U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Scalable, Adaptive, and Resilient Autonomy (SARA)

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DISTRIBUTION A –
APPROVED FOR PUBLIC RELEASE

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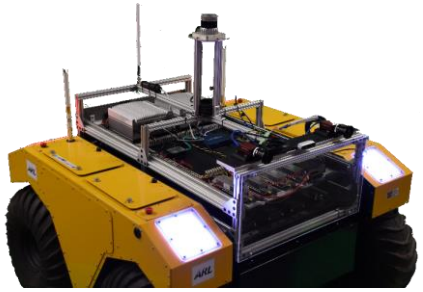
SCALABLE, ADAPTIVE, AND RESILIENT AUTONOMY (SARA)

- **Motivation**
- **Sprint topic logistics**
- **Technology Sprint #2 Topic Details** Autonomous Complex Terrain Maneuver
  - **Sub-topic #1:** Autonomous maneuver through increasingly complex levels of vegetation
  - **Sub-topic #2:** Autonomous maneuver through complex slopes, across dry river beds, fordable wet gap crossings, desert dry washes
- **Hardware testbed**
- **Autonomy architecture and simulation environment**
- **ARL experimentation location**
- **Proposal process and details**

SARA – PURPOSE

- **Enable autonomous maneuver in complex and contested environments**
- **Augment and increase the freedom of maneuver in complex and contested environments**
- **Realize adaptive and resilient Intelligent Systems that can reason about the environment, work in distributed and collaborative heterogeneous teams, and make decisions at operational tempo**
- **Engage with collaborators and enable a pathway for integrating emerging capabilities onto autonomous robotic testbeds**

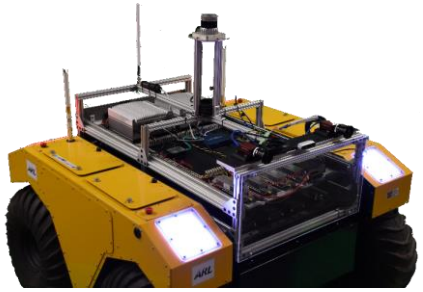
Off-Road Autonomous Maneuver



SARA – DESIRED OUTCOMES

- **Novel methods for all-terrain ground and aerial maneuver to interact with and move through complex environments**
- **Methods for scalable and heterogeneous collaborative behaviors in support of air and ground manned-unmanned teaming operations**
- **Techniques for improved perception, decision-making, and adaptive behaviors for fully-autonomous maneuver in contested environments**
- **Methods, metrics, and tools to facilitate, simulate, and enable testing and evaluation of emerging approaches for intelligent and autonomous systems under Army-relevant constraints and environments**
- **Experimental testbeds to develop and refine knowledge products to inform and transition technology to Army stakeholders**

Off-Road Autonomous Maneuver



SPRINT TOPIC PRIMER

- Sprints will be executed through a series of annual program cycles.
- The FOA will be amended annually to identify a specific problem statement, or topic, for that specific Cycle **(current is Cycle #2)**.
- Nine new topics (Cycles 1-9) are expected from FY20-FY29, with each topic focused on addressing a different scientific area within the scope of the broad research aims of SARA.
- Each topic will be carefully chosen based on both program achievements from the previous year, on scientific and technological advancements by the broader research community, and in a way to systematically converge on the specific long-term SARA program goals.
- For each topic, funding will be provided to those Recipients selected under a cooperative agreement (CA) described as the “seedling” project.
- The Recipients of a “seedling” CA are then eligible for consideration to receive funding for a single optional extension of up to 3 years at the conclusion of the “seedling” project.

EXPERIMENTATION ACTIVITIES

- **On-site collaboration at ARL facilities and with ARL researchers, as well as with other seedling Recipients, is encouraged**
- **All Recipients participate in bi-annual experimentation events**
  - Place of performance for SARA Cycle #2 is the Robotics Research Collaboration Campus (R2C2) at Graces Quarters, Aberdeen Proving Ground, Maryland
  - The first event is tentatively scheduled for May of 2021; a virtual event conducted by ARL to witness and discuss robotic testbeds, ARL baseline experimentation, and the ARL autonomy stack in operation
  - A full one-week experimentation event to evaluate integrated solutions from the seedling Recipients on ARL testbeds and within the ARL software autonomy stack
    - Mid-point evaluations scheduled for October of 2021
    - Final evaluations scheduled for April of 2022
- **Future SARA Cycles will rotate to different sites depending on the nature of the sprint topic**
- **There is no limitation on the place and time of experiments**

PROPOSING TO FUNDING OPPORTUNITY ANNOUNCEMENT

Eligible applicants: under this FOA include institutions of higher education, nonprofit organizations, and for-profit organizations (i.e., large and small businesses) for scientific research in the knowledge domains outlined throughout this Funding Opportunity. Federally Funded Research and Development Centers (FFRDC) may propose as well, with effort as allowed by their sponsoring agency and in accordance with their sponsoring agency policy.

Profit/Fee: Profit/fee is not permitted under the CA.

Cost Sharing: Cost sharing is not required under this FOA.

