An Overview of Research Development at the Autonomous Control & Information Technology Institute (ACIT) at N.C A&T State University

SUSTAINABLE FLEET TECHNOLOGY CONFERENCE & EXPO 2018

AUGUST 22-23, 2018

http://techlav.ncat.edu/

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Outline

- Center Overview
- TECHLAV Core Research
  - Research Thrusts and Highlights of Achievements
  - Demonstration, Implementation and Integration (DII)
- Data-Driven Intelligent Prediction Tool (DIPT)
- DoT Research Projects & Collaborations
- Outreach
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  - Research Outcomes
  - Outreach Outcomes
- Sustaining the Center Activities

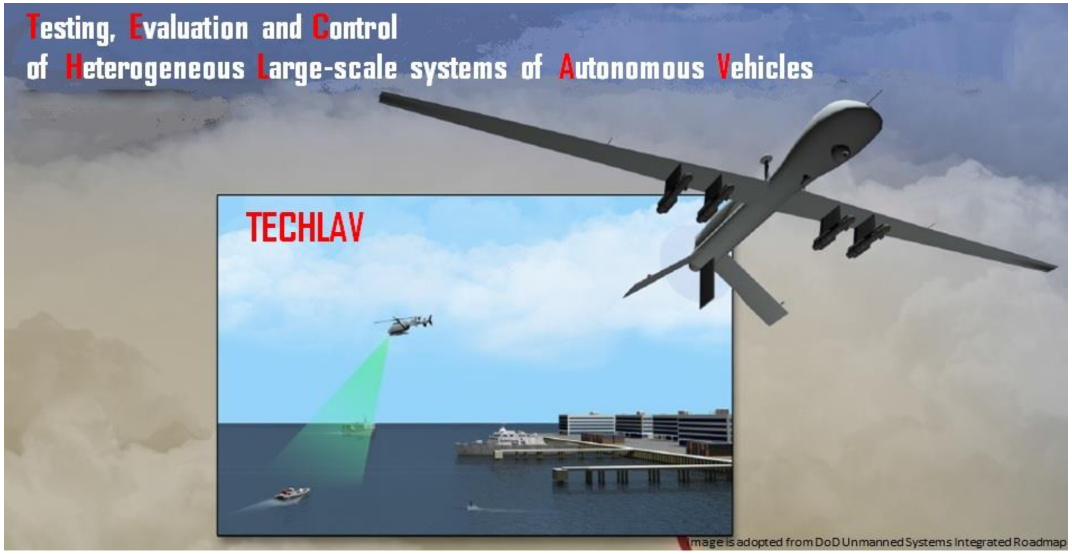
University Overview

- Nation's largest HBCU
- Enrollment: 11,177 students
- 1891 Land-grant University
- $60 Million Research Portfolio
- R2 Classification
- Top U.S. Producer of African-American B.Sc. Engineers and Female African American B.Sc. Engineers
- No. 2 in the nation for social mobility in Washington Monthly's 2013 College Rankings
- No. 1 Best Value HBCU in the Nation, Money Magazine
- Faculty Ranked No. 10 in the Nation, Wall Street Journal/Times Higher Education

