Title
SYS3: Cyclops: Image Based Sensing for Wireless Sensor Networks

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Cyclops - Image Based Sensing for Wireless Sensor Networks

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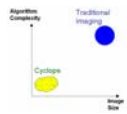
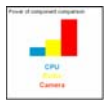
Problem: Vision Network

Why Vision

- **Vision provides humans with unmatched capabilities to disambiguate the environment**
  - Context, texture, Shape or change in shape, Presence or absence, Displacement, Interaction, Color
- **Low power networks of image sensors**
  - Enables new classes of applications
    - Security ,Biology, Precision Agriculture, Gesture recognition, Enhanced toys
  - Lossy inferences that reinforce by multiple observations in the network
    - Multiple view, Avoid occlusion, Close-up observation





Enabling Technology

- **CMOS vision sensors are low power and low cost**
- **Many vision inferences can be performed on low-quality images**
- **Image capture and image interpretation functions can be integrated on a single chip**
  - Low power capture
  - Low power lightweight inference
    - **Scalability in numbers can lead to less power hungry algorithms?**

Our Approach

Hardware Design Principles

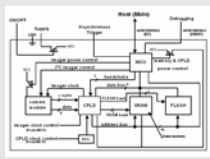
- **Low power consumption**
  - On the order of a sensor network node
- **Simple interface**
  - Mote class devices
- **On-demand access**
  - Computation
  - Clocking
  - Memory
- **Flexible Sensor**
  - Sensor for applicability to a variety of sensor network problems

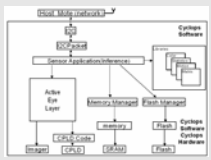
Hardware

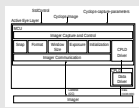
- **Stand Alone MCU**
  - Low power computation for inference
  - Isolate delay stringent networking from imaging
- **CPLD**
  - Low power frame grabber with controlled clocking
  - Dedicated logic at the same time as capture
- **Imager**
  - CMOS, medium quality and Low power
  - Access to lower layer of imaging such as exposure, raw data,
- **External SRAM**
  - Image capture and manipulation buffer
  - Auto sleep
- **External FLASH**
  - Permanent storage such as template matching

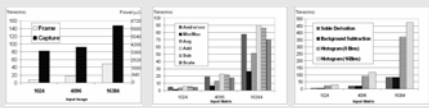
The Great Challenge

- **Vision Algorithms**
  - Designed for small number of highly capable nodes
  - Distributed image sensing has not been the norm
  - Vision algorithms are power hungry
- **Vision Sensors**
  - Complex, human pleasing image
  - High clocking, lots of unnecessary flexibility









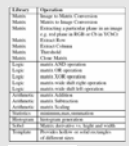
Some Power and Time Benchmarking

Software Design Principles

- **Transparency in using resources**
  - Still supporting their automatic relaxation to the lowest possible power state.
- **Supporting the long computations**
  - Image inference pipeline
- **Synchronized access**
  - MCU and the CPLD to shared resources such as SRAM and the imager

Software

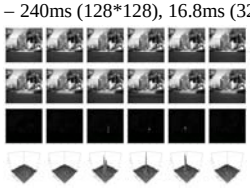
- **TinyOS, nesC**
  - To use component with clean interfaces
  - Leverage available code, scheduler and support
- **Sensor Application**
  - Communication with host to making Cyclops a sensor
- **Devices**
  - Hardware drivers
- **Libraries**
  - Hardware independent
  - Structural libraries
    - **Matrix**
    - **Statistics**
    - **histogram**
  - advanced libraries
    - **Background subtraction**
    - **Coordinate conversion**

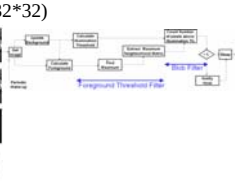


Results

Object Tracking

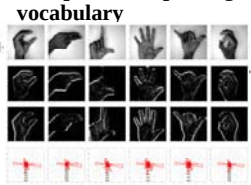
- **Periodic wake-up**
- **Background model** $B_n = \lambda \times B_{n-1} + (1-\lambda) \times \mathrm{Im}\, g$
  - Moving average of instantaneous images
- **Calculate foreground model**
- **Detect presence of object and its location**
  - based on luminance threshold and size filter
- **Run Time depends on the image size**
  - 240ms (128*128), 16.8ms (32*32)





Gesture Recognition

- **Trade simplicity vs. speed** $hist(\arctan(\frac{d\,\mathrm{Im}\,g/dx}{d\,\mathrm{Im}\,g/dy}))$
  - Limited set of vocabulary
- **Using orientation histogram as feature**
  - Orientation texture of a hand pose provides robustness to illumination changes
  - Histogram provides translational independence
- **Train phase to create and album of postures**
- **Test phase compare against the trained vocabulary**



Debugging Environment

- **Visibility**
  - Both into device operation and flow of algorithm
- **Looking at Cyclops memory**
  - To record images and results
  - Design algorithm offline
  - Debug the the algorithms implementation
- **Observing multiple Cyclops**
  - Debug distributed operation
  - Multiple Cyclops through serial multiplexer
  - Extension over radio relay for extending the coverage