Virtual Synergy: A Human-Robot Interface for Urban Search and Rescue

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Abstract

This paper describes the Virtual Synergy interface, which combines a three dimensional graphical interface with physical robots to allow for collaboration among multiple human researchers, simulated software agents and physical teams of multi-terrain robots for the task of Urban Search and Rescue (USAR) [8,9]. Using the interface to communicate and monitor the robots gives the human operators the ability to function as team members, where the robots can fluidly shift from being completely independent to tele-operated. This opens up opportunities to explore research in adjustable autonomy of robot teams [6,7,10,11], such as distributed planning, multi-agent learning, and dynamic collaboration.

Introduction

Figure 1: **University of New Orleans Urban Search and Rescue Robotics Team**

Our Urban Search and Rescue (USAR) robot team consists of 4 Sony Aibo Robotic Dogs (Figure 1), one wheeled robot and two flying blimps (Figure 2). All robots are connected by a three dimensional graphical interface called Virtual Synergy, in which each robot has a virtual character that it controls in a virtual three dimensional environment. This interface allows multiple robots to simultaneously create a virtual three dimensional map of the USAR environment, which is a challenging task because the robots must be able to reconcile their observations with each other in order to accurately map the area.

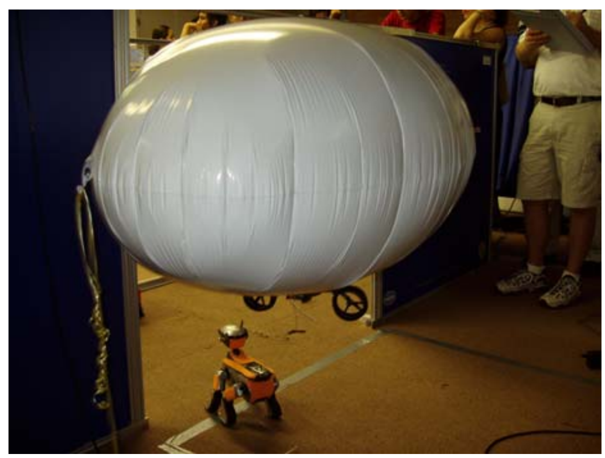

Figure 2: **USAR Blimp for obtaining an overhead view**

We are currently developing our USAR team using Virtual Synergy. As a robot in the physical world travels through a mock urban disaster area locating obstacles and potential victims, icons are placed in the virtual world to mark their location in the physical world as shown on the laptop. Virtual Synergy also allows a user to be present in the virtual environment, interacting with the robots through various mechanisms, which will be discussed in next section. We will then describe the team performance at the AAAI 2003 USAR competition, provide some related work, and conclude with a description of future directions.

Virtual Synergy Interface

We developed a robot team to participate in the AAAI 2003 Urban Search and Rescue competition. One of the tasks for the robots is to explore a simulated disaster area and map the environment, locating walls, fallen objects, areas to avoid for structural reasons and potential victims. The Virtual Synergy interface adapts Gamebots [1], which is a modification of the commercial three dimensional game *Unreal Tournament,* for both robotics and intelligent agent research.   This interface allows the robots to share two environments at once: the physical environment and a virtual environment.

