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TATRC and TARDEC Collaborative Robots Program

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Abstract: The OUSD Joint Robotics Program Office, the US Army Medical Research and Materiel Command (USAMRMC) Telemedicine and Advanced Technology Research Center (TATRC) and the US Army Tank Automotive Research Development and Engineering Center (TARDEC) have a joint program to develop a collaborative, multi-mission, robot team. Under the Army SBIR program, TATRC selected Applied Perception, Inc. (API) to receive a phase II robotic patient recovery development contract. The core effort involves building a prototype robotic patient recovery system, which includes a marsupial robotic vehicle pair incorporating teleoperation, semi-autonomous and autonomous control capabilities. TATRC's program goals include demonstrating the feasibility of possible medical applications for the Army Future Combat System (FCS) Small Unmanned Ground Vehicle (UGV) and the FCS MULE robots.

The robot pair act as a team (i.e., collaborate) and are configured to accomplish multiple missions, while sharing sensory information, teleoperator control station communications, and path/sensory analysis guidance. The robot team's second mission capabilities strive to demonstrate collaborative maneuvers for sentry/reconnaissance. This research focuses on sensor

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14. ABSTRACT

The OUSD Joint Robotics Program Office, the US Army Medical Research and Materiel Command (USAMRMC) Telemedicine and Advanced Technology Research Center (TA TRC) and the US Army Tank Automotive Research Development and Engineering Center (TARDEC) have a joint program to develop a collaborative, multi-mission, robot team. Under the Army SBIR program, TATRC selected Applied Perception, Inc. (API) to receive a phase II robotic patient recovery development contract. The core effort involves building a prototype robotic patient recovery system, which includes a marsupial robotic vehicle pair incorporating teleoperation, semi-autonomous and autonomous control capabilities. TATRC's program goals include demonstrating the feasibility of possible medical applications for the Army Future Combat System (FCS) Small Unmanned Ground Vehicle (UGV) and the FCS MULE robots. The robot pair act as a team (i.e., collaborate) and are configured to accomplish multiple missions, while sharing sensory information, teleoperator control station communications, and path/sensory analysis guidance. The robot team's second mission capabilities strive to demonstrate collaborative maneuvers for sentry/reconnaissance. This research focuses on sensor selection and integration, sensory software applications assessment and mission specific hardware design and development. The two robots have complementary and interchangeable quick-connect sensor suite hookup capabilities for rapid change-over for alternative mission roles. The designs include automated docking, common electrical and software programming interfaces and the use of JAUS-compliant perception and navigation components. Increased interaction between the robots enhances functionality across assigned operational domains, as well as improves perception and performance during the collaborative missions.

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selection and integration, sensory software applications assessment and mission specific hardware design and development. The two robots have complementary and interchangeable quick-connect sensor suite hookup capabilities for rapid change-over for alternative mission roles. The designs include automated docking, common electrical and software programming interfaces and the use of JAUS-compliant perception and navigation components. Increased interaction between the robots enhances functionality across assigned operational domains, as well as improves perception and performance during the collaborative missions.

Introduction: The collaborative robotic system comprises two marsupial robots and two user interfaces, a small, handheld Medic Interface Unit (MIU) for use in the field, and a larger, laptop size, Operator Control Unit (OCU) for remote use at the base. The two robots consist of a larger Robotic Evacuation Vehicle (REV) for long-range patient evacuation and a smaller Robotic Extraction Vehicle (REX) for short-range patient extraction (from site of injury to first responder medic). Both vehicles communicate via wireless radios to each other, the MIU and the OCU. The REV is a large, fast vehicle equipped with two Life Support for Trauma and Transport (LSTAT) litters. Designed for long-range transport of two wounded patients, the REV provides ballistic protection from small arms fire to both the medic and the wounded soldiers. The REV also transports the REX to and from the battlefield. The REX, a small, agile vehicle intended for short range in-the-field patient detection and retrieval, possesses a manipulator with a gripper that has enough strength to grasp and pull a wounded patient onto a retractable stretcher for wounded patient transport. Both robots have identical autonomous navigation systems for traversal from one location to another. In addition to its navigation sensors, the REX also possesses a suite of sensors for patient detection, including a color camera, long-wave infrared camera, and RF antenna for detecting signals from RF transponders that are placed on injured soldiers by the field medic or carried by combat personnel. All software components are compliant with the latest Joint Architecture for Unmanned Systems (JAUS) specification. JAUS compliance enables rapid hardware change-over for mission reconfiguration and provides transportable component software for use on other robotic platforms and applications. The system has a flexible control architecture through which the medic can easily switch the autonomy levels of the robots based on his assessment of the difficulty of the mission situation. The medic can teleoperate both vehicles either on-site or remotely from the base. In autonomous mode, the medic commands the vehicles using either the handheld MIU or the OCU interfaces. The medic at the remote base can supervise several patient recovery systems working simultaneously using the OCU. The following sections describe the major system components, which include the REV, REX, user interfaces, JAUS compliant software modules and their corresponding technologies in greater detail. We conclude by discussing design considerations that ease system reconfiguration and promote expansion of mission capabilities/applications.