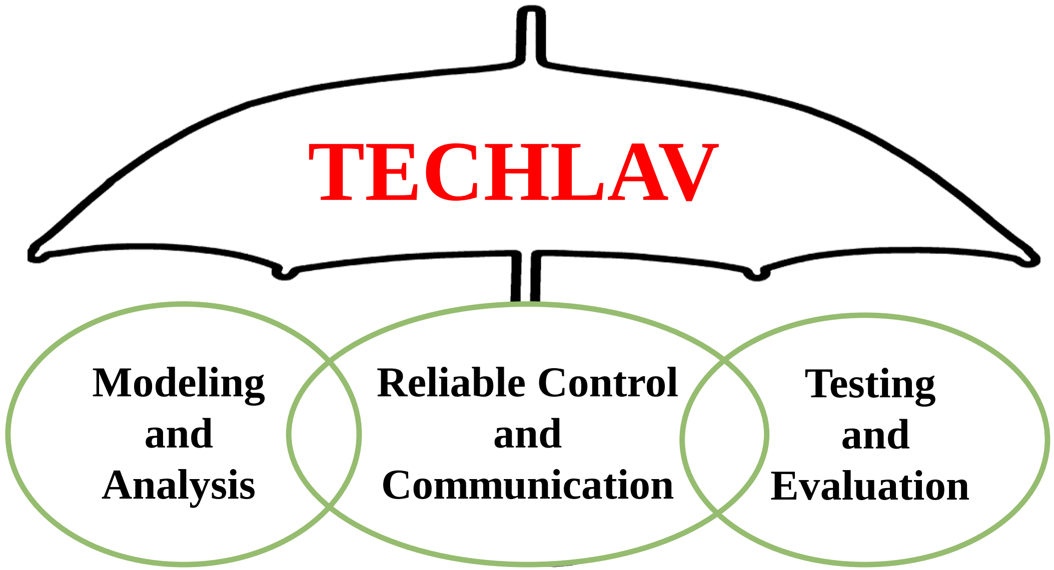
About TECHLAV

Testing, Evaluation, and Control of Heterogeneous Large-scale Systems of Autonomous Vehicles (TECHLAV) is a multidisciplinary research center on the leading edge of control, communication, computation, and human cognition to address two main problems:

1. Teaming and cooperative control of Large-scale Autonomous Systems of Vehicles (LSASVs) integrated with human operators.
2. Testing, Evaluation, Validation, and Verification of LSASVs.