Inhabiting Two Worlds

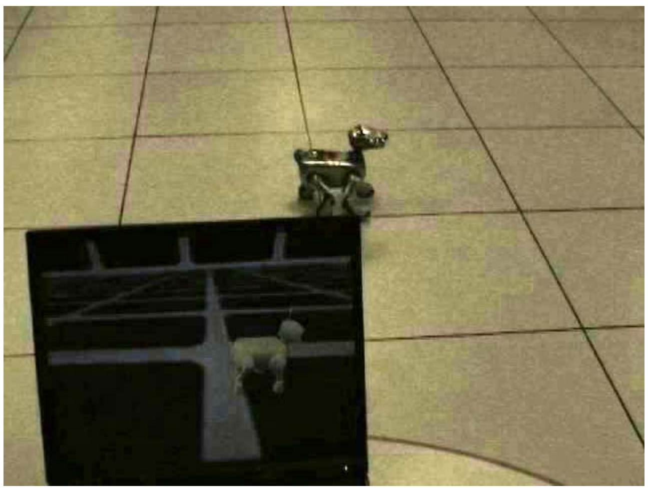

Figure 3: **Robot in the physical and virtual world**

The Virtual Synergy interface provides a means for agents in the virtual world to create a three-dimensional map by placing objects that are detected in the real world in their corresponding locations in the virtual environment. Every robot on the team exists in both the physical world and the virtual world of Virtual Synergy. Figure 3 demonstrates this ability by showing an Aibo moving in the physical world with its corresponding virtual character moving in the virtual world displayed on the laptop.

The robot has sensors in the physical environment, and is also receiving information about the world from the Virtual Synergy interface, which acts as a virtual sensor. Every robot shares the knowledge of the obstacles or items that have been placed into the world.   The virtual world also acts at the same time as a memory of the object, serves to communicate object information to users and other agents, and is the final map of the area to be used by rescue personnel.

Humans in the Mix

Figure 4: **UNO Team members interact with the robots for the USAR task**

Humans play a part in the virtual collaborative environment. Because of the nature of the environments where search and rescue robots will be used, humans will not always be with them physically. After debris falls, some passageways are too small for a human to fit through, and some disasters involve large amounts of radiation that could harm a human. Therefore, it is necessary to be able to monitor and direct the robots from a distance. Research indicates tele-operation of robots generally requires more than one operator per robot. Murphy et al. suggest that tele-operation can lead to “cognitive fatigue” of the operators during long periods of operation and that often there is too much information for a human operator to pay attention to at once [3]. This can be solved by using adjustable autonomy, where a robot can be controlled to varying degrees depending on the robot’s assessment of the situation. The adjustable autonomy of our robots using Virtual Synergy has some distinct advantages over more conventional forms of robot control. Humans become part of the robot team, taking on different roles as the situation demands.

While navigating the environment of Virtual Synergy, the user can use several modes such as flying unimpeded by gravity, walking through walls, or using a more realistic physical model. The choice of navigation method is made by the user, according to his needs at that moment. The interface for navigation has been tested and proven through many hours of intense game play where speed matters. We are currently performing experiments with the Virtual Synergy interface to determine how effective it is for human-robot-agent collaboration.   These evaluations will compare this interface to a variety of human-robot interfaces with a range of user types.

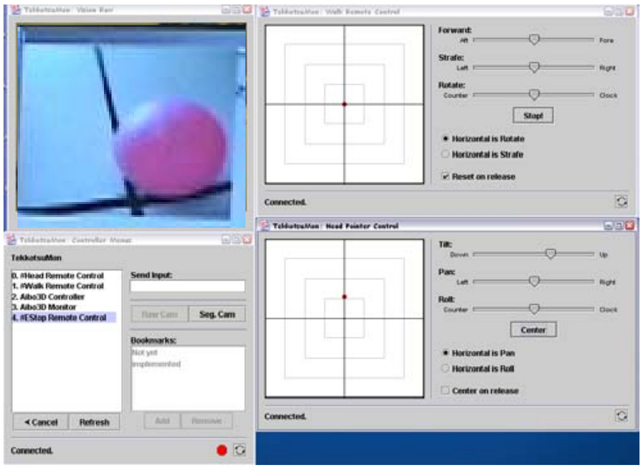

Figure 5: **TekkotsuMon Control Panel**

TekkotsuMon Control Panel

While navigating the virtual environment, the user can give commands to robots, like "come here," which instructs a robot to approach the user (Figure 5), or leave "hotspots" in the virtual environment as suggestions of where the robots should explore next. Tele-operation is also possible, temporarily inhabiting the representation of the robot in order to direct it through difficult areas that it could not handle on its own.

In order to control multiple robots with adjustable autonomy, we decided to use a robot view control panel provided by the Tekkotsu framework for each robot. The control panel's layout is divided into frames. The first shows the vision of the robot, the second contains robot head motion commands, the third controls the speed and movement of the robot, and the last controls higher-level autonomous behavior.