Event estimated date/timeframe

Opportunity released……..8 February 2021
Opportunity Webinar……**19 February 2021**
Deadline for Questions on Funding Opportunity.……5 March 2021
Proposals due for Cycle 2……..19 March 2021
Cycle 2 Awards…….May 2021 (Expected)

CYCLE 2 TECHNOLOGY SPRINT TOPIC: AUTONOMOUS COMPLEX TERRAIN MANEUVER

- **Assumptions**
  - Single Platform, GPS limited/denied navigation
  - Unprepared Terrain – as defined in sub-topics #1 and #2
  - While the end goal is Point A to B navigation over distances on the order of kilometers with terrain as defined in sub-topics #1 and #2, Cycle #2 experimentation is expected to be on the order of 10s of meters
  - Ability to operate with and without a stale map a priori – may have satellite or topographic maps but not high fidelity maps of local environments
  - Not reliant on communication/data feeds to complete a commanded task

- **Sub-topic #1: Autonomous maneuver through increasingly complex levels of vegetation**.
  - Focused on overcoming limitations in perception and understanding of the environment and vehicle performance to maneuver through traversable obstacles while identifying impassible obstacles.

- **Sub-topic #2: Autonomous maneuver through complex slopes, across dry river beds, fordable wet gap crossings, desert dry washes**.
  - Focused on overcoming limitations in perception and understanding of the environment and vehicle performance to traverse terrain containing sharp and varying slopes.

SARA – SUB-TOPIC #1

Autonomous maneuver through increasingly complex levels of vegetation

- Overcome limitations in perception and understanding of the environment and vehicle performance to maneuver through traversable obstacles while identifying impassible obstacles.

Assumptions for Sprint 2 sub-topic area #1:

- Navigation over distances of 10s of meters within a bounded corridor
- Vegetation is a mix of hard (trunks) and soft (branches and foliage) obstacles that are intermixed; exact vegetation composition is not known a priori but must be perceived and modeled in real-time
- Navigable paths through vegetation are not provided a priori
- Leverage physical interaction with the environment to establish and refine models of navigability

Representative natural terrains at Graces Quarters

SARA – SUB-TOPIC #2

Autonomous maneuver through complex slopes, across dry river beds, fordable wet gap crossings, desert dry washes

- Overcome limitations in perception and understanding of the environment and vehicle performance to cross terrain containing sharp and varying slopes.

Representative full-scale terrain

Assumptions for Sprint 2 sub-topic area #2:

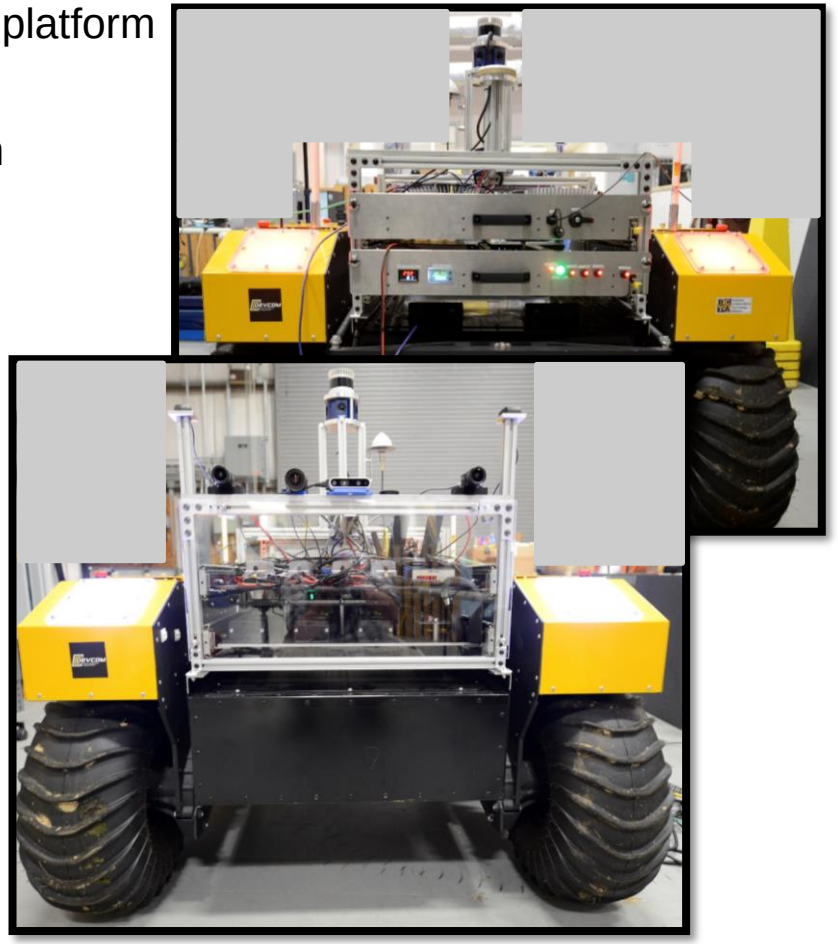
- Navigation over distances of 10s of meters within a bounded corridor
- Terrain is a mixture of dirt, mud, sand, and gravel not known a priori; terrain is of varying slopes that range from flat to impassable even at speed
- Approaches that can consider vehicle dynamics, vehicle speed, and terrain interactions in determining traversability and planning and executing navigation
- Leverage physical interaction with the environment to establish and refine models of navigability