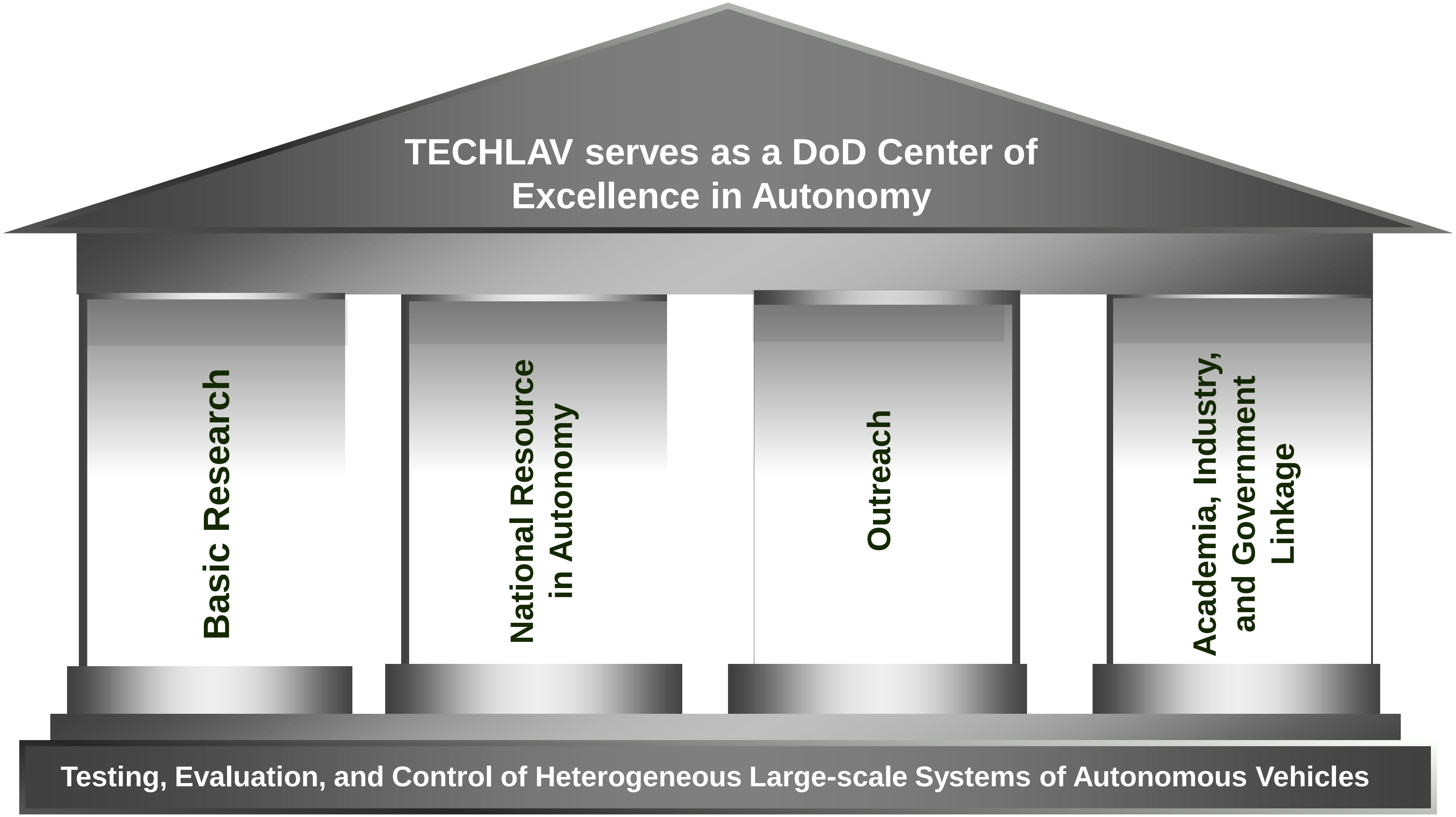


Challenges

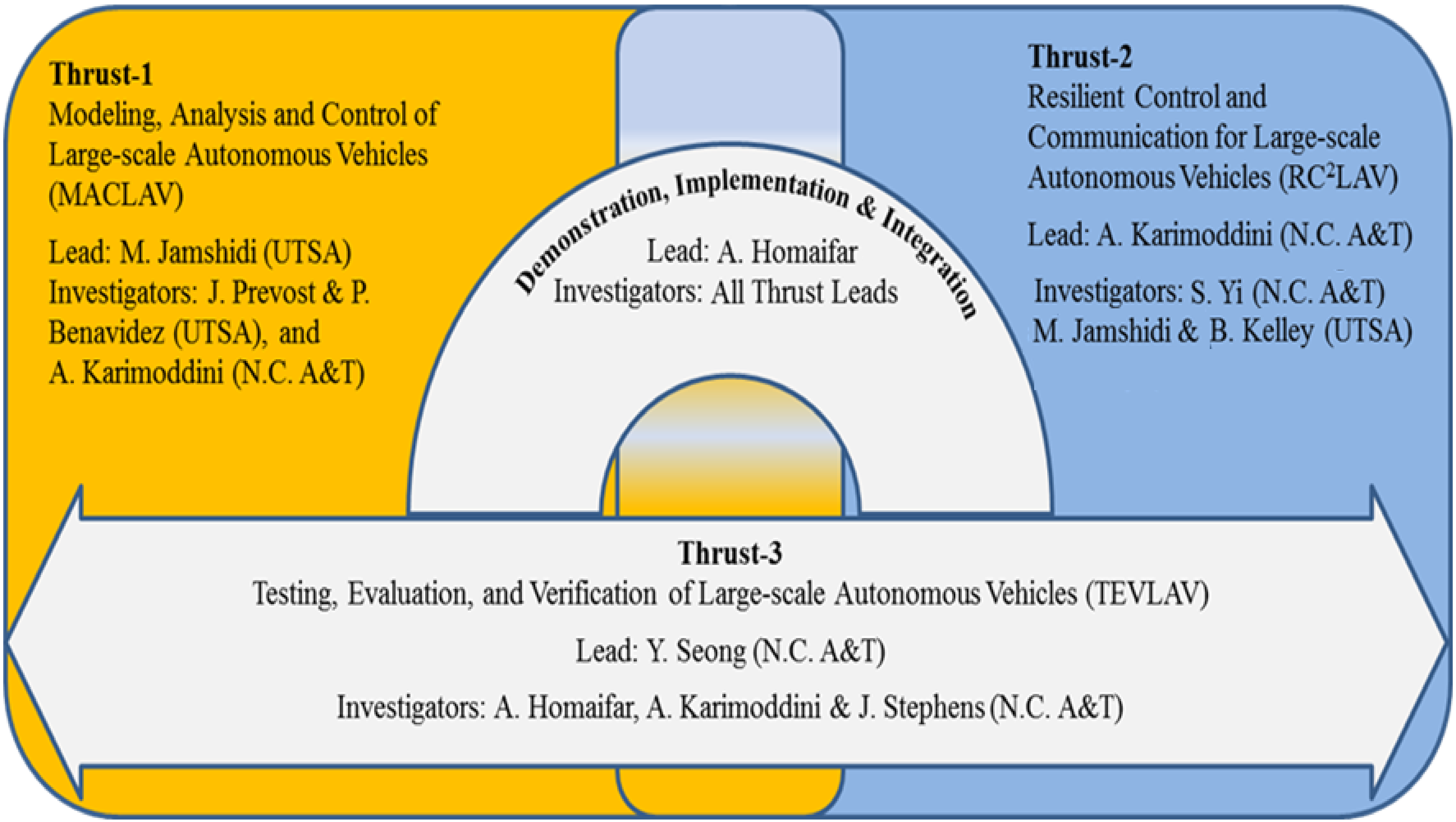


- How to mathematically describe the collective behaviors of systems of vehicles?
- How to reliably design decentralized control and communication for systems of vehicles to achieve desired collective performance?
- How to test and evaluate the control and communication between systems of vehicles?

TECHLAV creates a comprehensive umbrella covering different aspects of systems of vehicles ranging from modeling and analysis to control, communication, testing and evaluation.


TECHLAV serves as a DoD Center of Excellence in Autonomy
Basic Research
National Resource in Autonomy
Outreach
Academia, Industry, and Government Linkage
Testing, Evaluation, and Control of Heterogeneous Large-scale Systems of Autonomous Vehicles

TECHLAV Core Research