Tekkotsu is an application framework for programming the Aibo. Tekkotsu is designed to handle low level and routine tasks for the user. In this way, the programmer is free to work on interesting AI-Robotics issues. Tekkotsu's design is object oriented with an event based message model. The framework is written in OPEN-R, Sony's C++ SDK for the Aibo. Tekkotsu provides functionality for Vision Processing (via CMVision), wireless networking, walking (from CMPack '02) and motion control, a hierarchical state machine, and remote monitoring tools. Tekkotsu also implements mutual exclusion mechanisms for shared memory regions, as well as providing shared access to the robot's hardware.

Tekkotsu programs are designed as "behaviors," which can run concurrently with other behaviors. Each behavior represents a single application to be run on the robot. The behaviors communicate via the event passing mechanism. Since Tekkotsu provides concurrency mechanisms, multiple behaviors can share the control of any part of the robot. [21]

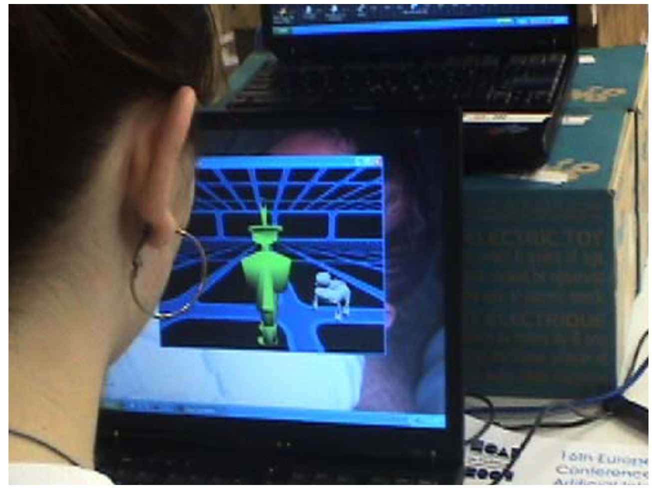

Figure 6: **Placing victim icon in the virtual world based on information for the TekkotsuMon Control Panel**

Environment Mapping

The Data Recording Agent has the important task of creating a log of the Aibos' journey through Virtual Synergy. This is done through a series of messages received from the Virtual Synergy server. The first message is a timestamp. Then, several messages may follow. The Agent receives a message from every player (or Aibo) at every time unit. The player's name, location, and orientation (direction) is recorded. The Agent also receives a message from every hotspot at every time unit. The hotspot name and location is written to the log. The Agent is also notified of any obstacles, victims, and/or potential victims that have been added or deleted since the last time unit. The locations and orientations of the obstacles and victims are included in the log. Finally, a timestamp, which matches the first message, is sent to end the time unit. Thus, the Agent is able to keep a record of the state of the world of Virtual Synergy at each time unit.

The log can be used for research and playback functions. The Agent reads each time unit record and uses the information to control the server to playback any experimental runs. So, in effect, Virtual Synergy is recreating the world at each time unit. Therefore, the log can generate a visual aid that can be used to study the Aibos and their environment.

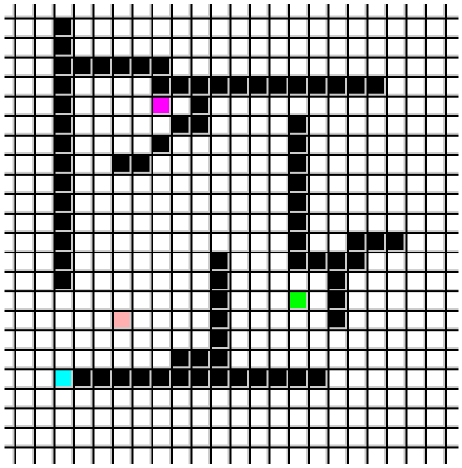

Figure 7: **2D Map created from Data Recording Agent logs**

The Data Recording Agent also produces to a two dimensional map. The map gives an overhead view of the Virtual Synergy world at a given time. The map shows the real-time location of the players, users, hotspots, obstacles, victims and potential victims. The two dimensional view is a useful tool to users and complements the three dimensional world of Virtual Synergy. Future work with the Data Recording Agent includes real-time path planning and team coordination and can be used to decide the best path for the rescue personnel entering the disaster area.

