Hybrid Exploration Agent Platform and Sensor Web System

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A sensor web to collect the scientific data needed to further exploration is a major and efficient asset to any exploration effort. This is true not only for lunar and planetary environments, but also for interplanetary and liquid environments. Such a system would also have myriad direct commercial spin-off applications.

The Hybrid Exploration Agent Platform and Sensor Web or HEAP-SW like the ANTS concept (Curtis 2003) is a Sensor Web concept. The HEAP-SW is conceptually and practically a very different system. HEAP-SW is applicable to any environment and a hug range of exploration tasks. It is a very robust, low cost, high return, solution to a complex problem. All of the technology for initial development and implementation is currently available.

The HEAP Sensor Web or HEAP-SW consists of three major parts, The Hybrid Exploration Agent Platforms or HEAP, the Sensor Web or SW and the immobile Data collection and Uplink units or DU. The HEAP-SW as a whole will refer to any group of mobile agents or robots where each robot is a mobile data collection unit that spends most of its time acting in concert with all other robots, DUs in the web, and the HEAP-SW's overall Command and Control (CC) system. Each DU and robot is, however, capable of acting independently. The Three parts of the HEAP-SW system are discussed in this paper.

The Goals of the HEAP-SW system are:

1. To maximize the amount of exploration enhancing science data collected;
2. To minimize data loss due to system malfunctions;
3. To minimize or, possibly, eliminate the risk of total system failure;
4. To minimize the size, weight, and power requirements of each HEAP robot; and
5. To minimize HEAP-SW system costs.

The rest of this paper discusses how these goals are attained.

The First major part of the Heap-SW is a Sensor Web. The SW refers to several aspects of the system. Each HEAP robot broadcasts information to its nearest neighbors about what it has found and where. This will occur in the same way that members of social insect colonies returning to the nest with information about the location of food spread the information to other members of the nest/hive. They signal the members closest to them and these members in turn inform other members and so on. This accomplishes two things. One, it saves on the power each robot needs to transmit basic information to the rest of the web. Two, it ensures that if any single HEAP robot suffers a fatal failure the mission will not suffer major loss of data, even if that robot's data had not gotten to a DU center yet. The system assures this by the information spreading strategy. Other HEAP robots will know what the failed robot found and where it found it, allowing Investigators to make a decision about whether the data is important enough to reaquire with other robots. The reacquisition will take place after the cause of the first robot's failure is diagnosed and attaining a comfort level that the subsequent robots will not suffer the same fate. Diagnosis of a robot's failure will be easier than current remote failure diagnostic techniques. There will be other robots to assist in the task instead of depending on ground control interpretation of historical data.

The Second major portion of the HEAP-SW will consist of a small number (perhaps, 1 per 1000 HEAP robots) of fixed, immobile Data collection and Uplink centers or DUs. Since each HEAP is expected to have limited power and data storage capacity, it will be important that the HEAP robots be able to move data to central facilities with greater data storage capacity on a continuous basis. These DU centers will be equipped with a powerful communications system to uplink the data to mission control through one of the other systems proposed elsewhere in the EI initiative. Again, having multiple data storage centers that can also back up highly compressed snap-shots of data from other DUs will produce another level of redundancy to protect exploration data.

The use of a sensor web addresses the first three goals and the first half of goal 5 above. First, data collection is maximized by using multiple interconnected robots.. Second, data loss is minimized due to partial system failure since the data in transit (robot to robot) will still be delivered and other robots can reaquire missing observations. Third, the SW attempts to minimize or eliminate the possibility of total system failure by eliminating any single point of failure. For goal Five, costs are minimized via the operational strategies discussed above.

Using more than one earth to planet delivery system such as was used with the Mars Rovers would eliminate the last single point of failure in the system. Whether this is cost effective will depend on the type and cost of propulsion systems and delivery strategies developed by the EI propulsion efforts.

The Third major part of the HEAP-SW system is the individual HEAPs (Hybrid Exploration Agent Platforms) . Maximal use of nanotechnology and miniaturized components throughout the HEAP will reduce the size of each unit. The largest objects on the HEAP robots will be the sensor heads and legs of the robots. The legs of the robots will have to be of sufficient size to allow the HEAP to traverse rough terrain if it is a terrestrial robot. For aquatic, underground, or space bound robotic vehicles, the mobility extensions would have to be appropriate to those environments. This paper will only deal with terrestrial robots.

Each Robot will consist of the following components:

1. A hybrid analog/digital mobility platform or HAMP.
2. An autonomous Guidance, Command and Control.
3. An exploration oriented scientific instrument package.
4. A data storage package.
5. A communications package.
6. A power supply.

The hybrid analog/digital mobility platform or HAMP, can have many configurations, one is a six-legged insect like robot where the front two legs are capable of serving as arms or retrieving tools. They will have basic claw attachments. The claws are shaped such that they will not interfere with the robot's ability to use the front legs for mobility. Such designs have already been built, tested, and implemented on earth.

The greatest advantage to the HAMP is that the use of analog circuits for most of the initial "What's out there" searching task are less expensive by several orders of magnitude than conventional digital robot, such as the Mars Rovers. There is no intelligence needed for the analog side of the mobility platform as it is designed to conduct the initial search in a random pattern. This part of the HEAP robot is much like the analog robots built at Los Alamos National Laboratory (Hasslacher and Tilden 1995). This cost reduction allows one to have many more HEAP robots in the HEAP-SW system. Combining the large number of robots initially disbursed evenly over a large area and allowing them to search randomly until they come to something of interest, gives Heap-SW the ability to cover a large surface area in a short period of time allowing for and promoting serendipitous discoveries.