Research Thrust 1

Lead: Dr. M. Jamshidi, UTSA

Members: Drs. J. Prevost,. P. Benavidez, UTSA; and A. Karimoddini, N.C. A&T

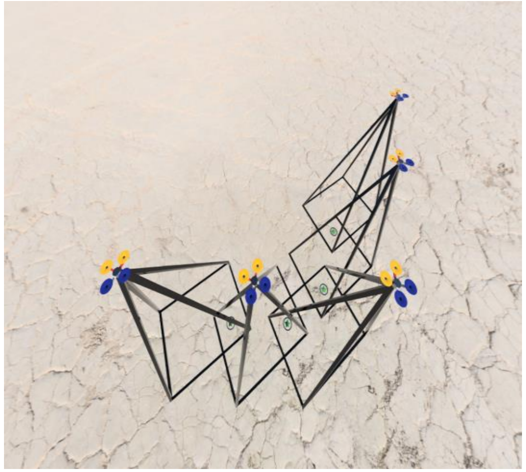
DoD Needs

- *Computer models system architectures for autonomous systems*
- *Adaptable systems, increased autonomy, improved sensor systems*

Highlights of Achievements

Models for Autonomous Systems

- Developed mathematical and data-based, machine learning-based on models of heterogeneous vehicles.



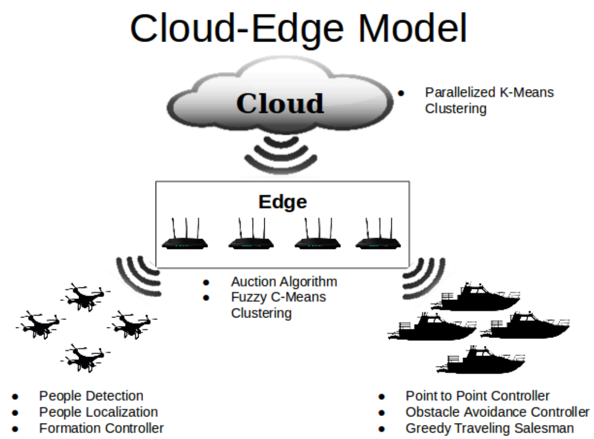
Navigation and Object / Human Identification

- Developed machine and deep learning algorithms for real-time identification of objects and humans by autonomous robots.
- Developed novel techniques for the planning and control of autonomous vehicles driven in adversarial environments - addressed the reach-avoid path planning problem.