AAAI 2003 USAR Competition

The UNO Robotics Team attended the IJCAI-03 in Acapulco, Mexico. While attending the conference the team competed in the AAAI RobotRescue Competition. The competition supports Urban Search and Rescue (USAR), with several teams from all over the country competing and collaborating on building a completely autonomous rescue system by 2050.

Figure 9: **Robot finding victim in yellow test arena**

Figure 8: **3D Map in Virtual Synergy of Figure 7**

This year was the first year our team competed in the USAR competition. The team finished with the third highest score and earned a technical award for an innovative three dimensional map created by the Virtual Synergy user interface. The competition consisted of three preliminary runs for all teams, and two final runs for the top four teams. The UNO Robotics Team was the only team to roughly double its score in each run. The UNO Robotics Team's platform has shown itself to be flexible and dynamic.

In the first two runs, the team used four Aibo robots, one blimp, and three human operators. The Aibos were individually tele-operated by two of the human operators and the third operator remotely controlled the blimp. The blimp operator also assumed the role of mapmaker. As the human controllers gathered data from the environment, they verbally communicated with the mapmaker to build a global map in the three dimensional environment. The team encountered setbacks because the competition rules assigned a large penalty to multiple operators. In addition, the Aibos moved too slowly to discover more than a few victims in the allocated time. However, the Aibos' integration with Virtual Synergy allowed for more consistent mapping of the environment than in later runs.

Because the Aibos moved too slowly, the team switched in the middle of the competition to the then-newly-released TekkotsuMon Control panel. Tekkotsu uses a faster walking algorithm for the Aibos. Consequently, the Aibos were faster in traversed the environment than they did in the previous runs. This allowed the team to find more victims and provided for more complete mapping. The only drawback to TekkotsuMon was that at that time it was not yet integrated with Virtual Synergy as previously described, thus degrading the consistency of the maps.

The team is currently developing an autonomous multi-agent system, which will include map-making and localization behaviors written for the Tekkotsu Framework.

Figure 10: **Robots finding victim in orange test arena**

RELATED WORK

Some of the earlier work on MAS infrastructures lead to ModSAF [8], a system for military training based on distributed simulations using computer generated military forces. The software agents, in addition to human participants, made up these forces (fixed or rotary wing pilots, tank drivers, etc.) and had to act in a coordinated fashion that involved team play, mission planning, and reactive behavior. Although commercially developed, this system is not broadly available which has prevented a larger participation by the research community.

More recently, the RoboCup initiative [14] has served as a growing software infrastructure for a wide variety of research in multi-agent systems. The main component of this framework is the RoboCup Soccer Server, a multi-agent environment that supports two teams of simulated soccer agents playing against each other in real time (with each agent running a client connected to the server) [15]. The rules of the game and the main task (score more goals than the opponent) cannot be changed, which can lead to the development of soccer-specific techniques that can not be reused for other tasks or environments.

John Laird developed the agent "Quakebot" [19] to play the popular first-person shooter video game Quake against human players. This agent player (or bot) is based on Soar [21], and uses dynamically hierarchical task decomposition to organize its knowledge and actions. It incorporates predictive capabilities and learning [18]. The Quakebot system is currently limited to single agent tasks.

Current work in human-robot interfaces have mainly dealt with physical interfaces or methods of communication with robots, either through PDAs, gesturing, or speech [20,21,22]. Perzanowski et al. have developed a system for controlling teams of robots using voice and gesture commands [4]. Our robotic interactions will not be based on speech or gestures, but on direct manipulation of the robot's world model.

