SCOPES: Smart Cameras Object Position Estimation System

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INTRODUCTION

In this work, we present SCOPES, a distributed Smart Camera Object Position Estimation sensor network System that provides maps of distribution of people in indoors environments. Each node in the system is comprised of a Cyclops camera that performs local detection and processing of the visual information and a Tmote Sky sensor node, which provides multihop communication. SCOPES uses local adaptive techniques that enables intelligent duty-cycling between the active sensing and the information processing tasks performed at each node. The system switches between the fast and simple background subtraction algorithms for object detection, to the more computationally intensive object grouping algorithms for estimating the number and direction of travel of multiple persons in the local field of view.

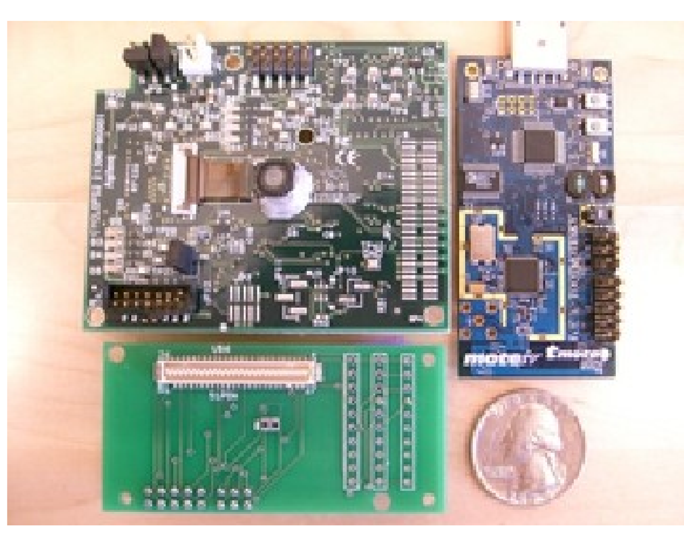
By aggregating meta-information generated by each node, SCOPES is able to minimize the total data transmitted in the network and still be able to generate an accurate density estimation map of the coverage area. Using analysis, simulation and experimentation, we show that the system is able to provide a small global error estimate of the spatio-temporal distribution of people in indoors environments despite the absence of continuous sensing when doing local information processing and sparse coverage. In the work, we show the results of people density estimation, power consumption, memory usage, latency and detection probability on a real system deployment at the University of California, Merced.

SYSTEM DESCRIPTION

Hardware:
- *Cyclops*: The Cyclops consists of an Agilent ADCM-1700 imager module, an ATMEL Atmega128L micro-controller (MCU), a Xilinx XC2C256 CoolRunner CPLD, an external SRAM (0.5MB) and an external Flash (0.5MB).
- *Tmote*: The Moteiv Tmote Sky module is comprised of an ultra low power Texas Instruments MSP430 F1611 micro-controller featuring 10kB of RAM, 48kB of flash and a Chipcon CC2420 radio for wireless communications.

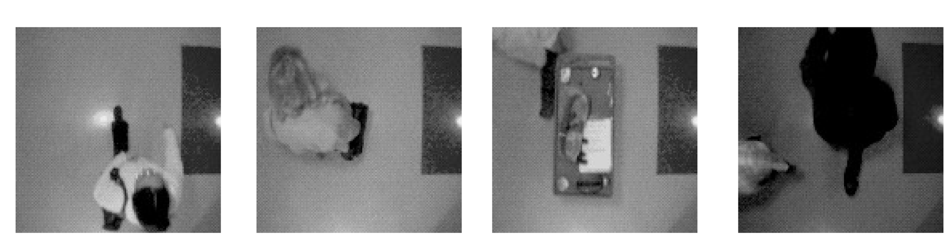
Software:
- The Cyclops and the Tmote run the event-based TinyOS operating system for wireless sensor network platforms.
- TinyOS is written in nesC. It is characterized by a small memory footprint and direct-access to the underlying hardware.
- TinyOS has a synchronous execution model wherein a task will run to completion if not preempted.

Algorithms:
- *Background Subtraction*: using weighted moving average to determine change in foreground.
- *Object Detection*: raster scanning the image and group pixels that exceed a pre-specified threshold.
- *Direction Inference*: classification of objects in successive frames to determine direction and velocity.