Robotic Evacuation Vehicle (REV) The REV provides a high speed, large payload evacuation capability for the medic in the field. The current design concept of the REV is shown in Figure 1. The REV platform is based on the tracked Tactical Amphibious Ground Support (TAGS-DM) vehicle. The TAGS-DM is shown in Figure 2. The vehicle specifications are listed in Table 1.

The REV walking beam suspension provides the ability to navigate through the harshest of terrains. The deployment mechanism for the LSTAT litter has a high-torque actuator for raising and lowering the litter and functions automatically or via teleoperation. The LSTAT litters, which remain in a horizontal position at all times, can be easily removed from the REV and replaced to accommodate rapid patient loading and unloading. The LSTAT deployment mechanism has been designed to lift and hold over 500 lbs at a lever arm length of 4 feet (2000 ft-lbs) (i.e., comprising the loads of the LSTAT, 160 lbs., the NATO Litter, 16 lbs., LSTAT containment tray, 50 lbs., and the patient, 300 lbs.).

Figure 1: (Left) REV with patient bays in transport position. (Center) REV with one tray for the LSTAT lowered to the ground. (Right) Front view of the REV.

Figure 2: TAGS-DM vehicle base for Robotic Evacuation Vehicle (REV).

Figure 3: CAD drawing of REX departing from the REV..

A height-adjustable platform, installed at the rear of the REV vehicle, enables transport of and collaborative marsupial operation with the REX vehicle. This is shown in Figure 3. The platform's hydraulic actuators, powered by the REV's auxiliary hydraulic pump, deploy a small ramp for REX loading and unloading. After the ramp has been deployed, the REX vehicle automatically detaches from its tethered position on the REV and begins independent operation. The marsupial robot pair design includes automated docking, common electrical and software programming interfaces and utilizes JAUS-compliant perception and navigation components.

REV Autonomous Navigation System The REV is equipped with sensors and algorithms for autonomous navigation, in addition to the teleoperation and semi-autonomous controls. There are two main autonomous navigation modes.

Table 1: REV vehicle specifications

Engine	60 HP Kubota diesel; 2 liter – 4 cylinder
Torque	120 ft-lbs.
Drive System	Hydrostatic – no mechanical transmission
Suspension	Walking beam
Vehicle speed	30 MPH road; 12-14 MPH in rough terrain
Hydraulic System	Variable displacement; Auxiliary hydraulic power available for external mechanisms
Dimensions	75 in. (width), 68 in. (height), 144 in. (length)
Gross Weight	5000 lbs.
Terrain Type	Amphibious
Payload	1500 lbs (land); 500 lbs (water)

Path Tracking: A series of GPS coordinates can be downloaded to the REV which define a desired path for the vehicle to follow. For a robust path tracking algorithm, inertial navigation sensors (INS) have been combined with the GPS sensor through a Kalman filter. This integrated approach greatly improves the accuracy of the vehicle path tracking and position estimation, as well as makes the navigation system insensitive to occasional GPS signal dropouts, which occur due to obstruction of the satellite signals by trees, buildings, or other structures. The navigation system uses the NovAtel GPS system and a KVH IMU 5000 gyro. This KVH INS sensor uses fiber optic technology to provide a highly accurate and noise free rate of vehicle rotation. The path tracking algorithm is the well-known and proven pure pursuit algorithm.