Research Thrust 1
Highlights of Achievements

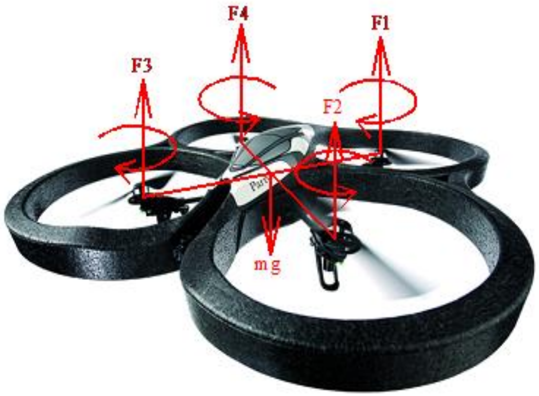
Cloud-based Autonomous Vehicles

- Implemented and tested peer-based and clone-based cloud computing models.
- Developed a testbed for evaluating various cloud-based models for robotic swarm computation offload.
- Tested the popular VSLAM algorithm RTAB-MAP (real time appearance based mapping) in a peer-based configuration.



Machine Learning-based Cyber-Physical Systems

- Developed a task-allocation algorithm for swarms of autonomous vehicles with application to search and rescue.



Smart and Safe Robot Operating Systems - ROS

- Evaluated ROS and popular embedded computers against well-known cyber-attacks, and introduced methods to eliminate cyber threats to help secure LSASV.

Research Thrust 2

Lead: Dr. A. Karimoddini, N.C. A&T
Members: Drs. S. Yi, N.C. A&T, M. Jamshidi and B. Kelley, UTSA

DoD Needs

- *Increased safety, communication, security and efficiency,*
- *Methods to reduce vulnerabilities of the autonomous systems*

Highlights of Achievements

Failure diagnosis:

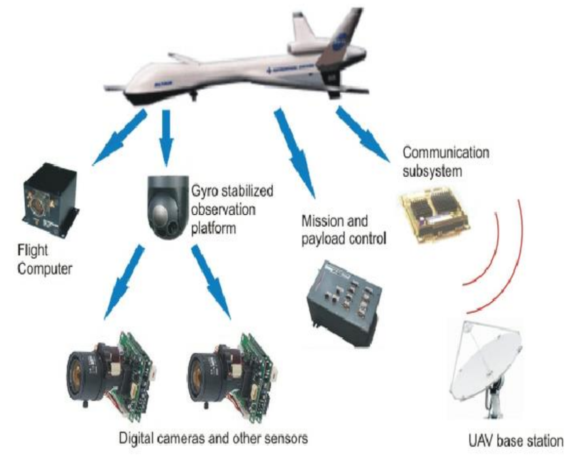
- Developed a new learning-based algorithm that can both identify and diagnose a system modelled by a discrete event system (DES).

- Developed a novel asynchronously activated systematic approach that can detect, identify, and locate the occurred faults from limited observations of a system's behavior.

Research Thrust 2
Highlights of Achievements

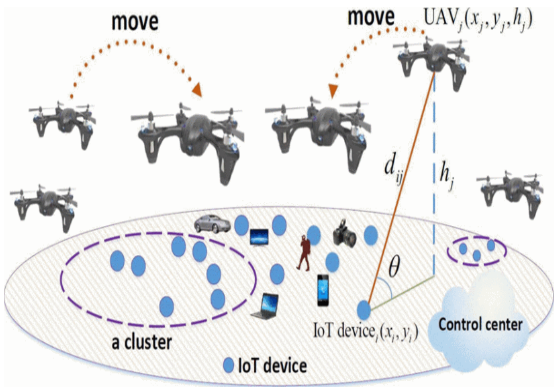
Time-delay in networked controlled systems

- Conducted quantitative analysis of effects of signal transmission delays for networked systems via infinite eigen-spectrum analysis.
- Developed control strategies which take into account varying delays of networked systems by incorporating estimation of delays into the control loop.