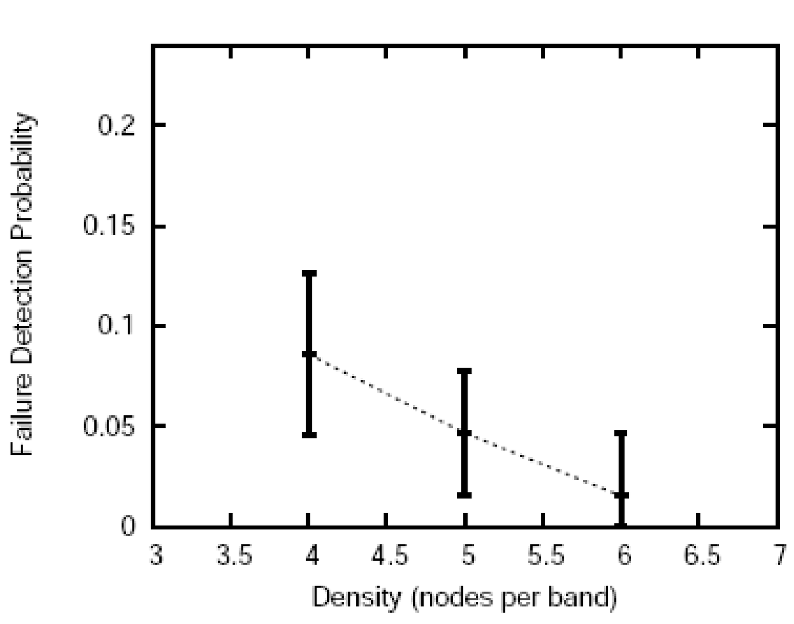


Clockwise from upper left: Cyclops, Tmote, US quarter Coin and Interface Board

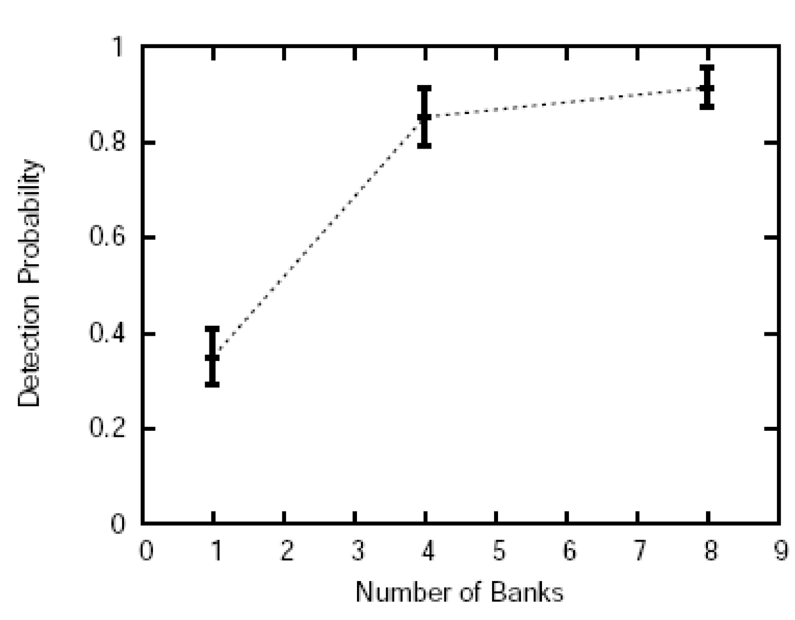
Unified Sensor Mote



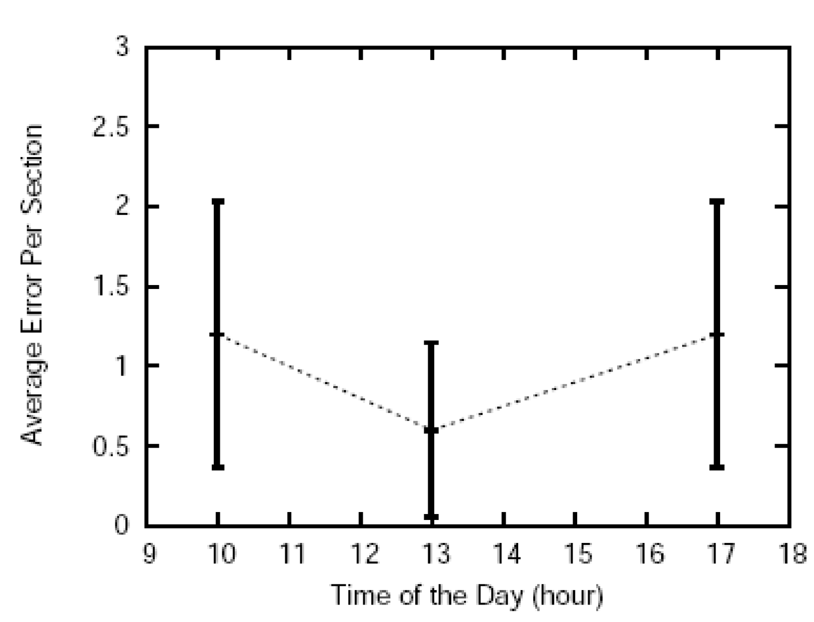
Actual Pictures From Camera (128 x 128 pixel resolution)



(a)

