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Web-based Teleautonomy and Telepresence

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Abstract

Recent innovations in real-time machine vision, distributed computing, software architectures, high-speed communication, and mobile robotic systems are expanding the available technology for intelligent system development. These technologies allow the realization of intelligent systems that provide the capabilities for a user to *experience* events from remote locations and to interact with that location using an array of robotic devices. In this paper we describe research being done in the UCSD CVRR that will lead to the realization of a powerful and integrated traffic-incident detection, monitoring, and recovery system. Sensor clusters utilizing both rectilinear and omni-directional cameras will automate information gathering about the incident and provide a real-time televiewing interface to emergency response crews. Ultimately, this system will have a direct impact on reducing incident related highway congestion by improving the quality of information to which emergency personnel have access.

1. Introduction: Research Motivation & Scope

The need for and value of intelligent systems capable of performing useful tasks at remote sites have been well recognized. Recent innovations in real-time machine vision, distributed computing, software architectures, high-speed communication, and mobile robotic systems are expanding the available technology base for developing such intelligent systems. These powerful new technologies allow our team to develop intelligent systems that provide powerful televiewing capabilities for users to *experience* events from remote locations and to interact with that location using an array of robotic devices. However there are still several unsolved research challenges that need to be overcome before such intelligent systems find widespread use. These important research challenges can best be resolved by considering a specific application domain. This allows incorporation of real-world constraints and requirements in the design and development phases. Also, specific applications allow careful and systematic means for evaluating performance of such complex systems.

The main goal of this research is to help in the realization of a powerful and integrated traffic incident detection, monitoring, and recovery system. More directly, this involves reducing emergency vehicle response time through higher quality information, and utilizing robotic systems located near the scene of the incident to provide immediate assistance before emergency response crews arrive. This system has the potential to make travel safer, smoother, and more economical, reducing wasted fuel and pollution. [2]

The architecture of the Autonomous Transportation Agents for On Scene Networked Incident Management (ATON) system is based upon sensor clusters placed at multiple locations along the monitored sections of highway. The ATON sensor clusters include pan/tilt/zoom rectilinear cameras and lower resolution 360° view coverage omni-directional video sensors (ODVS). By combining a heterogeneous cluster of sensors at each site and at multiple sites, sensor fusion will assist in correctly identifying when an incident has occurred and what type of emergency response may be necessary. In addition the mobile side of the system will be composed of a mobile monorail style robot (mothership) that will carry a lighted message board and a team of smaller (and less expensive) mobile robots equipped with orange cones and vision sensors. A potential scenario is illustrated in Figure 1.

A mothership will arrive at the scene immediately after the incident is detected and dispatch several of the smaller mobile robots to form a safety zone around the incident. Another mothership will travel a mile or two upstream from the incident to alert oncoming traffic of a potential hazard using its lighted sign. By using the multiple cameras surrounding the incident and onboard the robots, a televiewing interface is created, allowing emergency personnel from various groups to determine critical details about the situation well before they arrive. For example, the police may be interested mostly in the situation of the cars and how many of the lanes are being blocked, but the medical team may

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want to know if a person is lying on the ground or looks unconscious; in the current architecture these needs could be met simultaneously. Additionally, one of the smaller mobile robots equipped with a vision sensor can provide coverage of areas which may be occluded from the other sensors.

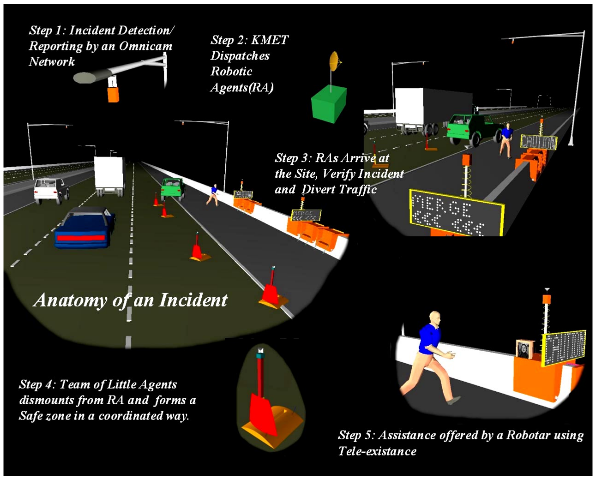

Figure 1. Scenario depicting steps associated with traffic incident management.