Representative sub-scale terrains at Graces Quarters

SARA – ARL TESTBED PLATFORM

- Development will be done on recipient surrogate platforms*, but the bi-annual experimentation events will be done on ARL-provided platforms and with recipient solutions integrated into the ARL Autonomy Architecture and Autonomy Software Stack
- ARL plans to support continuous development and integration of Recipient capabilities
- Data collection (i.e., bags) will be done with testbed platform

- The Warthog is approximately 2 m^3 with a maximum speed of 5 m/s
- Base autonomy stack (for now) includes the following compute and sensor payload:
  - **Compute:** Two (2) Intel i7 computers with minimum 32GB RAM, 1TB of SSD storage, and NVIDIA T4 GPU w/ minimum 16GB RAM
  - **LiDAR:** Ouster OS1-64 Gen 1
  - **IMU:** LORD Microstrain 3DM-GX5-25
  - **GPS:** U-Blox EVK-M8T
  - **RGBD camera:** Intel Realsense D435i
  - **High resolution cameras:** 2x FLIR Blackfly S
  - **High resolution camera lenses:** 2x Kowa LMVZ41
  - **Hardware time synchronization:** Masterclock GMR1000 providing PTP server to LiDAR and cameras, PPS signal to IMU
  - Custom 3-D printed mounts
  - Custom power and autonomy rack



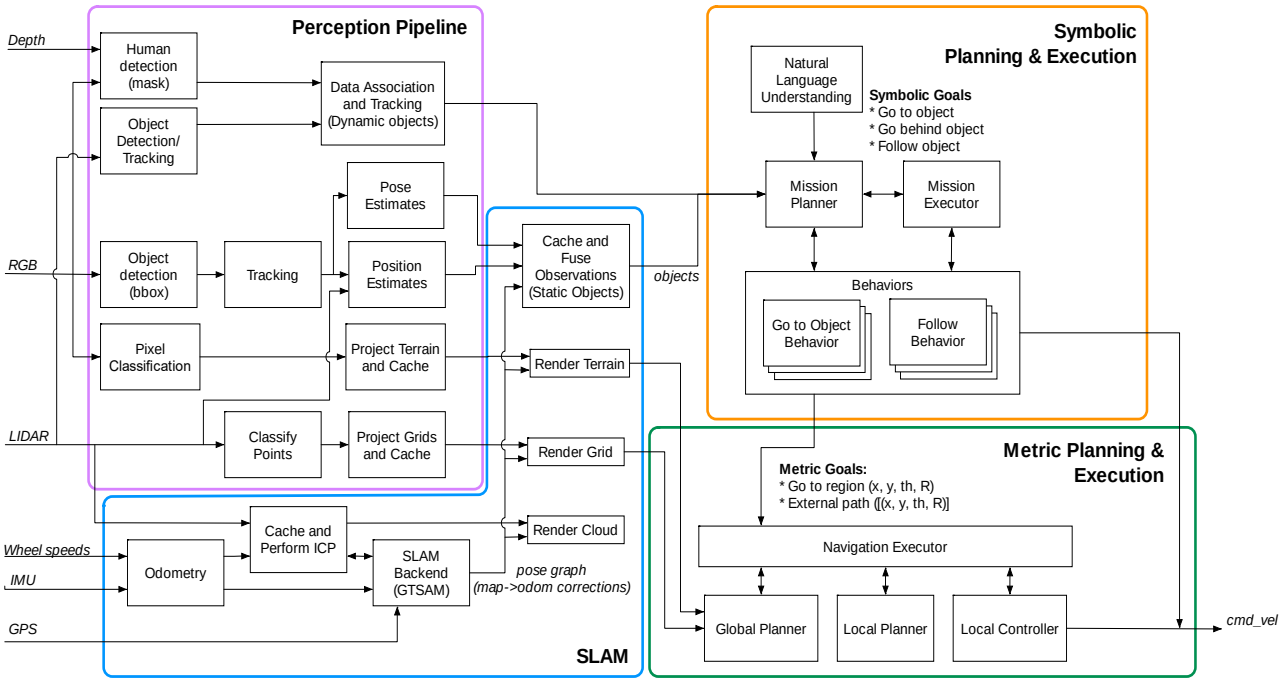
*It is not a requirement to match the ARL configuration one-for-one

SARA – ARL GROUND AUTONOMY SOFTWARE STACK

- The autonomy architecture is based on packages and components implemented with the Robot Operating System (ROS) to enable reproducibility and modularity
- We consider modularity at two scales: both individual algorithms/nodes and clusters of nodes that provide capability
- The architecture depends on the TF library and adheres to standard frame conventions
- Central to the world model and representations of the architecture is the adoption of pose-graph-based solutions to the simultaneous localization and mapping (SLAM) problem for GPS-denied or degraded localization. That is, representations of the world consume a list of frame correction (e.g., map to odometry) in order to process observations in a consistent frame (e.g., map).
- We assume a federated world model – the location and communication of data is in the hands of the system designer.

OVERVIEW OF BASELINE AUTONOMY STACK

- **ROS 1 (full distribution ~300 packages)**
  - Mainly C++, some python
- **Monolithic git repository**
- **Mostly an accumulation of internal, MAST, RCTA capabilities**
- **Core functions**
  - Perception (lidar and vision)
  - Localization and mapping
  - Metric planning and execution
  - Symbolic planning and execution
  - Simulation
- **Intended platform set:**



ARL GROUND AUTONOMY ARCHITECTURE

The existing ARL autonomy software stack provides an implementation of the architecture described in previous charts and will be provided as GFE to seedling recipient. It consists of four major capabilities:

1. Perception pipeline: Take sensor data, e.g., RGB images and point clouds, and process to symbolic observations. Components include object detection, per-pixel image classification, object position/pose estimation based on LIDAR, etc.