Virtual Synergy is the first work to combine a three dimensional graphical interface with physical robots, agents and human collaborators. A system called Player/Stage has been developed for simulating sensors and robots in a virtual two-dimensional world [2]. Virtual Synergy, however, does not simulate sensors. Instead, it provides mapping and path information; it also has the advantage of a three-dimensional view and the ability for humans to take on a persona in the environment.

CONCLUSIONS AND FUTURE WORK

In this article we describe the preliminary work on the Virtual Synergy to modify the Gamebots [1] system to represent a collaboratively shared map of an area for both multiple autonomous robots and agents for USAR. The use of a three dimensional virtual world interface will allow users to interact with the robots at multiple levels of adjustable or dynamic autonomy, from full autonomy, to accepting suggestions, to complete tele-operation. The advantage of using such a system is that the users can interact with robots and agents as another member of the team, taking on different roles to suit the situation.

The use of different roles, such as supervisor, peer, mechanic, and bystander will enrich the user experience by bringing more complex collaborations to user interactions. The robots and agents can perform tasks based on their relationship to the users who share their environments by also taking on these roles to facilitate improved collaboration. One of the goals of the Virtual Synergy project is to allow collaboration among humans, robots, and agents while at the same not overloading the users with information.

We are researching the use of user roles to facilitate user interactions with robots. Current research [5] defines levels of interaction with a robot as: supervisory, peer, and mechanic interactions, as well as bystander. The different roles define the information displayed to the user and the set of possible interactions available to the user. A mechanic will want nearly full cooperation to every command, down to the actuator level, with a complete diagnostic read-out. A peer relationship requires higher-level control, including leading the team to navigate to a goal and directing individuals to different tasks.

Figure 11: **Robot, Virtual Agent, and Human interaction**

We are also researching ways to increase the efficiency of robot operators. Virtual Synergy allows us to extend the robot team with software agents that exist only in the virtual world. The purpose of having such agents to perform tasks is to help users more effectively work with robots. Such as the case shown in Figure 11, where the agent, represented as the floating sphere, guides the user to locate the robot dog in the virtual environment.

Figure 12: **Human gathering multiple robots**

Figure 12 shows a human character interacting with multiple robot dogs. In the figure the user has sent a message to the robot dogs to follow the human character in the virtual world, allowing the user to guide the robots through both the virtual and physical world simultaneously. This demonstrates that through this interface a single user is able to supervise multiple robots.

The use of two environments, one virtual, one actual, allows for complex human-robot-agent interaction and useful inter-robot and inter-agent collaboration. Using a three dimensional environment such as Virtual Synergy will give the user an intuitive interface to interact with the robots as another member of the team. The software agents permit a human-oriented interface to information and automated tasks. Having a human-robot-agent interface, such as Virtual Synergy facilitates opportunities to explore research in adjustable autonomy of robot teams [6,7,10,11,16,17], such as distributed planning, multi-agent learning, and dynamic collaboration.

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REFERENCES

[1] Rogelio Adobbati, Andrew N. Marshall, Andrew Scholer, Sheila Tejada, Gal Kaminka, Steven Schaffer, and Chris Sollitto. Gamebots: A 3D Virtual World Test-Bed For Multi-Agent Research, *Proceedings of the International Conference on Autonomous Agents (Agents-2001) Workshop on Infrastructure for Agents, MAS, and Scalable MAS,* Montreal, Canada, 2001.

[2] Brian P. Gerkey, Richard T. Vaughan, Kasper Støy, Andrew Howard, Gaurav S. Sukhatme, and Maja J. Mataric. Most Valuable Player: A Robot Device Server for Distributed Control, *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2001)*, pages 1226-1231, Wailea, Hawaii, October 29 - November 3, 2001.

[3] R. Murphy, J. Casper, M. Micire, and J. Hyams. Mixed-initiative Control of Multiple Heterogeneous Robots for USAR.

[4] D. Perzanowski, A. C. Shultz, W. Adams, M. Bugajska, E. Marsh, J. G. Trafton, D. Brock, M. Skubic, M. Abramson. Communicating with Teams of Cooperative Robots in (Eds.) A.C. Schultz and L. E. Parker. *Multi-Robot Systems: From Swarms to Intelligent Automata*, pages 177-184, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2002.

