Semi-autonomous micro robot control and video relay through Internet and Iridium networks

Capt. Robert H. Bledsoe (USMC), Ravi Vaidyanathan, Jayson Durham, and Xiaoping Yun

Abstract *— This paper describes the experimental design, implementation, and testing of a network for tele-command, control, and communications of micro robots over long distances. The system utilizes commercial low bandwidth satellites to transmit near real-time video and leverages micro-robot platform synergies for command-communications relays. The system is capable of controlling micro ground vehicles and micro air vehicles (MAVs) over long distances using a small UAV as a communications relaying device. System elements meet size, power and mass constraints such that they may interface with control and power subsystems on micro robotic platforms and are scalable to control several entities simultaneously. We report the successful testing of the system in intercontinental experiments for control of both aerial and terrestrial micro robots between the Naval Postgraduate School (NPS) in Monterey, CA, USA, The University of Southampton, UK, and Space Warfare Systems Command (SPAWAR) in San Diego, CA, USA. We believe this research will serve as a proof of concept for future testing for a wide range of micro robotic command and control applications.*

Index Terms—Networked robots, micro robots, relayed communication, teleoperation, semi-autonomous systems, Internet, Iridium, distributed network, ad hoc networking

I. INTRODUCTION

Micro robots hold a wealth of promise for a very wide range of functions including: close-range inspection, surveillance, mapping, search, rescue, and reconnaissance. While their small size enables use in hazardous or difficult to reach locales, present utility predisposes that an operator be relatively nearby in order to control and receive feedback from the desired vehicle(s). As relevance for vehicles this size is determined for future deployments, a strong need has arisen for operators to be able to deploy, control, and receive feedback from micro robots from distances of a few miles up through intercontinental operation. Although recent work in web-based robotics [1-6] has made very significant advances in communications for robot teleoperation, implementations tend to be restricted to (indoor) controlled environments. The additional constraints faced by a micro robot system whose mission necessitates long-rage human operation and feedback in uncontrolled or hazardous field environments remains a largely unresolved issue in micro robotics.

A. Challenges in Micro-Robot Teleoperation

A significant breadth of factors have constrained the implementation of long-range teleoperative systems on micro robots for use in-the-field. Specific issues include:

- Power/size constraints: The vehicle, by definition, must be lightweight and man-portable; available power must be conserved for locomotion and sensing. Size, weight, and energy requirements prohibit high power transmission for long distance communication. Also, many missions (e.g. explosive detection) demand multi-modal sensor arrays that further consume critical payload mass and power.
- Operational theatres: Real-world environments for micro vehicles employment tend to be remote locations which do not support wireless internet, cell towers, nor other infrastructure that conventional systems utilize to transmit data, video, and command requirements.
- Subsystem interface: Communication systems must mesh with robot power, sensor, and control subsystems. Consider, for example, a micro air vehicle (MAV) operator interface. Low-level control input must have a high rate of feedback, yet Internet protocols incur packet delays that could destabilize flight. Any command/ communication system must interface seamlessly with closed-loop control systems on-board the plane/vehicle to be of practical use.
- Multi-robot distribution: Future visions of micro-robot operation involve groups of networked robots leveraging one-another's sensors and resources. Communication protocols must support cooperative algorithms that leverage robot swarming/teaming operations.

B. Summary of research

We have researched, designed and implemented a system that allows control of semi-autonomous micro air and ground vehicles securely through the Internet by relaying command through a primary UAV to a set ('swarm') of smaller vehicles. This allows command and control of forward placed vehicles located virtually anywhere in the world via commercial or government owned satellites services or via terrestrial LAN/WAN networks. In addition, we have established a means to transmit video through the Iridium satellite system, allowing remote monitoring of video from forward positioned vehicles.

Manuscript received June 10, 2007. This work was supported by the NPS/SOCOM Cooperative Field Experimentation Program and US Navy Space Warfare Command (SPAWAR) Center.

