SCHOOL: Wide Field-of-View Imaging Wireless Sensor Networks[1]

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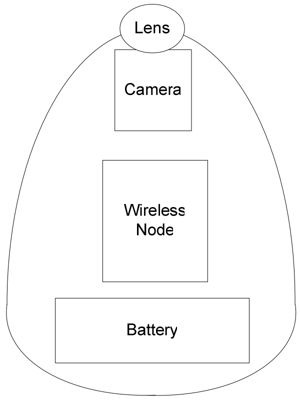
Low cost wireless sensors can be distributed to provide information about an environment. Even a network of sensors providing scalar measurements (for instance, of temperature) presents both formidable challenges and important opportunities. We can expect more of both with multi-dimensional sensors.

Natural image data is a particularly useful case of multi-dimension sensing; humans are adept at processing visual data and natural images match the peak illuminating power produced by the sun. So, attaching cameras to wireless sensor nodes is intrinsically interesting. A difficulty, though, is that cameras typically have a limited field of view, so that a network of such cameras either needs to be carefully pointed when set up or the nodes need to be able to be re-pointed, likely remotely.

We propose an alternative paradigm for imaging remote sensors; use of a wide field of view lens (typically called a fish eye lens) attached to a camera equipped node so that re-pointing is not required. We term a network of such wide field-of-view imaging wireless sensor nodes a school. A diagram of a typical node is shown in Figure 1.

[1] Bonus points to anybody who can figure out how to make SCHOOL into an acronym for this project.



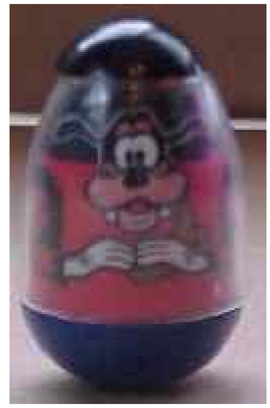


Figure 1. Single Fish-Eye Node and its Weeble predecessor.

The particular idea behind this design is that the heavy battery in the base and the shape of the exterior causes the node to self-right on reasonably level ground much like Weeble toys[2]. The fish-eye lens projects roughly a half sphere field of view onto the camera. We envision an inexpensive camera of the type currently used in low end disposable digital cameras and in camera equipped cell phones. The wireless node is of the MANTIS type[3]. An alternative to a fish eye lens would use a conical mirror, sacrificing the full half spherical field of view in return for better resolution in horizontal directions, shown in Figure 2.

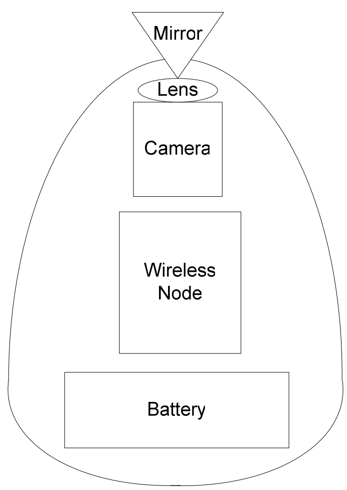


Figure 2. Conical mirror equipped node with 360^o but not half-spherical field of view.

[2] Weebles wobble but…
[3] http://www.cs.colorado.edu/~rhan/SensorNetworks.htm

A school could have both commercial and military applications. Consider a situation in which an area suddenly warrants sustained visual observation and there is insufficient time to set up pointed cameras or it is too hard to predict the correct collection of pointing angles. Examples might be an area that has been threatened, say a school shooting threat or a terrorist threat, a battlefield area that has just been entered but is expected to be contested for some time, a civil disaster area. Inexpensive nodes could be scattered throughout the area and start providing continuous and ubiquitous visual monitoring immediately.

Research Problems

Aside from direct application to visual monitoring applications, the School project also presents a set of interesting and likely tractable research problems that could assist in advancing the field of sensor networking in general. The overall context is one of very cost and size limited nodes; we don't want to rely on Moore's law to rescue complex designs since we are at least as much interested in scaling designs to smaller nodes as in holding node size constant and scaling to more complexity. Interesting problems include:

Usefully Fusing Image Data – the nodes provide a collection of highly distorted images from different locations. We need to combine this data in a useful way. For example, we may want to pick an arbitrary virtual location and orientation and fuse the image data from the nodes to form an estimate of an undistorted image we would see from that location. There are issues of geometry, combining images to reduce noise, dealing with obstruction, and a variety of other image processing challenges. Moreover, we expect the data to be of limited resolution, low update rate, and noisy, so we need unusually robust fusion techniques.

Self- and Mutual-Location – the ability to make sense of the data will depend strongly on an accurate estimate of the relative location and orientation of nodes. If we imagine that nodes are scattered rather than placed, nodes will need to be able to self-locate and mutually locate with high accuracy. We would not expect GPS positioning to be sufficiently accurate.

Severely Constrained Signal Processing – we have very limited communication bandwidth, limited processing power, and limited memory available. We need to optimize node image processing, image compression, and communication operations carefully. For example, we would want to consider combining operations to reduce complexity, such as selective encryption in which only parts of a compressed image format are encrypted and the compression protocol itself provides remaining necessary privacy.

Extending Network Semantics – wireless node networks have to be very simple and currently do not embrace the capabilities of typical LANs. But given the very limited communication bandwidth we envision, we will want to add the ability for nodes with particularly interesting local activity to preemptively secure bandwidth back to a base processing station. Adding limited quality-of-service style semantics to wireless node networks is intrinsically challenging.

Sensor Integration – aside from the problem of integrating camera and image processing with the computing node, we can quickly envision interesting multi-sensor integrations. For example, we may want to integrate an accelerometer to detect motion of the sensor (for example, if it is accidentally or intentionally moved). Combining multiple sensors at a node brings up the problem of partitioning sensor fusion between the low complexity node and a higher capability but remote (across a limited bandwidth communication path) base station.

Next Steps

The immediate goal for the project should be to acquire sufficient funding to pursue several if not all of the research questions cited above. Likely steps are:

1. Assemble an interested group of researchers and brainstorm. These researchers would collaborate on identifying possible funders, preparing and presenting proposals.

2. Develop simple prototypes. Two prototypes come to mind: a fish-eye-camera-MANTIS prototype (probably not in the weeble shell but sufficient to demonstrate functional feasibility) and a multi-node simulation based on camera equipped PC's. These prototypes would be used to give credibility to proposals. Prototyping will require some speculative funding and/or moonlighting.