Our team is active in intelligent systems research and has established some key research directions. Some work of particular interest to televiewing involves a ubiquitous vision system that can monitor dynamically changing environments through the use of multiple omni-directional vision sensors [7]. An extension of that work involves robotic avatars (robotars) that have the ability to sense their environment as well as navigate within the environment [5]. Additional works in the direction of mobile probes include one presented at SPIE in 1998 regarding development of sensor-less mobile robots [1] that rely on sensors placed in the environment for control creating a less expensive and more fault tolerant mobile unit. This work has been extended and is discussed in this paper. Most recently, research has been performed on distinguishing objects from shadows in traffic image segmentation [3] and designing a distributed video network system for solving the aforementioned traffic problem [2]. Additionally extensive research and development has been done on creating a working database architecture for incident management [4].

2. Video Clusters for Televiewing

We will address three areas of experimental testbed creation that have been the focus of recent work in the CVRR. First we will briefly discuss the sensor infrastructure that is being installed on the UCSD and University of California, Santa Barbara campuses. Secondly we will discuss the creation of a mobile video probe for data acquisition. Last, we will discuss the development of a system that presents access and control of the "sensor-less robots" [1] via a web browser. Emphasis will be placed on the systems that provide the integral televiewing aspect of the ATON project.

Distributed Video Clusters

We currently have two sets of sensor clusters on campus at UCSD (Figure 2). They are located on streetlights near an intersection on campus where by which buses, cars, bikes, and people regularly pass. This is an excellent location to test the ATON architecture and algorithms on a variety of situations. Each sensor cluster contains a high-speed pan/tilt rectilinear camera mounted in a weatherproof housing and an ODVS, providing a continuous 360° view of the area surrounding the pole. All of these cameras are wired directly back to the lab using fiber optics, a 1 Gigabit Cisco switch, and some AXIS video server units which together give us the capability of 16 high bandwidth bi-directional live feeds back to our lab.

Figure 2. UCSD base node capable of acquiring 16 video streams over a 1 Gigabit fiber optic link

Creating outdoor sensor clusters as part of the permanent infrastructure has a lot of utility, however it is not a simple task. Additionally, once a cluster is mounted and operational it is difficult to change the location or perspective of that cluster if further research determines a different placement would be more optimum. To solve this problem we determined there was a need for a mobile unit with the capability of taking on-demand sensor data from a variety of perspectives at heights similar to roadside streetlights to test the robustness of the ATON system (Figure 3).

The established mobile system is comprised of a ~12′ aluminum pole that is mounted on an electric golfcart and stabilized using chains attached to the cart frame. A camera mount is fixed on top for attachment of the omni-directional video sensor (ODVS) or rectilinear camera. The video can be stored by a rugged PC onboard the cart, or transmitted via wireless video link to the lab. An inverter that draws power from the main cart batteries powers any necessary peripherals. This mobile video probe has been instrumental in preparing visualizations of outdoor traffic scenes. Software developed in our lab [6] that creates a user-controlled virtual walkthrough of an environment has been used to generate some striking visualizations of traffic scenes. The result is a system that could be used by emergency response crews to view the scene of the incident and extract the information that they find most critical. This same software could also be used after the fact to analyze specific aspects of the incident.

Figure 3. Mobile unit for video capture and communication is used for acquiring traffic data

This software can smoothly fuse a high-resolution image directly into the lower-resolution ODVS view while the user is remotely viewing the environment. Several parameters need to be set in order to do this including: registration of the image onto the scene, the warping of the detail shot to match the perspective of the ODVS view, the area in which the hi-resolution image should be viewable (in pan and in tilt), and some speed and edge smoothing parameters that finish off the integration to create a smooth transition between the ODVS view and hi-resolution image (see figure 4).

