On the Role of Negotiations in *Ad Hoc* Networks of Smart Cameras

Faisal Z. Qureshi, *Member, IEEE*

***Abstract*—We introduce an *ad hoc* network of active pan/tilt/zoom and passive cameras capable of carrying out collaborative tasks through strictly local interactions. Camera interactions are modeled as negotiations between two or more cameras. Through negotiations camera agree upon how best to carry out an observation tasks. Our smart camera nodes are modeled as behavior-based agents and are capable of engaging in multiple negotiations and performing multiple tasks simultaneously. We expect the proposed camera network to be highly scalable due to the lack of any centralized control.**

***Index Terms*—Smart Camera Networks, Collaborative Sensing, Camera Control**

I. Introduction

We introduce a collaborative sensing framework that allows an *ad hoc* network of smart active pan/tilt/zoom (PTZ) cameras to capture seamless video of pedestrians during their stay in the designated region. Through strictly local interactions, camera nodes agree among themselves how best to carry out the observation tasks. Our cameras are highly competent self-managing sensor nodes, complete with visual analysis capabilities and a host of increasingly sophisticated low-level behaviors (fixating, zooming, etc.). A noteworthy feature of our approach is that it allows multi-tasking active cameras. The ability to reason about and perform multiple observation tasks simultaneously, we find, is central to developing camera network whose performance degrade gracefully as the number observation tasks increase (Fig. 1).

We model camera interactions as negotiations. A camera node initiates negotiations in order to establish a collaboration with other cameras in the vicinity. For example, such a collaboration is needed during camera handoffs. The camera that initiates the negotiations is referred to as the client camera; whereas, the cameras in the vicinity that take part in these negotiations are referred to as servers cameras. The client-server metaphor suggests the relationship between the cameras involved in the negotiations. Client cameras set the task description and requirements—e.g., "Acquire closeup video of pedestrian A." Server cameras can either agree to perform the task and meet all its requirements or give a counter offer to the client camera—e.g., "1) Cannot acquire closeup video of pedestrian A. 2) Can observe pedestrian A at a lower resolution."—when these are unable to meet the requirements set by the client camera. Successful negotiations enable cameras to establish mutually acceptable service commitments (Fig. 2). Task collaborations are dynamic arrangements and evolve over time.

F. Qureshi is with the Faculty of Science, University of Ontario Institute of Technology, Oshawa, Canada, ON L1H 7K4. e-mail: (see http://faculty.uoit.ca/qureshi).

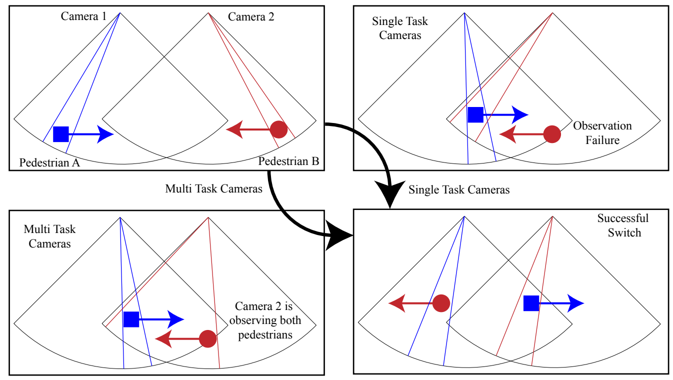

Fig. 1. Camera 1 is assigned to acquire close-up video of pedestrian A, while camera 2 is assigned to acquire close-up video of pedestrian B. Pedestrian A and B are shown walking towards each other. At some point, the cameras need to switch the observation tasks; i.e., camera 1 has to takeover observing pedestrian B and camera 2 needs to be re-assigned to pedestrian A. If camera 1 and 2 are only able to carry out a single observation task, camera switch will induce at least one failure. On the other hand, if cameras are allowed to carry out multiple tasks, cameras will continue to capture closeup video of the two pedestrians even during the switch, albeit at a lower video quality.

Our negotiation model is inspired by the observation that global consistency, and by extension finding globally optimal solutions, is an unreasonable goal in extremely large scale and rapidly evolving *ad hoc* networks. Our negotiation model aims to achieve a *satisficing* solution instead of finding the optimal solution. A satisficing solution is often very close to an optimal solution when the cost of obtaining complete information is factored into decision making.