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ROBOCOMM 2007, 14th – 16th Oct 2007, Athens, Greece.

ISBN 978-963-9799-08-0
DOI 10.4108/ICST.ROBOCOMM2007.2193

II. Implementation Platforms and Subsystem Integration

A. Robot platforms

1) Micro ground vehicles

The recipient ground vehicle utilized for system testing was a version of the highly mobile *MiniWhegs* (Figure 1) robot [7]. This vehicle receives commands via an XBee modem (ZigBee/802.15.4 device by MaxStream, with a 1 mile LOS, 8 DIO/ADC ports and ZigBee routing) and forwards all information serially to a Pololu serial to PWM micro controller. These features allow for potential relaying of swarms and control of sensors using ultra-low power and mass requirements while maximizing throughput.

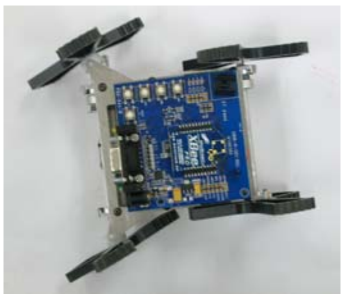

Figure 1: 10 cm long Mini-Whegs Robot

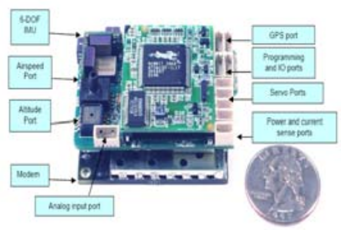

Figure2: Procerus Autopilot

2) Unmanned Air Vehicles (UAVs)

Two unmanned air vehicles (UAVs), equipped with Procerus Technologies autopilots (Figure 2) were utilized in the series of experiments for this research. The first vehicle was a Zagi aircraft (Figure 3), which was modified at Naval Postgraduate School (NPS) to allow for data relay and frequency deconfliction. The second vehicle, the Micro Air Land Vehicle (MALV) [8] (Figure 4), is currently being developed as a micro robot platform capable of both aerial and terrestrial locomotion. Both vehicles transmitted data and video separately in the 2.4 GHz range.

Figure 3: 120 cm wing span Zagi UAV

Figure 4: 30cm wing span Micro Air-Land Vehicle

B. General Dynamics Quad Iridium Reachback

The General Dynamics Quad Iridium Reachback (Figure 5) was utilized for the transmission of video over the Iridium Satellite network. The Reachback multiplexes four Iridium phones together, which provides 9.6 kbps via an Ethernet port. The unit occupies a single rack mount position with four antennas attached to a tripod or magnetically mounted.

Figure 5: Field use package for General Dynamics Reachback

Figure 6: Pelco Encoder Shown on Car Seat with Micro Camera

C. Pelco Encoder/Decoder Set

Video transmission over the Internet and Reachback setups was achieved by encoding the video at a datarate desired for the bandwidth available per setup using the Pelco 300 devices (Figure 6). In addition, serial communications for sending commands from the flight computer, or virtual cockpit, to the communication box of the UAVs was passed through the Pelco devices' serial ports. Originally developed for security companies, the Pelco 300 encoder and decoder allows for transmission of RS-232 and video over IP networks.

D. NetGear VPN Router and Wave Server Software

A commercially available NetGear VPN Router provided a secure point-to-point communication over the Internet. This device allowed for a secure connection from England to a laboratory at NPS. The Wave Server software allowed for Voice over IP communications for coordination is between personnel in the UK and the US.

III. System Architecture

A system test between Southampton, UK to work simultaneously through the Internet at NPS in Monterey, CA, USA, and to provide video via the Iridium satellite network to SPAWAR in San Diego, CA was arranged. The primary experiment was to engineer and test the capability of reliably sending control signals and video over the Internet between the UK and USA to control multiple UAVs and ground vehicles (Figure 7). Secondarily there was to be a link established to provide video over the General Dynamics Quad Iridium ReachBack system.