IoT resource allocation

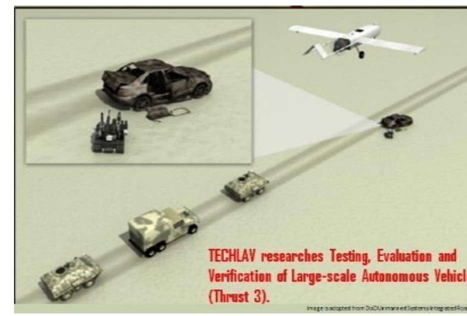
- Developed an effective resource allocation strategy for the Unmanned Aerial Vehicles (UAV)-based IoT systems.
- Developed a novel algorithm for minimizing the transmit energy of the UAVs for a general model of UAV-supported ad-hoc network of IoT devices.



Research Thrust 3

Lead: Dr. Y. Seong , N.C. A&T
Members: Drs. A. Homaifar, A. Karimoddini, and J. Stephens, N.C. A&T

DoD Needs
- *Methods for successful verification and validation of autonomous systems*
- *Ability to interact with human operators or other autonomous systems*



<u>Highlights of Achievements</u>

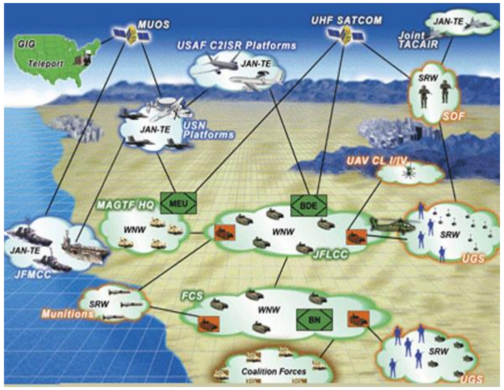
Formal modular verification approaches
- Model checking by using the abstraction hierarchy technique to relate intended purposes to physical functions in order to divide the system into manageable identities.

Evaluation of emergent behavior
- Developed a novel clustering-based data-driven technique for the detection of emergent behavior of autonomous vehicles through sensor data analysis.

Research Thrust 3
Highlights of Achievements

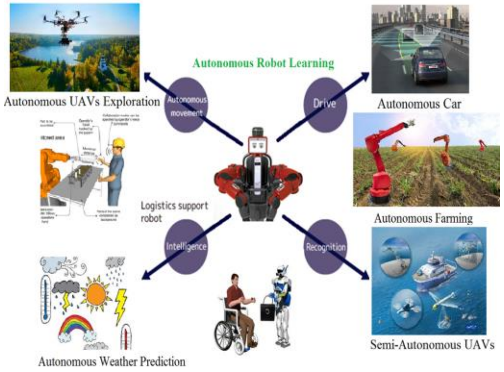
Uncertainty Modeling

- Implemented various approaches of modeling uncertainty and developed a novel combination rule to manage conflict in evidence theory.
- Verified the functionality of the proposed method to a multi-sensor decision fusion for target recognition problem.



Human trust in autonomous systems and cognition of uncertain environment

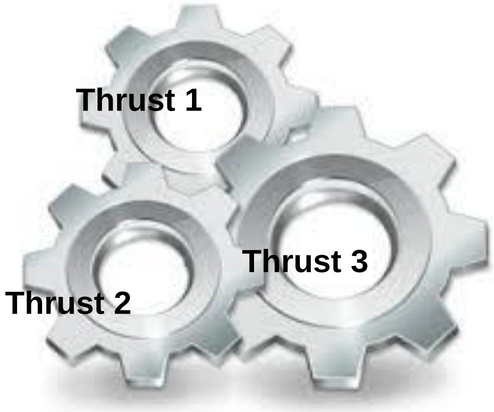
- Designed experiments in usage of electroencephalography (EEG) to understand how the brain responds to trust/mistrust situations towards automated systems.
- Efficiency of EEG methods in capturing correspondence between human cognition of uncertain environments and human brain has been evaluated using Task Engagement Index (TEI).