Obstacle Detection: To support the autonomous path tracking function, a Sick laser range finder is mounted on the front of the vehicle to provide information for basic obstacle detection. Although the path that has been given to the vehicle should be known to be traversable and clear of obstacles, obstacle detection and avoidance capabilities permit autonomous path corrections to adapt to dynamic battlefield scenarios. The REV vehicle either makes path adjustments, if there are only minor obstructions, or signals for help from a human operator about how to proceed in the event of a significant path blockage. The REV is equipped with a color camera on a pan/tilt/elevation mast, which relays live video imagery back to the Operator Control Unit at the base. The cameras allow the remote medic to see the local environment around the REV and deal with path blockages. The laser-based obstacle detection and avoidance software incorporate adjustments of steering commands to avoid obstacles. With this capability, the robot can detect and anticipate an obstacle well before it nears it, allowing time and space for the robot to make small steering corrections and avoid hitting the obstacle. Speed-control software limits the vehicle's maximum speed based on a series of safety zones, which are areas in front of the robot.

Robotic Extraction Vehicle (REX) The REX is a small, agile, electric drive vehicle designed for short range in-the-field patient detection and extraction. It possesses a manipulator with a gripper that has enough strength to grasp and drag a wounded soldier onto a retractable stretcher for patient transport. Like the REV, it possesses sensors and on-board computing for autonomous navigation. In addition, the REX contains software to allow it to automatically generate a search pattern given the boundaries of a known area. The REX and REV have common navigation sensor suites. The REX also contains sensors to seek and detect injured soldiers. Using its wireless communication system, it can be controlled by an operator, either locally from the REV or at the remote base. The REX transmits telemetry, imagery, and system status information to both the REV and operator control units.

The Robotic Extraction vehicle uses the Remotec® ANDROS Wolverine, as the base-platform, for which vehicle specifications are presented in Table 2. The Wolverine is an ideal vehicle for meeting the requirements of short-range patient extraction. Over 600 of these vehicles have been fielded by Remotec, worldwide.

REX Patient Transport The REX incorporates a retractable stretcher for short-range patient transport. A concept drawing of this mechanism is shown in Figure 4. When the stretcher is not occupied, the REX's manipulator will fold up over the stretcher to conserve space and improve mobility. If a patient is being transported, the manipulator will stay in the vertical position. After the stretcher is deployed, the REX's robotic arm will grasp the patient (or a second flexible stretcher on which the patient has been placed) and pull them onto the deployed stretcher for transport back to the REV. This technique avoids having to pull the injured soldier over rough terrain with little or no protection, and largely mitigates the constant tugging of the grasping arm.

REX Autonomous Navigation The REX, like the REV, has drive encoders and closed-loop velocity control for its autonomous navigation system, along with the necessary sensors and computing capacity for autonomous navigation, search pattern generation, and patient detection. The wheel encoders provide vehicle speed data, providing better speed control on hills;

Table 2: REX vehicle specifications

Drive System	6 wheel, 24V direct drive motors
Vehicle speed	2 MPH
Dimensions	28 in. (width), 40 in. (height), 58 in. (length)
Gross Weight	600 lbs.
Terrain Type	All terrain / operates on wet and dry surfaces
Audio System	Two-way voice communication
Manipulator Reach	64 in. horizontal. 100 in. vertical
Lift Capacity	100 lbs. at 18 in. reach. 60 lbs. at full reach
Camera System	3 low-light color cameras standard

Figure 4: Left: Conceptual drawing of REX with deployed stretcher.
Right: Load Bearing Equipment harness for patient extraction.

anticipating upcoming path curvature to modulate vehicle speed and provide better tracking accuracy; and implementing a turn-around maneuver to allow the vehicle to automatically align itself, if it is facing the wrong direction from the desired path.

The common navigation sensor suite to the REV includes the NovAtel GPS system and a KVH IMU 5000 gyro. A commercially available 24 GHZ radar unit complements the forward looking Sick sensor on the REX. This sensor provides a short-range foliage-penetration capability that improves autonomous navigation in unknown terrain, in which the REX will typically be operating.