IV. System Testing

Testing protocol and implementation

First, a VPN connection was established from Southhampton, UK to the NPS Tactical Network Topology (TNT) network, US. The IP address given to the UK VPN

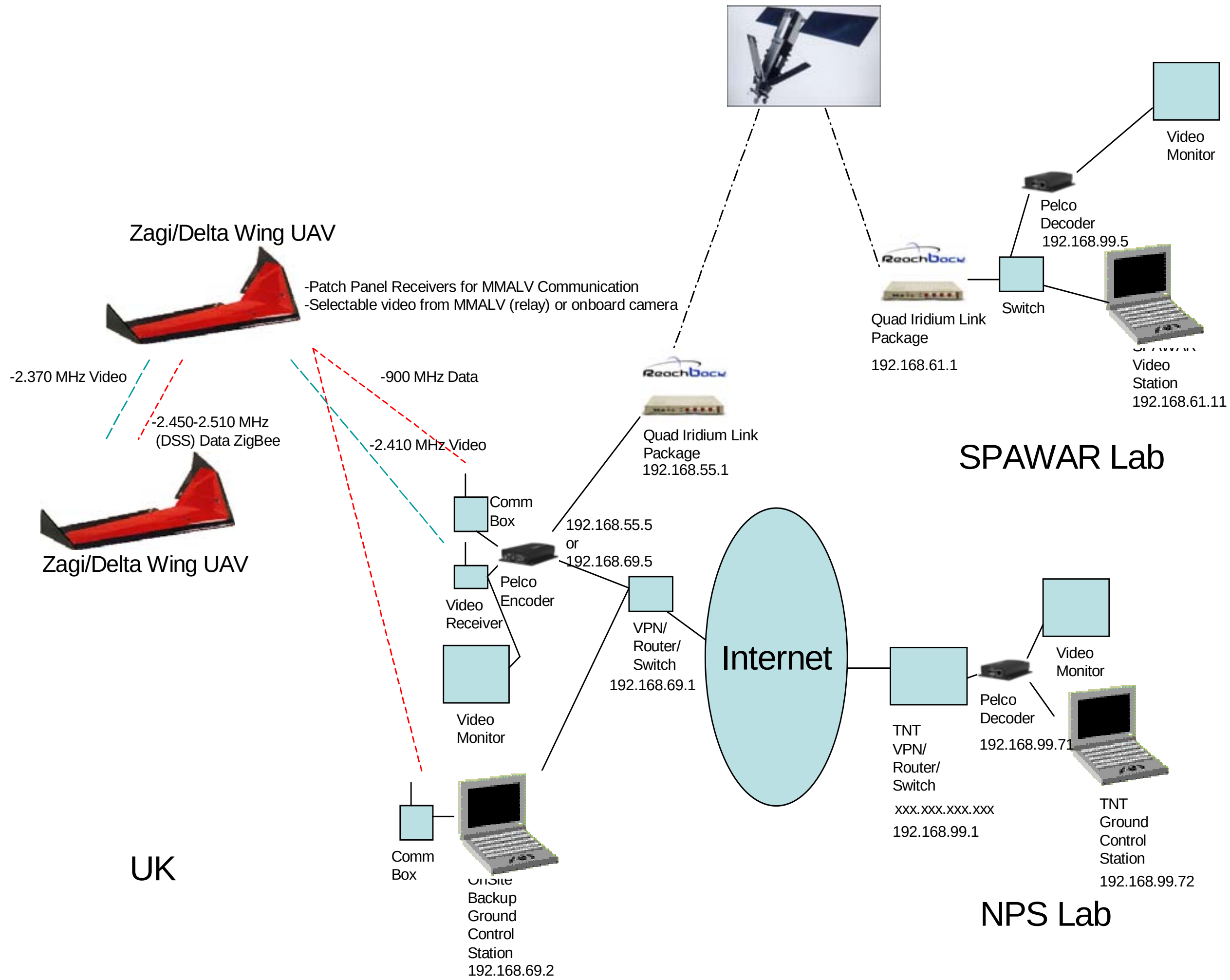

Figure 7: Network Diagram

box was routable. This allowed the VPN concentrator in the NPS Lab to establish connectivity by identifying the UK IP in its allowable connecting addresses database.