Demonstration, Implementation and Integration

Lead: Dr. A. Homaifar, N.C. A&T
Members: Drs. A. Karimoddini, Y. Seong, N.C. A&T, M. Jamshidi, UTSA

– Five from Thrust 1, one from Thrust 2 and two from Thrust 3
– Test and validate the performance of the developed tools and protocols in real-world scenarios related to the DoD's mission.



Demonstration, Implementation and Integration

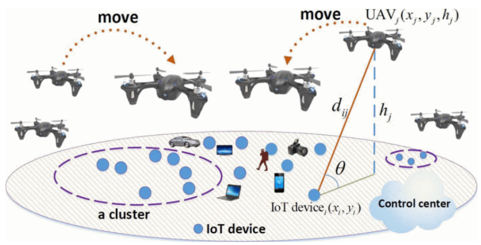
GPS Denied Positioning for Formation Control

Multiple Quadcopters

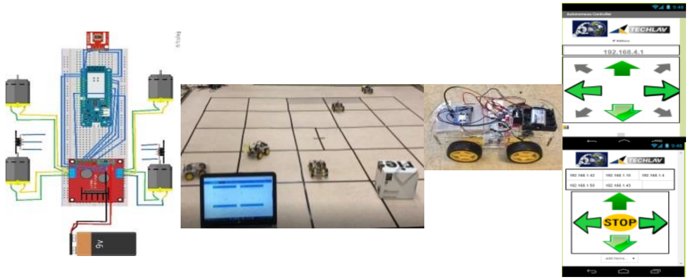
Interval Type-2 FLC

Aggies Autonomous Auto – A3

Control of Multiple UAVs



UAVs for IoT Applications

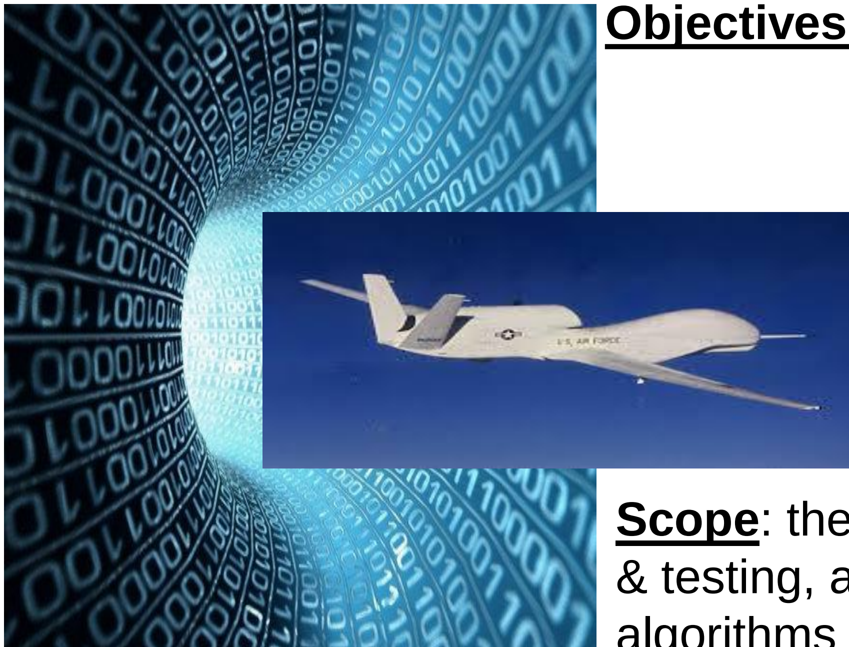


Autonomous Vehicles Monitoring

Perception Inference Engine

Data-driven Intelligent Prediction Tool (DIPT)

"*Data-driven Intelligent Prediction Tool (DIPT)*," DOD Test Resource Management Center, $5,300,000, 2016-2020.