The REX also possesses additional algorithms to automatically generate paths to execute a full-coverage area search for patients. The REX has several navigation setup modes through which it receives path information. One approach allows the medic to transmit a path of his own movement, GPS coordinates recorded by the MIU, to the REX, which then follows these coordinates upon the operator's command. A second navigation mode involves the REX storing its own path coordinates, which have been followed under either teleoperation or autonomous control, and retracing that path back to its starting point.

REX Patient Detection The REX also contains a suite of sensors for patient detection. These include a color camera, a long wave infra-red camera, and a long-range RF antenna for detecting signals from passive transponders. Research is also being performed in evaluating Ultra Wide-band Radar sensors, which can detect heartbeat and breathing motions through walls and rubble. These different sensing modalities will be fused to provide a highly robust patient detection system. All sensors will be mounted on the same pan/tilt/elevation mast on the Wolverine base vehicle.

The patient detection sensor suite and processing algorithms will be operational for all vehicle control modes. In the teleoperation mode, the cameras serve as an extra set of eyes for the medic by highlighting areas in the images on his OCU display that may contain a wounded soldier. By using the absolute temperature readings provided by the infra-red camera, overall system performance will be improved in both day and night, since much of the scene can be filtered in most conditions.

The RF antenna is used to locate RF tags that have either been placed on a soldier by the medic or are carried by all combat personnel. The presence of a definite signal provides either the medic or the autonomous system with positive evidence that a wounded soldier is somewhere close to the extraction vehicle. The REX incorporates a long range RF antenna that can detect the transponders out to a distance of 10-15 feet. When in an autonomous control mode, the patient detection sensor suite will operate in conjunction with the autonomous navigation system. While following the planned search patterns, if the patient detection sensor processing believes it has located a wounded soldier, the vehicle will stop and alert the remote medic of the situation. If a soldier has been found, the medic will initiate the patient extraction procedures.

User Interfaces: The final hardware components of the collaborative robot system are the user interfaces and communication equipment. Dual user interfaces offer the medic flexibility for system control, mission reconfiguration and robot task assignment. The data transmitted are command and path information to the vehicles, and imagery, telemetry and system status information back to the user interfaces. The REX can relay image and telemetry information back to the operator console and receive control commands either directly from the medic or base station, or through the REV, which can act like a signal repeater. The Medic Interface Unit can also communicate with the Operator Control Unit at the base, as well as download stored GPS coordinate waypoint paths to either robot.

For the lines of communication, the system uses 802.11 wireless Ethernet radios, augmented with signal boosters and directional antennas for longer range control interface. The UDP communications protocol will be used for all wireless information that is transmitted between vehicles and operator interfaces. The UDP protocol is well suited for handling occasional signal dropouts, which might cause other communications protocol to block until the signal was reestablished.

Operator Control Unit (OCU): The OCU is a table-top suitcase-sized console configured on a COTS, Dell laptop, computer, which also serves for software development. It displays live images from both vehicles, as well as system status and vehicle locations. From the OCU, the medic can command multiple vehicles, either through teleoperational controls such as a joystick, or by sending autonomous commands, such as "Go to Location." An image of the Graphical User Interface of the OCU is shown in Figure 5.

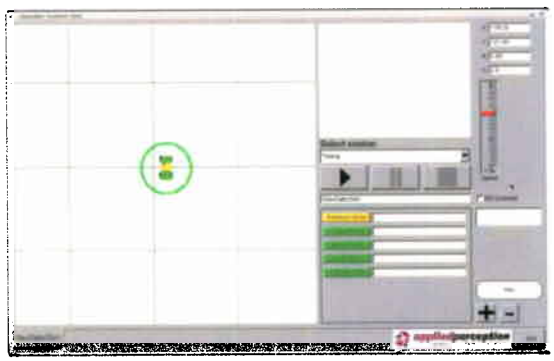

Figure 5:.Graphical display of Operator Control Unit.

