Position Paper on Sensor Webs

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A generic definition of a sensor web might be: A Sensor Web is a network of interlinked sensor platforms with onboard information processing systems capable of collaborative operations with other sensor platforms and human users.

Even this generic definition uses terms that require further definition:

1. Interlinked: There is the assumption that the platforms are part of a network. Part of this is addressed by NASA's work on the space internet. Other work might be related to DARPA's Rapidly Deployable Radio Network effort, where nodes (platforms for our purposes) entering a theatre of operations dynamically and automatically link up into a network. A fundamental issue is dealing with the dynamic nature of the platforms, in that they might enter and exit the network at any time.
2. Sensor platform: This includes space platforms, mobile terrestrial platforms (e.g. buoys, sea-borne and undersea sensors, aircraft sensors, etc.), and sessile terrestrial platforms (e.g. weather stations).
3. Onboard information processing: Beyond the obvious issues of miniaturization and energy consumption that must be investigated to achieve onboard processing, a major issue refers to the type of processing that will be performed. On a simple level, processing could be sensor-specific: for example, SAR backscatter data could be calibrated and processed onboard, resulting in immediately usable imagery data. More complicated would be processing that is *observation specific*. For example, a SAR space sensor instead of producing simply an image of Arctic sea ice would also generate distributions of sea ice types. Such processing requires knowledge of the phenomena that are of interest, and would need complex pattern recognition algorithms that could not work in real time, or even near-real time, requiring significant onboard storage capacity.
4. Collaborative operations: Collaboration requires that platforms be intelligent and capable of, at least, introspection (so that they can recognize when they need to collaborate), high-level communication (to request cooperation and to respond to such requests), reasoning (to decide whether cooperation is beneficial as well as to plan on how to cooperate), and the willingness to help (sometimes in detriment of one's own sensing plans). To do so, the platforms need to be viewed as intelligent agents in a collaborative, multi-agent environment.

Our work addresses the latter issue.

When viewing a platform as an intelligent agent, one shifts the discussion from sensors to agents. There are many definitions of an "intelligent agent" (or simply, "agent"), but most researchers agree that an agent is an *autonomous* program, that has the ability to *sense* the environment, the ability to *communicate* with users and other agents, and the ability to *effect changes* to the environment. Additionally, agents may be able to *learn* new behaviors, *collaborate* with others to resolve conflicts or perform tasks, and *negotiate* to share limited resources.

Basic agent characteristics fit sensor platforms on a Sensor Web. The platforms need to operate continuously, without human supervision (autonomously), must sense the state of the world, must be able to communicate amongst each other and with humans, and must be able to perform actions that change the operations of the sensor web. They must also collaborate, and negotiate for optimal sharing of sensor resources.

To illustrate some of the issues associated with platforms-as-agents we will use a simple example:

A local weather station measures rainfall at location A. It notices that the rain over a period of D days is substantially above historical averages.
This requires access to historical information and the ability to store data in some database in order to assess trends.

The station requests rainfall information from neighboring stations to determine if the trend is widespread over a larger area[1].
This requires knowledge of other agents and their abilities, ability to communicate, and also the knowledge of the rainfall phenomenon.

If the agent determines that increased rainfall is widespread, it asks weather satellites to provide it with their predictions of future rainfall.
This requires knowledge of other agents and their abilities, ability to communicate, and also the knowledge of the rainfall phenomenon.

If it determines that increased rainfall is predicted, it computes that this could lead to flooding. It then creates a plan for sensing flooding in the area, as well as downstream.
This requires an –at least- adequate model of physical processes, and the ability to create sensing plans that involve other sensors.

The sensing plan is transmitted to the space platforms that must sense the flooding.
This requires knowledge of other agents and their abilities, and the ability to communicate.

The sensors contacted must determine if they can help with the sensing request. To do so they need to know their own capabilities ("can I sense flooding, and, if so, with what

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[1] It is possible that multiple agents sense the same event and make similar requests of others. This "race condition" can lead to oscillations if not treated.

accuracy and resolution?"), and also what their sensing commitments are during the time they are asked to sense flooding.
This requires introspection and keeping a long-term sensing plan.

If a sensor determines that it cannot assist in the request, it must justify why (for example: my "flood sensor" is inoperative, or, maneuvering over the flood area will cost too much fuel, or, I will be busy sensing something else). The agent that made the original request will determine if enough sensors have joined its sensing coalition. If not, it will attempt to convince the ones who did not accept its request by providing them with arguments as to why flood sensing is worth their fuel consumption, or worth giving up their other sensing task, etc.
This requires introspection, the ability to negotiate for limited resources, the ability to formulate arguments, and the ability to evaluate arguments.

Finally, if a sensor has committed to a future task, or has refused to assist in a future sensing plan, and its situation changes, it must inform the original requestor of either its decommitment or late agreement.
This requires the ability to constantly track ones state and plans, and to keep track of long-term agreements.

These and other issues are addressed in multiagent systems' research under the topics of coalition formation and negotiation.