The digital part of the hybrid analog/digital mobility system is used to steer the robot in a particular direction once the instrument package senses that something interesting is nearby. This will be done autonomously through a feedback loop from the activated sensor on the instrument package and the digital mobility system. One of the sensors envisioned to be part of a scientific instrument package is an airborne particle detector with sufficient on board analysis capability to allow the HEAP to determine what the detected particles are. For example the "electronic nose" from Cyrano Sciences (Albert et. al.,2000). Once particles of interest are found, the robot can be guided toward the source of the particles by simply signaling the digital steering system to move the robot in that direction. Once the robot begins to move in a certain direction the analog system can be set to follow the source of the signaled input. A behavior that analog chips can handle easily because you can give them a sense of inertia just by switching the rhythm of the analog chips' signal firing pattern that controls the leg movements so the chip no longer fires in an offset pattern. The offset pattern is what gives the robot its random motion. If the sensor then senses that the particle density is getting lower in the direction the robot is going, it signals the digital steering system again. This time the robot is told to let the analog system move randomly until the particle density increases again. At that point, the robot is, again via the sensor-digital steering mechanism feedback loop, told to head in the direction of greatest particle density and on and on. The result is that the system uses very little intelligence but gets to the goal without ground control commands and in an efficient manner. An ant behaves in much the same way when trying to stay on a scent trail. The ant will exhibit a similar random search pattern when it loses the scent trail until it finds it again.

This simple feedback loop is the way living organisms perform these tasks and why they can move so efficiently with minimal involvement from higher cognitive centers. The discovery of this fact explained why it was so difficult for legged robots to be developed. The systems under development in the 1980s and before were far too complicated and assumed that motility required complex, high-level cognitive functionality or, in the digital world, complicated and long programming routines. These programs could not keep up with the pace needed for efficient and rapid leg movement. Robots using such simple biommimetic feedback loops are built under a DARPA grant (Clark, Jonathan E. et. al.,2001)

The autonomous Guidance, Command & Control Module or GC&C has several purposes. The GC&C directs the Hybrid Analog/Digital Mobility Platform to follow a specific sensor's direction cues to get to a location. At this point, the simple feed back loop discussed above takes over and no further interaction takes place between the GC&C and the rest of the analog portion of the robot. The GC&C will keep track of where that particular HEAP unit is by using data collected from the planetary GPS like systems that EI documentation indicates will be needed for planetary exploration. All instructions from HEAP-SW Ground Control will be handle by the GC&C and routed to the appropriate subsystem. The GC&C will be autonomous in that most of the time it will not be acting on commands from ground control but will use AI algorithms and intelligent learning software agents to monitor and control HEAP tasks, respond to exploratory finds, maintain the integrity of the data collected and protect the health and safety of the HEAP robot. This can be done with conventional software algorithms that already exist, especially the fault detection and fault correction tasks. Eventually HEAP-SW will use intelligent learning software agents to give the HEAP robots true learning capability. These agents will be derived from the agents used in the robots built at MIT, derived from their Mathematic Models of organic learning systems (Nayar and Poggio 1996)

The intelligent learning agent is the only component of the HEAP-SW which will take further software R&D work to convert from the existing state of the art to a generalized learning agent based on the mathematical learning models.. This component is not essential to the HEAP-SW and the system will be autonomous without it.

The exploration Instrument package is the single most important module of the HEAP, as without it HEAP-SW has no mission. The type of data collected will further the ongoing exploration of the target planetary and/or other object(s) or space. Several instruments could be part of a HEAP instrument package. Examples include: particle and field sensors; spectrometer; imaging camera; weather station; radio tranceiver; and laser for ranging, mapping, optical interferometry, backup communications, etc.

Another advantage of having a large number of HEAP units in the HEAP-SW system is that not every instrument has to be on every HEAP unit. Instruments can be on just enough HEAP units to maintain redundancy, eliminating another single point of failure. When multiple types of instruments are needed for a task, a HEAP unit with each type of instrument needed is brought to the location where that specific task will be performed and those units work in concert.

The data storage package is simply the on board memory buffer and solid-state "long term" data storage device that each HEAP unit will carry. The data storage module will store the observations, telemetry data, and the location information. Since the data storage module will be limited data will have to be transmitted on a regular basis.. When a particular HEAP robot is out of touch with all DUs the robot will transmit what data it can via the nearby HEAP robots n the SW

The communications package on each HEAP has three tasks. The First task is the proliferation of rudimentary information about what each HEAP has found and where that find is located through a robot-to-robot information spreading system. This, occurs in much the same way that members of social insect colonies disperse information. The second task is continuously sending the observational and telemetry data collected to the DU centers directly or through the robot-to-robot path. The third task is receiving information and high level goals and commands from other parts of the HEAP-SW and ground control.

The choice of a power supply for the system is yet to be determined. Various proposals are being discussed and developed for planetary and space exploration under the EI initiative and the HEAP will use the most appropriate one. Two, possible candidates are the standard solar panel and battery storage supply system or a rechargeable fuel cell. Whatever power supply is chosen it will have to meet certain requirements. It will have to be a compact, lightweight, efficient, low cost, and have to use a renewable fuel source or one that is available on site.

In conclusion, the HEAP-SW will be a major asset to the exploration initiative. It will be very robust by reducing or eliminating any single point of failure. It will be able to explore a large area in a short time allowing for and promoting serendipitous discoveries. Finally, the HEAP-SW system will be a low cost system for three reasons. One, HEAP-SW uses smart strategies such as combining with other EI systems already under development in the EI initiative to complete its mission rather than reinventing the wheel. Two, it uses smart operational strategies. Three, HEAP-SW minimizes the cost of each HEAP robot through its innovative design.

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