II. Background

Control problems within smart camera networks have been studied within the context of camera assignment, selection, and handoff. To perform camera handoffs, [1] construct a distributed lookup table, which encodes the suitability of a camera to observe a specific location. For continuous tracking across multiple cameras, [2] propose the use of a handoff function, which is defined as the ratio of co-occurrence to occurrence for point pairs in two views. Their approach does not require calibration or 3D scene information. [3] develop a game theoretic approach to achieve camera handoffs. When a target is visible in multiple cameras, the best camera is selected based on its expected utility. They also propose a number of criteria to construct the utility function, such as the number of pixels occupied by the selected target in an image. Their approach eschews spatial and geometric information. [4] develops a probabilistic framework for selecting the "dominant" camera for observing a pedestrian, defined

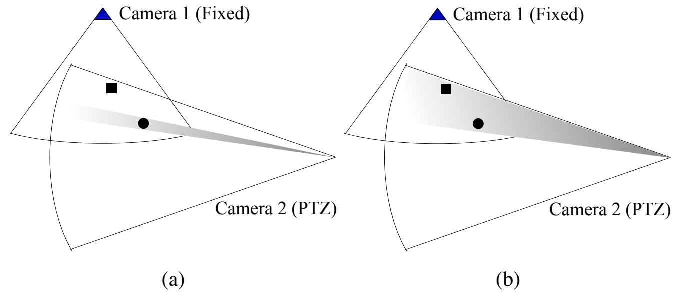

Fig. 2. (a) Camera 1 is observing pedestrian A (indicated as a square). Camera 1 attempts to set up a task collaboration with a PTZ camera to acquire a closeup video of this pedestrian. The only PTZ camera in the vicinity (camera 2) is currently observing pedestrian B (indicated as a circle) and it can not meet the requirements set by camera 1. (b) Through negotiations both cameras agree that camera 2 will acquire a lower-quality close-up video of pedestrian A. Consequently, camera 2 is now observing both pedestrians A and B, albeit at a lower-resolution.

as the camera with the highest proximity probability, which is computed as the ratio of the foreground blocks occupied by the selected pedestrian and the angular distance between the camera and that pedestrian. [5] presents a game-theoretic strategy for cooperative control of a set of decentralized cameras. The cameras work together to track every target in the area at acceptable image resolutions. The camera network can also be tasked to record higher-resolution imagery of a selected target. Recently, [6] proposes a strategy for proactive PTZ camera control strategy. Here, long-term consequences of camera assignments are taken into account when determining how best to carry out a camera handoff task.

Our previous work on *ad hoc* networks of smart cameras [7] is closest to the work presented here. There we propose an uncalibrated camera network capable of persistent surveillance. Cameras form groups and cooperatively carry out the observation tasks. Groups are dynamic arrangements and are set up through a distributed auction process. Assignment conflicts are modeled as a constraint satisfaction problem whose solution determines appropriate camera assignments. There we assumed that each camera can only perform a single observation task. Here we relax this assumption and develop camera controllers that can carry out more than one observation tasks simultaneously. This allows the proposed model to handle camera selection and assignment conflicts in a completely distributed fashion. Additionally, the performance of the camera network degrades gracefully when it is overwhelmed by a multitude of observation tasks.

III. Summary

Future visual sensor networks will rely on smart cameras, which are self-contained vision systems, with increasingly sophisticated image sensors, on-board processing and storage capabilities, power, and (wireless) communication interfaces. Smart cameras networked through wireless links and the Internet provide unprecedented opportunities for developing multi-camera systems capable of visually surveilling extensive public spaces, disaster zones, battlefields, or even entire ecosystems. The effective visual coverage of extensive areas requires multiple cameras to collaborate towards common sensing goals. As the size of these camera networks increase, it becomes infeasible for human operators to monitor the multiple video feeds to identify events of interest, or even to control individual cameras directly for the purposes of persistent surveillance. In dynamic environments, especially, camera nodes must be managed in real time to satisfy the observation task requirements. Therefore, it is desirable to design camera sensor networks that are capable of performing visual surveillance tasks autonomously, or at least with minimal human intervention. To be truly scalable smart camera networks must support distributed, in-network processing and storage. The work presented in this paper is another step toward the realization of such smart camera networks and our initial results appear promising.

The overall behavior of our network is governed by local decision making at each camera node and negotiations between neighbouring camera nodes. The proposed network carries out collaborative observation tasks in a completely distributed manner, which suggests that the proposed approach is well-suited to large-scale camera networks. Our approach shuns camera calibration or a detailed world model, which makes it suitable for *ad hoc* networks of smart cameras. Prior camera network calibration, we believe, is an unrealistic goal for a large-scale camera network consisting of heterogeneous cameras. Similarly, our approach does not expect a detailed world model which, in general, is hard to acquire.

We have developed multi-tasking smart camera nodes and introduced a negotiation model that enables these cameras to set up collaborative observation tasks. Our preliminary results appear promising.

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