2. Simultaneous Localization and Mapping (SLAM): Using sensor data and perception pipeline products, formulate SLAM problem as a pose-graph optimization and solve. Includes components for point cloud alignment (ICP), pose-graph optimization (GTSAM), caching/data-association/fusion of symbolic object measurements, renderers of terrain classes/occupancy grids/point clouds.

3. Metric Planning and Execution: Use metric model of the world to achieve metric goals, e.g., waypoint navigation. Includes components for global planning (e.g., lattice-based motion planning), local planning (e.g., trajectory optimization), and an executor to sequence planning and control.

4. Symbolic Planning: Use symbolic model of the world to achieve symbolic goals, e.g., going near a particular object. Underlying symbolic planning architecture is based on behavior trees. Includes components for mission planning (e.g., the Planning and Acting using Behavior Trees), mission execution, sample behaviors that interface with mission planning/execution and the metric planning/execution layer (e.g., going to an object).

CONTRIBUTING TO ARL GROUND AUTONOMY ARCHITECTURE

Contributions to the existing architecture come in three (for now) possible ways:

- **Replace** an existing algorithm or capability with a newly-developed or already-existing one. Experiments should then be conducted to show improved performance.
- **Add** an algorithm or capability, either already-existing or newly-developed. Experiments should then be conducted to show augmented capability.
- **Modify** an existing algorithm or capability. Experiments should then be conducted to show improved performance.

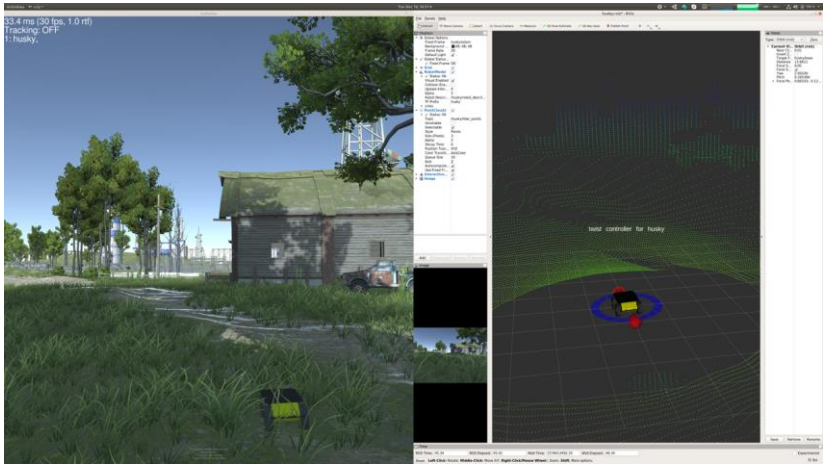
To support this collaborative and cumulative engagement and environment, software code developed under the SARA program will be added to the ARL Autonomy Stack Repository for use by current and future ARL and sprint recipients.

Recipients will be given access to a private Gitlab project so that SARA technologies can be integrated into the baseline ARL Autonomy Stack through a feature-branch methodology including pull requests, code review, and automated testing.

DEVELOPMENT & INTEGRATION STRATEGY

Geared to support collaborative and reproducible research

- Monolithic repository
- Catkin Workspace (ROS 1)
- Feature branches with pull requests, code review, and automated CI testing
- Common simulation tools (Unity)
- Docker-based development and deployment available
- Tools to run using database of real-world platform data