[5] Jean C. Scholtz. Human-Robot Interactions: Creating Synergistic Cyber Forces in (Eds.) A.C. Schultz and L. E. Parker. *Multi-Robot Systems: From Swarms to Intelligent Automata*, pages 177-184, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2002.

[6] Balch, T. and Hybinette, M. Behavior-based coordination of large-scale robot formations, *International Conference on Multiagent Systems (ICMAS-2000)*, Boston, 2000.

[7] Tucker Balch, The impact of diversity on performance in multi-robot foraging, *Agents '99*, Seattle, WA, May, 1999.

[8] Calder, R. B., Smith, J.E., Courtemarche, A.J., Mar, J.M.F., Ceranowicz, A.Z.. ModSAF Behavior Simulation and Control. Proceedings of the Second Conference on Computer Generated Forces and Behavioral Representation, STRICOM-DMSO, July 1993.

[9] J. Casper, Human-Robot Interactions during the Robot-Assisted Urban Search and Rescue Response at the World Trade Center, *MS Thesis, Computer Science and Engineering, USF*, Apr. 2002.

[10] Dani Goldberg, Maja J. Mataric. Reward maximization in a non-stationary mobile robot environment. *Agents 2000*: 92-99.

[11] Dani Goldberg, Maja J. Mataric. Coordinating Mobile Robot Group Behavior Using a Model of Interaction Dynamics. *Agents 1999*: 100-107

[12] Kitano H., Asada M. , Kuniyoshi Y., Noda I., Osawa E. Robocup: The Robot World Cup Initiative, Proceeding of the first International Conference on Autonomous Agents, Marina del Rey, CA, 1997, 340-347.

[13] Kitano, H., Tambe, M., Stone, P., Veloso, M., Coradeschi, S., Osawa, E., Matsubara, H., Noda, I., and Asada, M. The RoboCup Synthetic Agent Challenge 97. Fifteenth International Joint Conference on Artificial Intelligence, Nagoya, Japan, 1997.

[14] David Kortenkamp, Tod Milam, Reid Simmons and Joaquin Lopez Fernandez, A Suite of Tools for Debugging Distributed Autonomous Systems, in *Proceedings of the IEEE International Conference on Robotics and Automation*, 2002.

[15] David Kortenkamp, Debra Schreckenghost and Cheryl Martin, *User Interaction with Multi-Robot Systems,* in *Workshop on Multi-Robot Systems*, 2002.

[16] Laird, J. E. It Knows What You're Going to Do: Adding Anticipation to a Quakebot. AAAI 2000 Spring Symposium Series: Artificial Intelligence and Interactive Entertainment, March 2000: AAAI Technical Report SS00 -02.

[17] Laird, J.E. and van Lent, M. Human-level AI’s Killer Application: Interactive Computer Games. AAAI Fall Symposium Technical Report, North Falmouth, Massachusetts, 2000, 80-97.

[18] Mitchell A. Potter, Lisa A. Meeden, and Alan C. Schultz (2001). Heterogeneity in the Coevolved Behaviors of Mobile Robots: The Emergence of Specialists. Proceedings of Seventeenth International Joint Conference on Artificial Intelligence, Seattle, Washington, 2001.

[19] D. Schreckenghost, C. Thronesbery, P. Bonasso, D. Kortenkamp and C. Martin, *Intelligent Control of Life Support for Space Missions,* in *IEEE Intelligent Systems Magazine*, September/October, 2002.

[20] Schultz, A. C. and Grefenstette, J.J., "Continuous and Embedded Learning in Autonomous Vehicles: Adapting to sensor failures," in Unmanned Ground Vehicle Technology II, Grant R. Gerhart, Robert W. Gunderson, Chuck M. Shoemaker, Editors, *Proceedings of SPIE* Vol.4024, pg. 55-62 (2000).

[21] Thompson, Ethan. "Tekkotsu Development Framework for AIBO Robots." <http://www.tekkotsu.org>