

Toward a Science of Autonomy for Physical Systems: Disaster

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The Need

Over a million people are killed in disasters worldwide each year while another 2.5 million individuals are displaced or disabled. It takes a community 20 to 30 years to recover and \$986.7 billion in economic losses. However, it has been shown that if the length of the initial emergency response by search and rescue teams is reduced by 1 day the total recovery time is shortened by 1,000 days or 3 years. It follows that if the sequence of initial life-saving and mitigation response, restoration of basic services, reconstruction, and betterment could be parallelized so that these activities happened concurrently, then total recovery could be accelerated even more.

While advances in wireless networks, unmanned systems, embedded sensors, pattern recognition, surface reconstruction, data fusion, and scheduling algorithms can be expected to continue and even accelerate, these advances individually will not necessarily result in usable information or better decisions. This is because decision makers have to work over extreme scales and with other agencies and data that has hidden dependencies.

Four different extreme scales illustrate the complexity of decision-making during a disaster:

Time: Disaster management encompasses preparedness and prevention (past), real-time response (present), and recovery (future). Events can be discrete and short lived, as in the case of a tornado, or long-term, as with climate change.

Space: Damage can be highly localized, e.g., a bridge collapse, or spread over states, e.g., a hurricane or earthquake, while the economic impacts can be national or global.

Stakeholders: Citizens, governments (municipal, county, state and federal), industry, and non-governmental organizations all have roles to play.

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Data: Data is heterogeneous, takes many forms and content, comes from different sources, arrives in different volumes at different times, and exhibits different priorities for different phases of the disaster.

The Value of Autonomy

A Science of **Autonomy** is critically needed because it would enable computational agents that can manage the extreme scales and mine for hidden dependencies, threats, and opportunities in order to assist the accountable parties. Autonomous agents do not tire or become distracted by the emotional nature of large scale disasters. Agents can work fully autonomously, exploring areas otherwise inaccessible to human operators, and can provide a semi-autonomous triage function either in-situ or via teleoperation, filtering 90-99% of situations that are not worthy of human attention and intervention, and directing human resources to the requisite critical locations. Autonomous systems allow scaling in space (many agents cover a large area) and time (agents can work over days, weeks, or years to assimilate information)

Why: Increased research in autonomy for disasters is needed but little sustained progress has heretofore been made. Largely, we conjecture research on autonomous systems for disaster response requires a different approach in at least three ways.

- First, autonomy has to be considered within the larger context of the disaster management enterprise; making a better engine doesn't make a faster car if the transmission is poor, thus focusing on one facet of autonomy does not lead to contributions that scale.
- Second, the design of autonomous capabilities should be driven by the limitations of human decision makers, which are extracted primarily through empirical methodologies versus the reductionist methodologies used in physical sciences.
- Third, as with health and wellness initiatives, research must be conducted in partnership with practitioners. Autonomous systems in the disaster response space must be designed with humans intimately in the loop, and this offers interesting and somewhat unique research challenges in terms both of optimal planning algorithms for teams of collaborative humans and autonomous agents, and for human – agent interface development.

What: Examples of what could be accomplished with autonomous assistive agents are:

- Mining and analyzing maps, building and land-use plans, and predictive models of the location and severity of damage to ground prevention and preparedness and to bootstrap response and recovery planning.
- Accurately assess the severity and extent of an event such as a hurricane by fusing data using diverse components including sensors, an acquisition

- network, local and virtual human volunteers and/or trained staff.
- Distributed and coordinated search and rescue at both scale and granularity impossible using current systems.
 - Acquire, transmit and transform the data into actionable information, while hiding complexities of superfluous information, and help provide accurate situation awareness across all echelons of decision makers.
 - Project the social, behavioral, and economic consequences, and opportunities, of disasters.
 - Optimize resources and logistics, as well as help predict and maintain the critical infrastructure; this could include but not be limited to delivering supplies, creating temporary infrastructure (e.g. drones as cell towers), as well as providing ongoing assessment and updates as resources and logistics change with time .

Research Questions: The important research topics identified to date include:

- Sensing research (particularly computer vision) to interpret imagery from mobile perceptive devices (e.g., unmanned aerial, ground, or marine systems, smart phones, etc.) and imagery and associated feeds from social networks.
- Coordination of air and ground assets for information gathering and active intervention in disaster scenarios.
- Acquiring new concepts based on what the users are searching for and what additional data they request and examine.
- Natural interfaces and tools that enhance human capabilities to ask questions in a high level manner that facilitate making decisions for extreme events.
- Probabilistic modeling of complex events to enhance the capabilities for appropriate and adaptive response as well as in response planning.

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