Once the VPN connection was established, connectivity with the Pelco devices began immediately. In the UK this implementation involved a communication box connecting the computer to the UAV with the Procerus autopilot that was connected to the Pelco encoder, via the RS-232 port, as well as a video receiver to the video input port. These two signals were then multiplexed together by the Pelco encoder and sent via Ethernet through the VPN concentrators on the Internet to the Pelco decoder at NPS. At NPS, the Pelco decoder broke the Ethernet packets back out to the RS-232 serial port of the Virtual Cockpit flight control computer and a video monitor, off the video output port.

Likewise, communications between the primary UAV and piloting system at NPS also began once the VPN was established. This UAV had onboard a long-range (up to 32 Kms) AeroComm modem, which communicated with the Comm Box. The NPS team reported over the Wave client that the Virtual Cockpit reflected information of the Comm Box as well as the telemetry data from the UAV.

The Video receiver was then enabled (2.390 GHz) so that the Pelco device could begin encoding. Fluidity tests of video were performed to ensure timeliness and quality. Video encoding on the Pelco device had been set to 500 Kbps with a frame skip ratio of 1 since there was a large amount of bandwidth available from the university network.

An operator at NPS provided and verified waypoints for the UAV. Next, the MALV was brought online for control using the integrated Zigbee modems (2.450 – 2.510 GHz DSSS with AES encryption capability) connected to the Modem mirror port on the primary autopilot and began reporting with the ground control station. NPS verified they were able to send and receive commands to this UAV. NPS also received the video from the secondary UAV (2.370 GHz).

The final item regarding relaying through the primary UAV was the control of the ground vehicle, *MiniWhegs*. The Zigbee modem was connected as a payload item to the primary UAV in this case. This meant that the control commands for the MiniWhegs were given directly by the operator at the Flight Control station. The operator provided hexadecimal commands in a special window of the autopilot ground station software to control payload items. In this case the payload item was a modem that communicated directly to the *MiniWhegs* vehicle. Thus all commands the operator entered were passed transparently through to the UAVs payload to the *MiniWhegs* vehicle.

On the *MiniWhegs* vehicle, the Zigbee modem was connected to a Pololu micro serial to 8-port servo controller. This device allows control of up to 8 Pulse Width Modulation (PWM) ports that can control servos and speed controllers. For the *MiniWhegs* vehicle there are only two PWM devices, a steering servo and a bi-directional speed controller. The Pololu device expects a series of commands to control servos. The default period was changed from 150 ms to 110ms to arm the Electronic Speed Controller.

The Pelco encoder/decoder was used for the video transmission over the SPAWAR Quad Iridium satellite link as well. Only video was transmitted, as the bandwidth was 9.6 Kbps. The Pelco devices are designed for to monitor remote sites by connecting analog video sources and relays to the device and encode them for IP transmission. The encoder was setup to send encoded video at 7 kbps while skipping every third frame. This was done at normal CIF rate, which is 352 x 288 pixels per frame. It was also tested at the lesser QCIF of 176 x 144 pixel resolution. Both settings worked well so the CIF rate was chosen for better resolution while sacrificing frame rate (every forth frame was encoded). Note that ONLY one video feed via the satellite can be viewed at a time due to the limited bandwidth. If more than one view is attempted frames will be lost or entirely dropped.