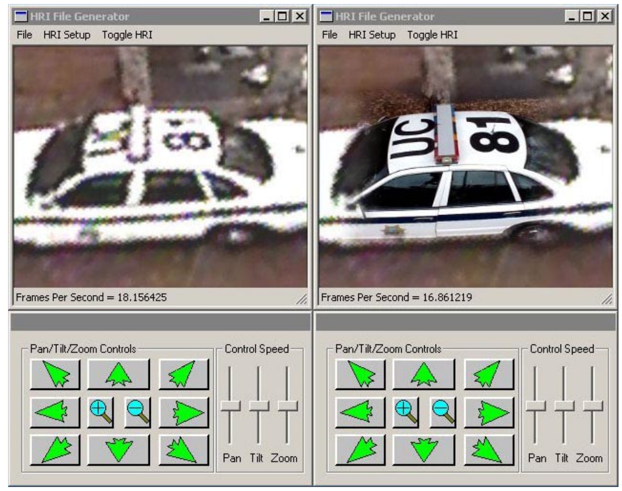

Figure 4. Results of seamlessly integrating a high resolution image and an omni-directional image. The GUI allows an observer to explore remote sites.

The software will then enable the user to look around the area where the previous image was taken in a pan/tilt fashion, just as if you were physically present in the location. When an area where a detail snapshot was integrated is viewed, the user will see a clear, high-resolution area where the detail is sharp. The software also supports making a virtual walkthrough of an area (more than one perspective) by taking the snapshots in a grid around the area and integrating them into a final walkthrough package [6].

3. Teleautonomous Mobile Probes

In addition to distributed video clusters, we have continued to develop a system that allows simple and very inexpensive "sensor-less" mobile robots to be controlled using a camera placed in the surrounding environment [1]. For this extension to the research an architecture was created that allows a remote user to control the movements of the robots in the UCSD CVRR lab by providing only high-level input, and allowing the environment to make low-level path planning decisions. This unique combination of a low-cost system, a simple control interface, and teleautonomy makes a powerful combination.

The intelligent environment in which these robots operate in consists of both rectilinear cameras and ODVS which provide visual coverage of the environment. Roger Tsai's method is used to calibrate the rectilinear cameras, but a method of calibrating the ODVS had to be developed. For this we have created a model of the omni-camera that consists of a pinhole camera pointed at a hyperbolic mirror. The parameters of the hyperbola can be estimated by using a spatial search. A standard PC is used to digitize the video stream, creating an inexpensive and modular hardware configuration. The resulting system has a client – server architecture, where the client is written in Java and can run on a wide variety of platforms – and the server sits in the lab near the robot monitoring the cameras and controlling the robot.

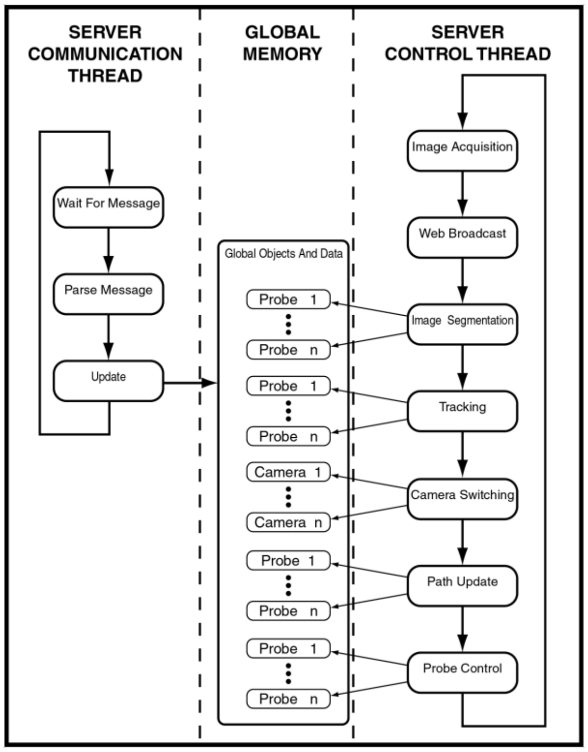

Figure 5. Overview of the server side software for realizing web-based teleautonomy of the mobile video probes.