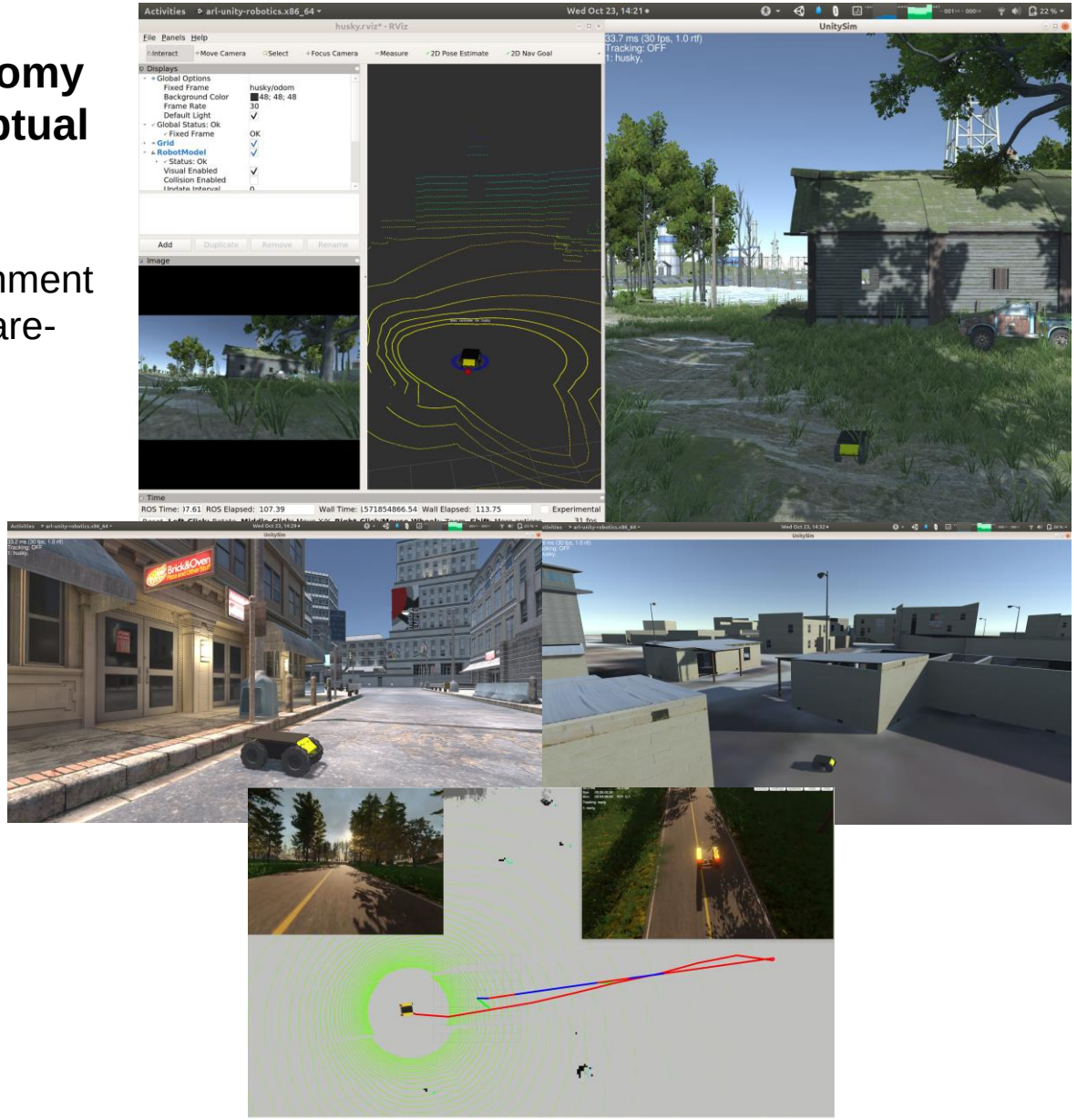
https://gitlab.sitcore.net/aimm/phoenix-r1

