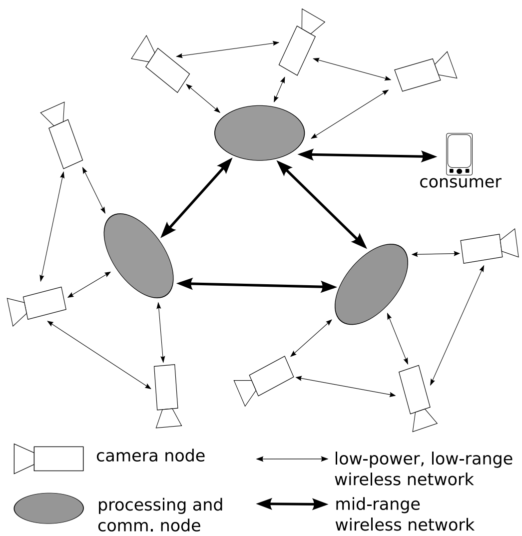

Fig. 1: Two layer architecture for pervasive smart cams.

Aside from providing services like information aggregation, cluster formation or service advertisement, the general purpose nodes are designed to provide the runtime environment for the actual applications executed in the network. One approach is to design the applications using the mobile agents paradigm. Consumers of information can be equipped with handhelds allowing them to freely move around within the network. These devices connect wirelessly to one of the general purpose processing nodes nearby and inject an agent that has been assigned a special task such as collecting and delivering information about a certain area covered by the network. The agent uses the services offered by the network to determine the second level node providing the required information. Typically, this should be the node that is closest to the camera nodes observing the region that is of interest for the agent. The agent then moves to this node where it starts to work on its tasks, like e.g., counting the persons in this area or detecting the human motion flow. Note that the agent relies on abstract information delivered by the cameras to the general purpose node that is executing the agent.

IV. Research Questions

The application scenarios and the architecture approach of a wireless, pervasive smart camera network bring up many questions from different areas of research. A highly dynamic environment makes fast and simple mechanisms for network adaption necessary. Adding and removing cameras in a self-organizing network leads to questions about ad-hoc networking, self-configuration, self-localization, neighborhood discovery and role assignment. We will focus our work on these questions under the aspects of energy efficiency of smart cameras.

In wireless smart camera networks, sensors with overlapping fields of view can be rather far away from each other, potentially too far for being in direct networking range. Hence, obvious approaches for node clustering based on network topology might not be an appropriate solution for this type of networks. Taking ideas of topology based clustering approaches as a basis, important questions will be how to automatically form logical clusters comprised of camera nodes with overlapping or adjacent fields of view. The main goals will be to maximize the entropy while keeping the involved overhead as low as possible.

Algorithms for distributed image processing are usually based on precise information about the field of view of the camera sensors. By freely positioning camera nodes, this information is a priori not available but must be retrieved by appropriate methods for self-localization and heading determination. Potential approaches use in-network information and auxiliary devices attached to the nodes. Major research topics are to evaluate methods to generate sufficient information quality for distributed image processing and to adapt algorithms for being more tolerant for imprecise measurement.

A requirement for enlarging maintenance-free operation of autonomous systems is energy aware design. In pervasive smart camera networks, trade-off between communication overhead and the need for information interchange is crucial. The focus of research is on evaluating approaches for system-wide power management by using in-node and in-network processing.

Beyond development of theoretical models, our proposed pervasive smart camera network and its algorithms will be evaluated using software simulation, and tested in practice using dedicated camera nodes and motes.

References

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