The server software is implemented with an object-oriented design to incorporate modularity and flexibility. For example, each robot object and sensor within the environment is represented in the software architecture by a corresponding object. To include new or different types of robots or sensors, these objects need only be modified so that the different characteristics of the new hardware are reflected within the objects. This avoids dependency on particular types of sensors or robots. The currently implemented system consists of two lab computers, each of which runs a thread that operates on the global memory. A control thread is responsible for all the sensor processing, computer vision tasks, and robot control activities. This thread also serves all real-time video streams over the Web. The second thread is responsible for communicating with clients, and updating the global memory to reflect any user input received via the client interface.

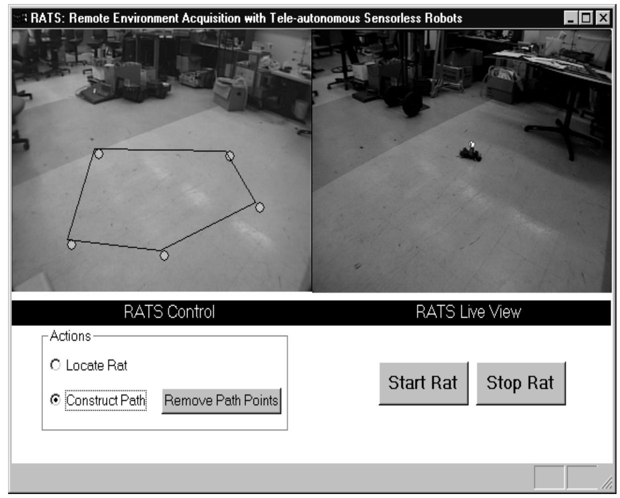

Figure 6. Web-based teleautonomous operation of a mobile probe. The user specifies only the path which the remote probe traverses autonomously.

The client interface is constructed entirely in Java, allowing the system to be run on a wide variety of computer hardware. The interface is also designed to be simple to learn and use; the user simply uses a mouse to select a path through an arbitrary number of points within an image of the remote environment. The client sends these points to the server, which then constructs a path for the robot to follow such that the robot travels through each of the selected points. A live video of the robot is provided for the user to verify correct robot movements.

This is an example of a shared-control architecture, giving the user control of the robot's large-scale behavior and letting the environment control the low level behaviors. In this application the amount of user input required versus the input that would be required to manually steer the robot through the selected points is greatly reduced, thus reducing complexity to the user and bandwidth difficulties.

The architecture described can be extended to cover much larger environments, covering very large and varied areas and terrain, as well as different types of robots. Next steps for this research include sensor handoff while tracking multiple robots to enable larger area coverage, use of sensor data from a wireless video link on the mobile robot to aid the control and increase the immersion experience of the user, and extending the system to work outdoors.

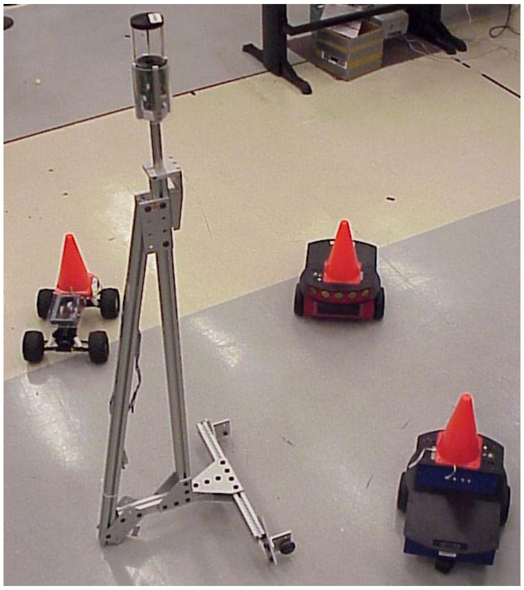

Figure 7. Multiple mobile units and ODVS during experimental trials.

4. Concluding Remarks

In this paper we have summarized our efforts in developing a novel architecture for the realization of a powerful and integrated traffic-incident detection, monitoring, and recovery system. The experimental research areas that have been presented are still under development, but are being folded into a fully integrated system to achieve the goals that have been stated. Many of the details of the systems involved have been summarized in this broad scope paper, however more information would be available by checking the references section for more in-depth papers.

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