https://gitlab.sitcore.net/arl/robotics-simulation/arl-unity-ros

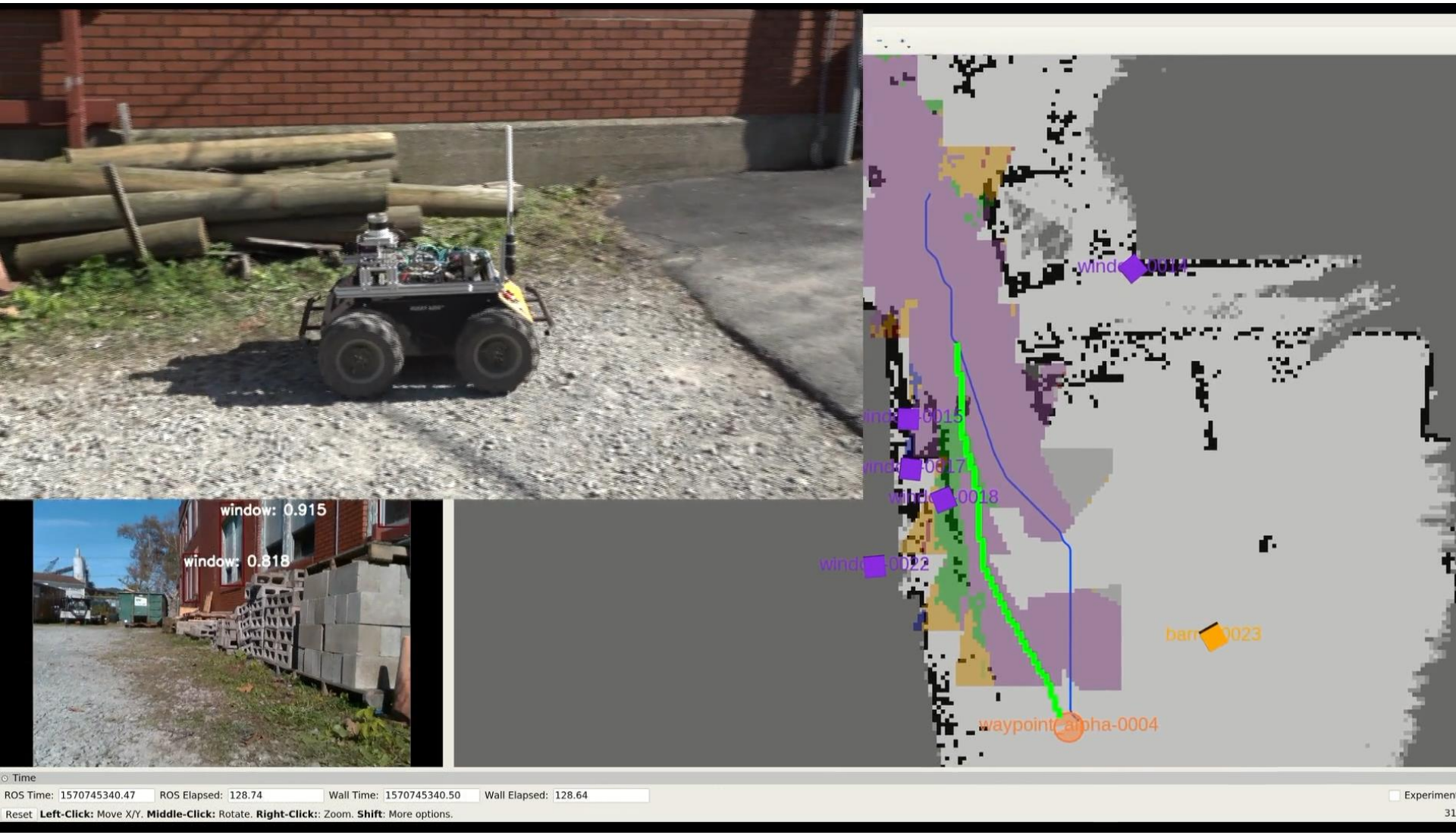
ARL SIMULATION TESTBED

Included with baseline autonomy stack is a Unity-based perceptual and physics simulation

- ROS Interface
  - Spawn robots, sensors, environment
  - Receive sensor data on hardware-compatible topics
  - Send actuation commands to simulated platform
- Platforms
  - Clearpath Husky
  - Clearpath Warthog
  - Polaris MRZR (coming soon)
- Sensors
  - IMU
  - Cameras
    - RGB
    - Panoramic/fisheye
    - Depth
    - Semantic segmentation
  - 3-D LiDAR



ARL's Autonomy Stack implemented on Husky Platform At RCTA Capstone

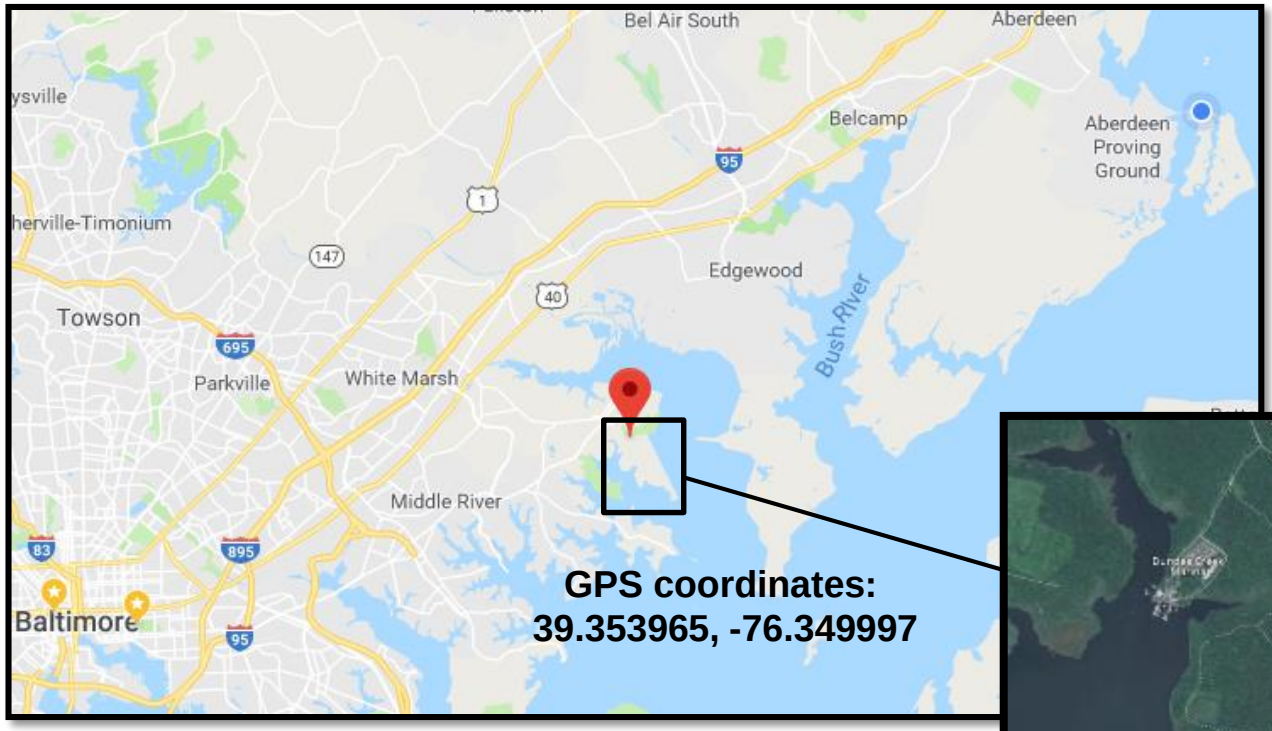


ARL's Autonomy Stack implemented on Husky Platform At RCTA Capstone

SARA – SPRINT #2 METRICS

- Recipients will be expected to integrate their solutions onto ARL testbeds and into ARL's autonomy stack for the experimental events.
- At these experimental events, Recipients, using the ARL testbeds and their solutions integrated into the ARL autonomy stack, will conduct autonomous maneuvers per the assumptions above and their performance will be evaluated against criteria such as:
  - Number and duration of Human interactions needed to complete task
  - Mean Distance Between Interactions
  - Mean Time Between Interactions
  - Speed to complete navigation task compared to a manned system, a single tele-operated ground RAS
  - Complexity of terrain traversed based on number, density, and type of obstacles