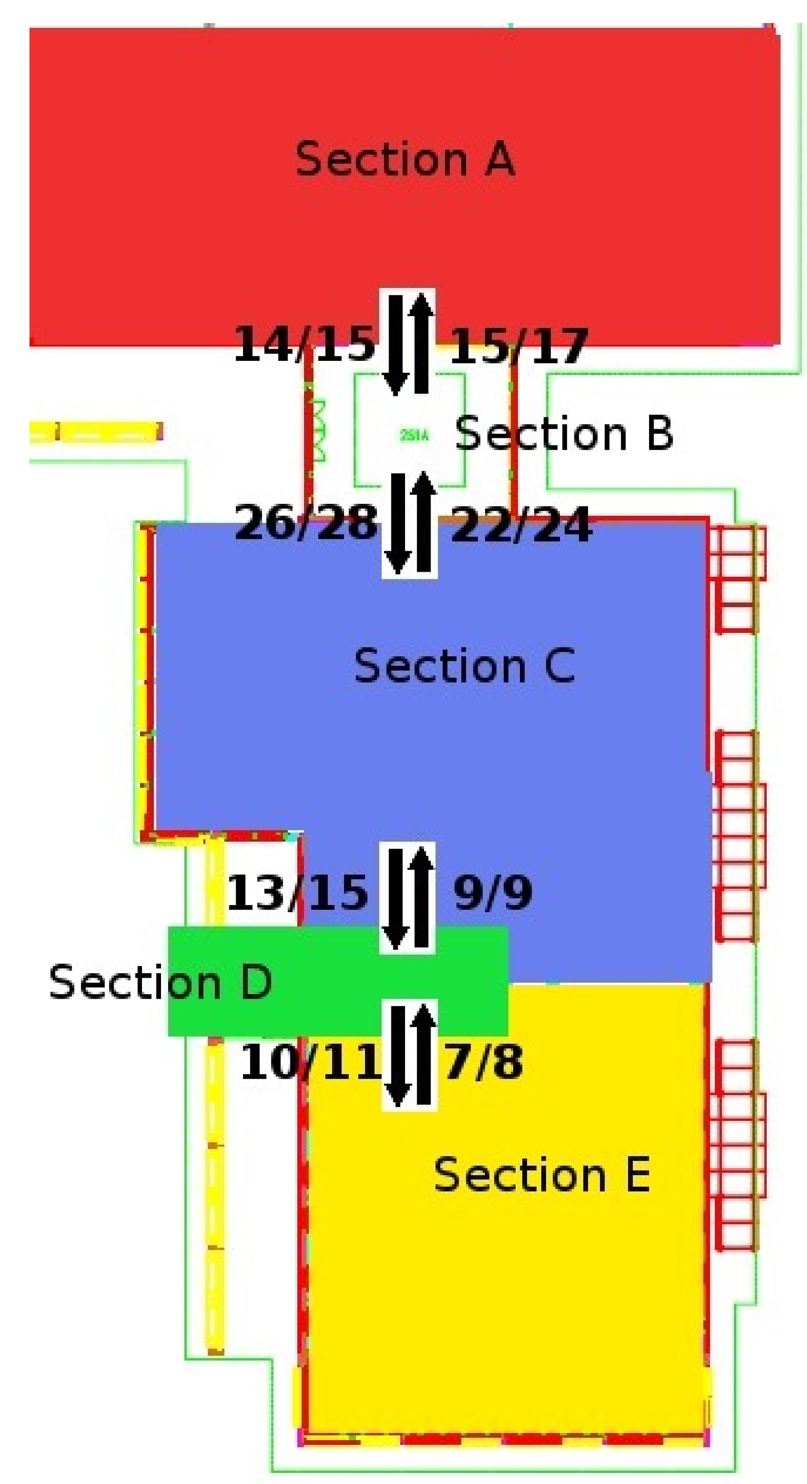


(b)



(c)

Fig. (a) shows the Failure Detection Probability as a function of the density of nodes covering the same area. The detection failure probability converges to a very small value after 6 nodes. Fig. (b) shows the Detection Probability as a function of the number of memory banks. The detection probability tends to increase as we increase the available memory due to larger duty cycle and higher probability of a person walking down the camera while sensinge Fig. (c) shows the Average Position Estimation Error per section for different times of the day. The position estimation error tend to be stable and small over time. The error shown on the Y-axis is in terms of number of people.



Occupancy and Flow Estimation Maps created by data from SCOPES. (The arrows indicate the direction of motion. The number above the arrow indicates the number of people traveling in that direction as observed by the SCOPES node (number on the left) and by the Panasonic network cameras (number on the right).)

PERFORMANCE EVALUATION

- Performance of the system is determined by its ability to effectively monitor the target area for movement of individuals.
- Key metric is Failure Detection Probability.
- Increase in the number of sensors provides lower failure detection probability due to redundancy.
- Increase in memory allows the sensor to process more data at a time which on an average should increase the probability of detection.
- Average error per section depends upon factors like the presence of external illumination.
- Provide a sample map of the transition of individuals inside different sections of a building from our deployment.

CONCLUSION

We showed that SCOPES is able to provide a small global error estimate of the spatio-temporal distribution of people in indoors environments despite the absence of continuous sensing when doing local information processing and sparse coverage, under severe resource constraints.