SensorFly: A Collaborative Lightweight Rapidly Deployable Aerial Sensing System

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(i) The background and experience of the participant in this field: Pei Zhang is an assistant research professor in the Cylab, INI, SV, and ECE departments at Carnegie Mellon Silicon Valley. He received his Bachelor's degree with honors from California Institute of Technology in 2002, and his Ph.D. degree in Electrical Engineering from Princeton University in 2008. While at Princeton University, he developed the ZebraNet system, which is used to track zebras in Kenya. It was the first deployed, wireless, ad-hoc, mobile sensor network. His primary research interest is in mobile sensing networks. Currently his work includes SensorFly, which uses a swarm of miniature helicopter based sensor nodes to research rapid deployment and collaborative sensing issues. He is especially interested in developing practical system solutions to improving ubiquitous system's adaptability, robustness, and autonomy. In addition to technical publications, his work has also been featured in popular media including: The Science Channel, Popular Science, New Scientist, Wired, etc.

Figure 1: One SensorFly node hovering in the hallway.

(ii) The vision of the participant: In an emergency situation like an earthquake or fire, the rapid discovery of trapped survivors is key for their survival. As delay increases, a trapped survivor's chance for survival drops significantly. To assist the efforts of emergency responders and ensure their safety, traditional sensor networks and robotic solutions have been proposed. Unfortunately, limitations (including deployment logistics, variable environmental problems, infrastructural dependence, and speed) have hampered their adaptation. Because of the fundamental nature of these challenges, there is a need for a new approach to this problem. This approach needs to provide an autonomous, rapidly deployable system while meeting stringent constraints associated with low-cost sensors.

To solve these problems, we propose a novel type of sensing networks, a distributed mobile sensor network system based on miniature helicopter-based (SensorFly) nodes. Due to its numbers, this system would offer greater reliability and performance than current platforms. The low weight and cost limit severely reduce their control, processing, and sensing capabilities. To accomplish this highly dynamic system, key breakthroughs will be needed in areas including:

- Dynamic system migration & control (i.e. processing, networking and physical mobility);
- Distributed sensing using low accuracy sensors (i.e. vision, far field audio, radio patterns);
- Multi-level understanding and recognition algorithms.

(iii) Evidence that pursuing this vision will lead to major advances in the field: SensorFly research aims to develop truly lightweight distributed protocols for enabling effective object recognition in a novel controlled-mobile sensing network. These algorithms can apply for both self-mobile systems (swarms of robots), and aided-mobile systems (swarm of mobile phones). Completion of complex sensing tasks, such as multi-view vision, using reconfigurable SensorFly nodes are compelling system research problems requiring multi-level decision making and dynamic task distribution. This cyber-physical system not only do the networked nodes sense and understand the physical world through cyber distribution and mobility of processes, they also adapt to the physical world through their physical mobility (either directly or informing the holder of the device). This vision explores the new dimensions of collaborative-mobility, multi-level distributed processing, and collaborative sensing with minimal capability sensors. This proposed vision will develop sound theoretical research that will not only be applicable to controlled mobile systems, but because the instant configuration required, will also greatly improve the configuration and deployment speed of current sensor systems.

Challenges and Constraints Overview:

The aim of the SensorFly vision is to study collaborative sensing and distributed control in an ultra-light, miniature flying sensor network. Although the weight limit for a given size micro-helicopters may increase in the future, increasingly smaller nodes will be attractive due to their minimal intrusiveness. Furthermore, fast and autonomous setup and collaboration is not only applicable for self-mobile networks but also necessary for future rapidly deployable or movable sensing applications, such as consumer sensing products. Therefore, this investigation into limited capability mobile sensors will have a lasting impact that extends beyond today's sensor systems. The low-cost, low-weight aerial sensing platform presents several constraints and challenges, occupying a new and unique space. The following are some factors that affect algorithm design and approach:

Cost: Low per-device cost allows us to scale up senor node deployments. As a result, for the equivalent cost of an intelligent robot, many more sensor nodes can be used, enabling higher sensing coverage as well as discovery speed. The navigational capability of individual sensor nodes must be attained through low-cost COTS sensors. A trade-off must thus be made forgoing accuracy for deployment scale, which can be utilized, to better realize our application objectives.

Weight: The miniature aerial platform adds a new metric, weight. The small weight enables longer flight times, greater reach and better safety for indoor emergency response scenarios. The weight limit is decided by delicate trade-off point. Adding more weight requires bigger motors, which in turn requires a bigger battery. A larger platform eventually sacrifices the miniature form factor along with the mobility and scalability advantages. The entire SensorFly node, including battery and driving mechanisms, has a target weight of 29 grams, approximately the weight of 10 pennies. A node that is heavier than 30 grams is still able to fly, but has higher energy consumption. This weight constraint also limits the number of sensors that can be carried. Thus sensor reuse and software sensing are desired.

Energy: Similar to many battery-operated systems, the SensorFly platform is highly energy constrained. Unlike most other sensor systems, however, SensorFly has many different operating modes with vastly different energy characteristics. The modes involving movement are the most expensive in terms of energy usage. This further underscores the need for collaborative movement algorithms, to reduce the power consumption.

The SensorFly system proposed here requires a vertical approach to systems research, incorporating elements that span the entire spectrum from hardware to applications. By taking this approach, this will not only achieve practical research on mobility and system collaboration but also sound theoretical research validated in this novel platform.

Reference:

1. Purohit, A., Pei Zhang. "SensorFly: A Controlled-Mobile Aerial Sensor Network". SenSys 2009. The Seventh ACM Conference on Embedded Networked Sensor Systems. Demo Session Nov, 2009.