Robotics Research Collaboration Campus (R2C2) at Graces Quarters



Recommended reading:

- https://www.afcea.org/content/army-robots-gain-real-world-testbed
- https://www.army.mil/article/243448

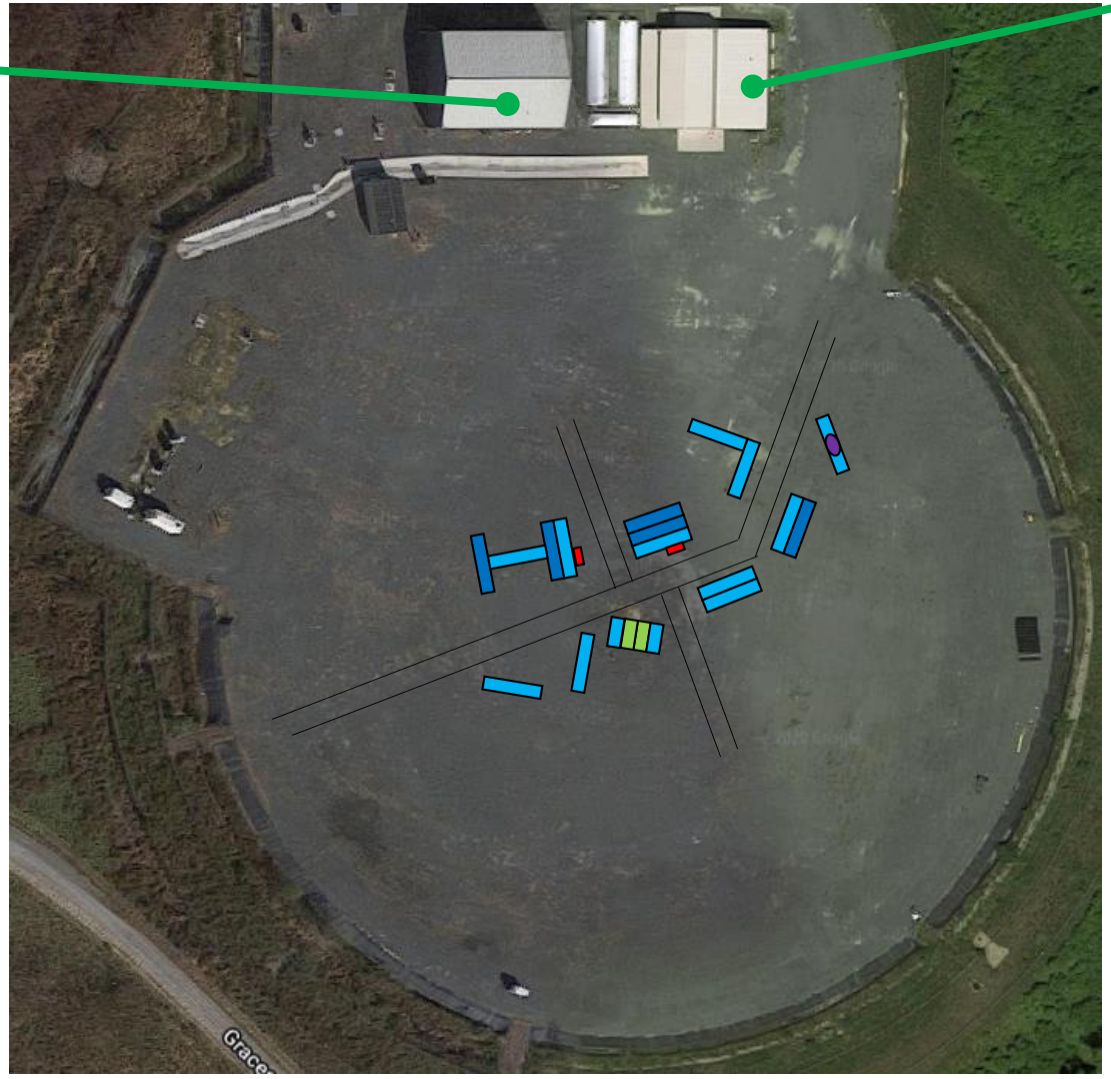
A U.S. Government-owned research facility, under operational control of ARL, to explore and rapidly accelerate knowledge acquisition and understanding of autonomous systems technologies

GRACES QUARTERS TERRAIN FEATURES

- **600-ft diameter gravel pad**
  - MOUT site
  - Multi-terrain track (sand, mud, turf, rock, gravel)
- **Unmarked network of forested trails**
  - Fallen trees and branches
  - Hills and valleys/gulches
  - Mature trees, variable spacing
  - Dense saplings
  - Low-hanging trees
  - Traversable vegetation and brush
  - Single and double track trails
  - Open fields
- **Office building with conference rooms and collaboration space**
- **Support facility with UGV storage and machine shop**

GRACES QUARTERS SITE OVERVIEW

Administrative building
- Office space
- Restrooms
- Collaboration space
- Equipment storage



Support building
- UGV and support equipment storage
- Machine shop
- Tools

GRACES QUARTERS IN FALL / WINTER

A few representative images of expected testing environments, actual testing will involve other sites and more terrain features.

