A Cyber-Physical System for Situation Awareness
Following a Diaster Situation

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Abstract—With the emergence in research addressing cyber-physical systems, problems that previously were ignored or thought to be too complex, can now be investigated. A particular problem which we consider in this paper is that of environmental mapping and monitoring immediately following a natural disaster or hazardous contamination to obtain situation awareness. With the tight integration of control, computation, sensing, and communication one can create a cyber-physical system to address situation awareness in such scenarios. In this paper we present a novel application of a cyber-physical system and provide possible design challenges that must be addressed when trying to realize such a cyber-physical system.

I. INTRODUCTION

A cyber-physical system (CPS) is a network of physically distributed sensors and actuators capable of computation, communication, and control that relies highly on the integration of these capabilities for its operation and interaction with the physical environment in which it is deployed. Although each individual sensor and actuator is unsuitable to monitor or regulate the environment on its own, with the cooperation and coordination among the individual sensors and actuators, the network has the potential to carry out tasks that otherwise would be infeasible by a single node.

With the emergence in research addressing cyber-physical systems, problems that previously were ignored or thought to be too complex, can now be investigated. A particular problem which we consider in this paper is that of environmental mapping and monitoring immediately following a natural disaster or hazardous contamination to obtain situation awareness.

Having the ability to obtain important information in real-time is a valuable asset in the hands of decision-makers whose decisions are, more often that not, a matter of life and death. This particular application can provide situational awareness in real-time, which allows intelligent decisions to be made quickly. Some possible decisions which may be addressed by such an application include, when to send in rescue/clean-up teams after a disaster, where are the most probably areas of finding survivors, and which areas are accessible to rescue/clean-up teams, to name a few.

Every year we see or hear on the news another natural disaster completely devastate a city, town, or village. Unfortunately, shortly there after we hear about the problems rescue teams face with having very little knowledge of how the area was affected, where possible survivors may be, and how dangerous a particular area is for rescue or clean-up workers to be deployed in. Sometimes it make take days to asses some of these problems. The hope is that with the CPS proposed in this paper, the time needed for critical information to make its way back to decision makers can be significantly reduced.

II. PROPOSED APPROACH

At first glance addressing the problem of environmental mapping and monitoring immediately following a natural disaster or hazardous contamination may seem like a daunting task. However, with an approach that utilizes a cyber-physical system, a solution is feasible. We envision a CPS to address this problem as a group of autonomous agents, both ground and aerial vehicles, that are equipped with environmental sensing capabilities, a communication network, as well as having the capability of receiving control inputs. Through the interaction and coordination of the autonomous agents, real-time information can be relayed to a central station where decision-makers can utilize this information to aid in the decision making process.

A few main reasons a cyber-physical system is necessary to addressing this particular application are the following,

- Coordination of multiple sensors to obtain a global view of the affected area
- Communication between sensors and a central base station for real-time information
- Communication between sensors themselves for redistribution in critical areas
- Control of sensors to place them in appropriate positions for data collection

It is seen that to address this problem one must combine coordination, communication, and control to achieve a system capable of relaying real-time information from “ground zero” to a central base. This problem likely cannot be addressed without a CPS because of the inherent coupling of communication, coordination, sensing of the environment, and control of the network agents.

III. RESEARCH CHALLENGES

Although a CPS that utilizes autonomous agents can address the problem possed in this paper, designing such a CPS does not come without its challenges. The tight integration of communication, computation, control, and sensing of the environment creates multiple vulnerabilities to failure, which could possibly debilitating the CPS from carrying out its mission. One must keep these vulnerabilities in mind during the design phase and try to mitigate their impact on the overall mission of the CPS. Now we present some design challenges.
that arise in creating a CPS to address situation awareness during or following a disaster situation.

- Should the control design of the CPS be centralized or decentralized?
- What type of communication network topology should be used?
- What constraints should be considered on the CPS?
- How/when should sensor data be fused together?
- When should information be relayed to an end-user?

Although the design challenges listed here is not exhaustive, we see how difficult creating a CPS can become. One of the first challenges will be whether the control of the CPS should be centralized or decentralized. Because of the high data flow requirements, network bandwidth must be considered when deciding between centralized or decentralized control. Another major factor in design is communication network topology. Allowing a dynamic communication network topology may help relax the communication constraints, but may complicate the control and sensor data fusion aspects of the CPS. Also, some level of abstraction must be used to address CPS design. The main question here is, at what level should the abstraction be done, i.e. what constraints should be considered when designing the CPS? Energy requirements, communication link quality, environmental factors, etc. all play a role on how well the CPS will be able to carry out its mission.

At a higher level there are still questions that remain. After the control and computation have been addressed, there still remains the question as when or how often information should be relayed back to an end-user to insure the best information is available without overflowing the CPS with unneeded or repeated data. Also, how should the data from individual sensors/nodes be fused together such that the end-user obtains a realistic global view of the situation? These design challenges are critical to the overall usefulness of the CPS in its intended use.

IV. RELATED WORK

Despite the fact that the CPS envisioned in this paper is quite unique, there does exist research in the literature that has begun to address a few of the design challenges mentioned in the previous section. Papers that address communication challenges among autonomous agents can be found in [1] and [2]. Other works that try to address centralized and decentralized control of autonomous agents are seen in [3] and [4]. Research in autonomous agents that addresses environmental sensing can be found in [5] and [6]. The related work cited here is just a fraction of the ongoing research in these areas, however we do see promising work in overcoming some of the design challenges that must be addressed in creating a CPS with autonomous agents. The works cited in this paper as well as much in the literature have begun to address "pieces of the puzzle;" however to my knowledge there does not exist a work that incorporates all these pieces into a “complete package.” The vision of this paper is a CPS that incorporates the “complete package,” sensing, communication, computation, and control in a way that may look something similar to Figure 1.

V. CONCLUSION

We presented a novel CPS to address situational awareness following a disaster situation. The proposed CPS involves a tight coupling between control, computation, sensing, and communication where real-time information is relayed to an end-user who utilizes the information to make informed decisions. We also presented some possible design challenges that arise when trying to realize a CPS to address situational awareness.

REFERENCES