Medic Interface Unit (MIU): The interface that will be used by the medic in the field is the Medical Interface Unit (MIU). This is a small, lightweight, hand-held device that the medic can use to call for a REV, query the location of either the REV or REX vehicles, and record the medic's path of GPS coordinates to download to either vehicle. The MIU uses a COTS handheld device, the Hewlett-Packard iPaq 5500 PDA, integrated with a plug-in PocketMap Navigator CF WAAS-enabled GPS receiver, shown in Figure 6.

Figure 6: (left) HP iPaq in rugged case with GPS receiver. (right) Initial version of MIU interface running in iPaq emulator.

The small screen size presents a human interface design challenge. One concept to overcome viewing space limitations is to use a "tabbed" design for various control and status monitoring panels. A COTS wireless card has been interfaced to the IPaq to enable wireless communications. The Windows CE software development environment is used to develop and compile code for the handheld interface unit, MIU. JAUS-compliant libraries and software components have been ported to the Windows CE operating system in order to run them on the iPaq.

JAUS Software Design and Testing: The collaborative robot system uses fully JAUS compliant software components for navigation and communication. A John Deere Gator surrogate vehicle has been used to develop JAUS compliant software modules during the REV and REX build period. The current suite of JAUS compliant software components include:

- Communicator / Node Manager
- Primitive Driver
- Reflexive Driver
- Global Vector Driver

- Global Waypoint Driver
- Global Pose Sensor
- Local Pose Sensor
- Velocity State Sensor
- Visual Sensor
- Medic Interface Unit Subsystem Commander
- Operator Control Interface Subsystem Commander

Figure 7 shows the software architecture for the navigation system on both vehicles, REV and REX. The software, including the low-level interfaces to the vehicles' actuators, will be identical for both vehicles. Again, the software architecture complies with the latest Joint Architecture for Unmanned Systems (JAUS) specifications. Individual software modules are shown in the green ovals. Sensors and other hardware are shown in the boxes.

Collaboration: This research focuses on creating the software infrastructure to enable vehicle collaboration and rapid reconfiguration of the vehicles' capabilities for new missions. We will develop advanced intelligent tactical behaviors and enhance survivability (e.g. anti-tamper approaches, bounding overwatch, etc.), as well as increase task accomplishment efficiency (e.g. collaborative mapping and sharing of information for navigation/image recognition).

A JAUS standard interface, software infrastructure, for all subsystem payloads is being developed and tested. The interface is identical for all payloads and contains the information necessary to automatically create a command and display "plug-in" for the Operator Control Unit. In this way, payloads can be swapped in and out with no change to the control software. We plan to design common hardware mechanical and electrical links to allow the payloads to be as interchangeable as possible (subject to size constraints). This design approach will allow rapid vehicle reconfiguration by creating a simple "plug-and-play" payload capability. For examplefor a robotic sentry / reconnaissance type of mission, cameras may be used first as a payload to