GRACES QUARTERS IN SUMMER / SPRING

SARA – SPRINT #2 PROPOSAL INTENT

- Funding will be provided to selected Recipients under a cooperative agreement (CA). For Cycle # 2 the period of performance will be twelve (12) months.
- 1st year CA awards are described as the “seedling” project
- Multiple awards are expected. Total number of seedling Recipients and funding per Recipient will vary from year-to-year at the discretion of the Government and based on available funding.
- Proposals are to be bid commensurate with level of effort proposed. A total of **$1.9M** is expected for all proposals to be awarded, not per proposal.
- Proposals can address one or both sub-topics within this amended special notice.
- Proposals must address one or more, but need not address all, of the assumptions and challenges listed within each sub-topic within this amended special notice. Proposals are also not limited to assumptions and challenges listed.
- ARL reserves the right to negotiate with an Applicant to re-scope their proposal technical focus, period of performance, and associated costs in order to maximize the available program funding, balance of research topics across the program, and overall impact to the program.

SARA – SPRINT #2 PROPOSAL INTENT (CONT.)

- The Recipients of a “seedling” CA are then eligible for consideration of a single optional extension of up to 3 years at the conclusion of the “seedling” project.
- Proposals should also **include descriptions for optional extensions** of their proposed seedling effort for consideration in the optional period of performance.
- The success of this multidisciplinary effort will require meaningful collaborative partnerships between government, academia, and industry to advance the science. Proposals should **address their intellectual property (IP) approach and how their approach will foster collaboration with ARL and other SARA Recipients**, and how their solution will further advance the state-of-art of open source or ARL/government owned autonomy solutions.
- Proposals that include **innovation in open architecture** hardware design, selection and algorithm implementation leading to significant decreases in size, weight, power and cost **will be a priority**. Solutions with restrictive Intellectual Property or non-open architecture solutions will also be considered, but must show a pathway to transition to future Army systems and integration and operation within the ARL autonomy software stack.

SARA – PROJECT NARRATIVE ON GRANTS.GOV

Chapter 1: Technical Component.

- Will not exceed 10 pages, utilizing one side of the page.
  - Proposed Effort (approximately 4-5 pages)
  - Proposed Experimentation Event Participation and Collaboration Development (approximately 1-2 pages)
  - Participant roles, qualifications and bio-sketches (approximately 2 pages)
  - Proposed timeline (approximately 0.5-1 page)

Chapter 2: Optional Technical Component.

- Will not exceed 4 pages, utilizing one side of the page.
  - Proposed Effort (approximately 2-4 pages)

Chapter 3: Cost Component.

- Chapter 3 does not have a page limitation
- Include costs for Base period and Option period

Proposals are due in Grants.gov by 3:00pm (local time in North Carolina, USA) on 5 March 2021

APPLICATION REVIEW / EVALUATION INFORMATION

Factor 1: Scientific Merit and Relevance: Evaluation of this factor will concentrate on the overall scientific and technical merit, creativity, innovation, and flexibility of the proposed research in light of the current state-of-the-art of SARA-relevant scientific topics, and the expected outcomes based on the timeline of execution.

Factor 2: Research Plan and Plan for Collaboration: Evaluation of this factor will concentrate on the Applicant's strategies, plans and experience in fostering collaborative research and managing collaborative research programs as set forth in this FOA.

Factor 3: Experience and Qualifications of Scientific Staff and Junior Investigator Development: Evaluation of this factor will concentrate on the qualifications, capabilities, availability, proposed level of effort, and experience of both the Applicant's key research personnel (individually and as a whole), their relevant past accomplishments, and their ability to achieve the proposed technical objectives.

Factor 4: Cost. While this area will not be weighted, evaluation of this area will consider cost realism, cost reasonableness, and affordability within funding constraints. The Government may make adjustments to the cost of the total proposed effort as deemed necessary to reflect what the effort should cost.

PROPOSAL REVIEW AND SELECTION PROCESS

- Proposals are expected to be evaluated by a group of qualified scientists and managers from the Government.
- Proposals that are timely and in compliance with the requirements of the FOA will be evaluated in accordance with merit based, competitive procedures.
- The Government will make award to the Applicant(s), whose proposal conforms to the Funding Opportunity that offers the most-favorably rated proposal(s) based on the evaluation criteria.
- The Government reserves the right not to make an award should no acceptable Proposal be submitted.
- The Government also reserves the right to negotiate with an Applicant to re-scope their proposal or optional proposal technical focus, period of performance, and associated costs in order to maximize the available program funding, balance of research topics across the program, and overall impact to the program resulting in the development of an annual program plan to cover the optional research to be performed and the period of performance of that research.
- At the end of Cycle #2, the decision to exercise option periods of any seedling awards remains at the discretion of the Government.

SARA – CLOSING NOTES

- Nothing in this presentation or discussed during the webinar supersedes the FOA for purposes of proposal preparation.
- Any changes to the FOA will be issued as amendments.
- Please continue to monitor grants.gov for changes at https://www.grants.gov/web/grants/view-opportunity.html?oppId=323682
- Any additional questions can be submitted through the SARA website https://www.arl.army.mil/sara/sara-questions-answers/
- Last day for questions 5 March 2021

Questions?