Intial testing with this device produced grainy and unclear video on the receiving end. This test proved different by adjusting the quality setting within the encoder device to produce a usable image. The video showed good fluidity, however it was observed that as the Iridium link lost connectivity, the packets of video would buffer in the Reachback device for later transmission and delay video for several seconds (fluidity of the video remained however, simply delayed). The reason for this is due to the method of transmission and network setup between distant ends.

Given that the encoder and decoder were physically and logically on two separate networks (Figure 7), the encoder needed to send the video packets via TCP connection vice UDP. The difference being is that the TCP packets ensure delivery of information to the distant end whereas UDP packets are sent and do not wait for acknowledgement if they are being received. The TCP packets will therefore queue in a buffer and be resent if not acknowledged, hence the delay of video. A solution to this in the future could simply utilize two end points on the same logical network, but may require researching a way to route the UDP packets (UDP packets are generally not routed) to ensure no backlog and near real time video over this limited bandwidth link.

V. Conclusions

We have successfully designed, implemented and tested an experimental network setup allowing the control of robotic vehicles and transmitting (video) feedback from vehicles in remote locations with no communications support infrastructure. The system is capable of controlling ground vehicles and UAVs over long distances using a small UAV as a communications-relaying device. Elements integrated onto robotic platforms are light and low power enough to be used on micro robotic platforms.

The system has been successfully tested in intercontinental experiments on both aerial and terrestrial micro robots and is scalable to securely control several different platforms at one time. We believe this research will serve as a proof of concept for future testing on specific mission assignments for exploration, mapping, surveillance, and eventual commercial implementation onto a wide range of micro robotic platforms such as the MALV. For future testing, the Base station could be any place in the world connected to the Internet with control elsewhere while controlling a set of vehicles through a satellite radio (vice Comm Box) and allow control of vehicle(s) capable of close up inspection of a point of interest by either direct line of communication to the primary vehicle or relay through an ad hoc network.

Acknowledgments

The authors would like to acknowledge Dr. David Netzer and Dr. Alex Bortesky of the Naval Postgraduate School (NPS)/USSCOM Cooperative Field Experimentation Program and Mr. Richard Bachmann of *BioRobots*, Ltd. and Mr. Christopher Martinez and Christopher Giezel of SPAWAR Systems San Diego

References

[1] Special Issue, "Robots on the Web," *IEEE Robotics and Automation Magazine*, vol. 7 2001.

[2] C. Kuan and Y. Kuu, "Challenges in VR-Based Robot Teleoperation," in *IEEE International. Conference on Robotics and Automation (ICRA)*, 2003.

[3] R. Marin, P. J. Sanz, P. Nebot, and R. Wirz, "A multimodal interface to control a robot arm via the web: a case study on remote programming," *IEEE Transactions on Industrial Electronics*, vol. 52, pp. 1506-1520, Dec 2005

[4] R. C. Luo, K. L. Su, S. H. Shen, and K. H. Tsai, "Networked intelligent robots through the Internet: issues and opportunities," *Proceedings of the IEEE*, vol. 91, pp. 371-382, 2003.

[5] W. Zheng, Y. Wang, and N. Xi, "Behavior Coordination in the Internet-based Multi-robot Teleoperation System," in *IEEE International. Conference Robotics and Biomimetics*, 2006.

[6] Y. Y. Li, W. H. Fan, Y. H. Liu, and X. P. Cai, "Teleoperation of robots via the mobile communication networks," in *IEEE Int. Conf. on Robotics and Biomimetics* 2005.

[7] B. G. A. Lambrecht, A. D. Horchler, J. M. Morrey, R. E. Ritzmann, and R. D. Quinn, "“A Series of Highly Mobile and Robust Small Quadruped Robots” *Robotics and Autonomous Systems*, In Press, 2004.

[8] F. J. Boria, R. J. Bachmann, P. G. Ifju, R. D. Quinn, R. Vaidyanathan, C. Perry, and J. Wagener, "A Sensor Platform Capable of Aerial and Terrestrial Locomotion " in *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* Edmonton, Alberta, Canada, 2005.