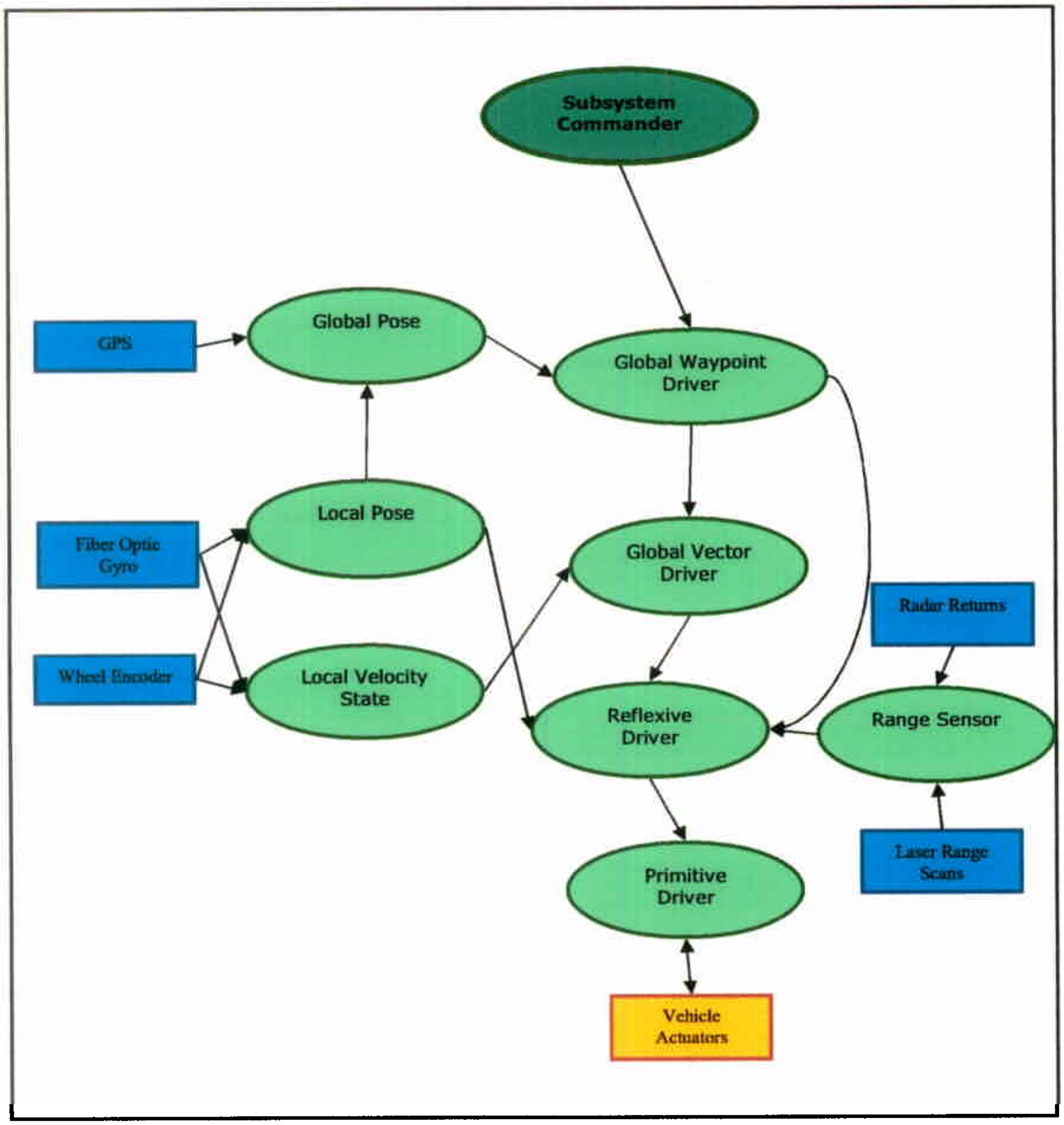

Figure 7: JAUS compliant software system architecture

allow the remote operator to get a broad sense of the surrounding area. Once interesting locations have been found, the payload may be switched to an Ultra Wide-Band radar sensor for detection of human motion or breathing behind walls or through debris.

The software infrastructure for robot collaboration is also being developed. Specifically, this includes designing and implementing a data representation of terrain information that can be collected, shared, and merged across multiple vehicles. One vehicle, which has searched a specific area, will be able to transfer its information about the area to a second vehicle, which may have a unique payload capability that is needed for the next step of the mission. Algorithms are also being developed to allow robots to share their sensing, computing, and other resources among each other without compromising their own performance.

Finally, a collaborative mission planner is being developed that will allow an operator to create multi-robot missions. These could include collaborative mapping, where multiple vehicles collect data about a certain area simultaneously thus increasing overall productivity; bounding overwatch, where one vehicle "protects" the other as they move through a certain area, or anti-tamper strategies where, for example in the Robotic Patient Recovery case, the larger REV vehicle provides cover and protection with its own weapons, while the smaller REX vehicle moves to extract and retrieve a wounded patient.

As described, the REV and REX will collaborate, configured to accomplish multiple missions, while sharing sensory information, teleoperator control station communications, and path/sensory analysis guidance. The two robots' designs include complementary and interchangeable quick-connect sensor suite hookup capabilities for rapid change-over for alternative mission roles. The systems interface includes automated docking, common electrical and OCU hardware and the use of JAUS-compliant perception and navigation components.