Objectives: (1) monitor and understand the UAS processes without interfering with them, (2) understand the behavioral state of a UAS during its mission, (3) understand the UAS' perception capabilities, (4) visualize its autonomy processes in real time through a user-friendly interface.

Scope: the development of T&E algorithms, simulation & testing, and finally the implementation of the algorithms on actual Department of Defense platforms.

DoT Research Projects at ACIT

- **The Crash Imminent Safety (CrIs) University Transportation Center (UTC)**

Objective

To develop models and control techniques required for designing an Advanced Driver Assistance Systems (ADAS)

Impact

- Developing a comprehensive model including uncertainty for human driver behavior at urban environments
- Understanding driver distraction and designing a semi-autonomous controller aimed at mitigating the effects of driver distraction

Tasks of ADAS

- Predict other drivers' actions to avoid crashes
- Detect driver distraction and take over more control
- Detect and warn drivers of their dangerous driving

Challenges

- People drive differently based on their age, gender and environment
- Various environmental factors affect modeling the human driver such as: traffic light, time of the day, weather conditions etc.
- Human driver behaviors include several uncertainties which must be considered during modeling
- The developed models may be sensitive to hyper-parameters
- Sufficient data is not available for all maneuvers and conditions

- Thus: In this study driving scenarios are considered for which relevant data was available

Sample DoT Research Projects at ACIT…

Driver Behavior Modeling at Intersections

- Fuzzy based modeling technique with Takagi-Sugeno models and Gath-Geva fuzzy clustering is introduced for estimation of driver behavior at intersections.

Hidden Markov Models Sensitivity Analysis

- Sensitivity analysis in HMM is performed by taking small perturbations in parameter values and re-computing the output probability of interest.

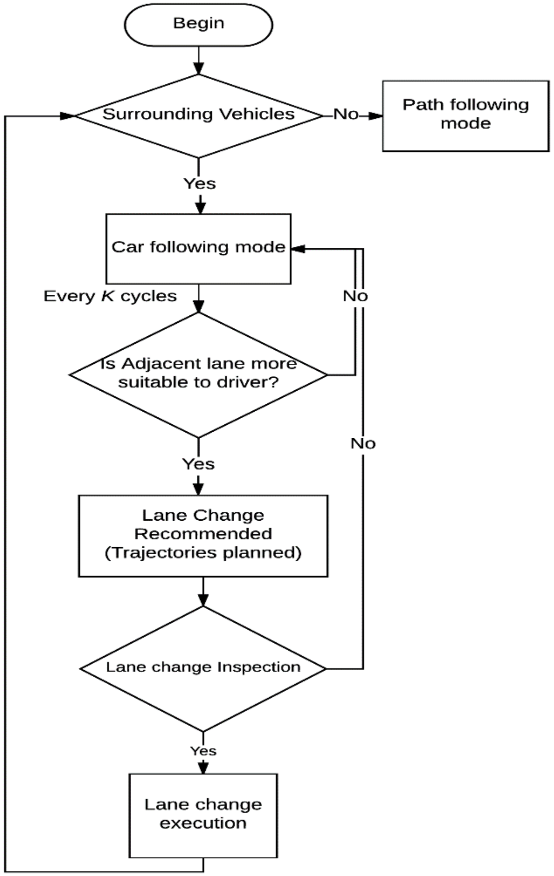
Lane-Change Naturalistic Safety Monitoring

- A safety monitoring system with one-class SVM is developed to detect anomaly/dangerous lane changes.

Sample DoT Research Projects at ACIT…

Personalized Highway Driving Assistance System

- A highway driving system is proposed, which performed according to the driver's preference, while maintaining the safety of the vehicle.
- The driver's preference is captured using machine learning techniques such as the Random Forest and the Support Vector Machine.
- The proposed algorithm for this system makes the decision to change lanes and alternate between car following and path following in different traffic conditions.



Kinematic-based Framework for Autonomous Ground Vehicle Trajectory Planning

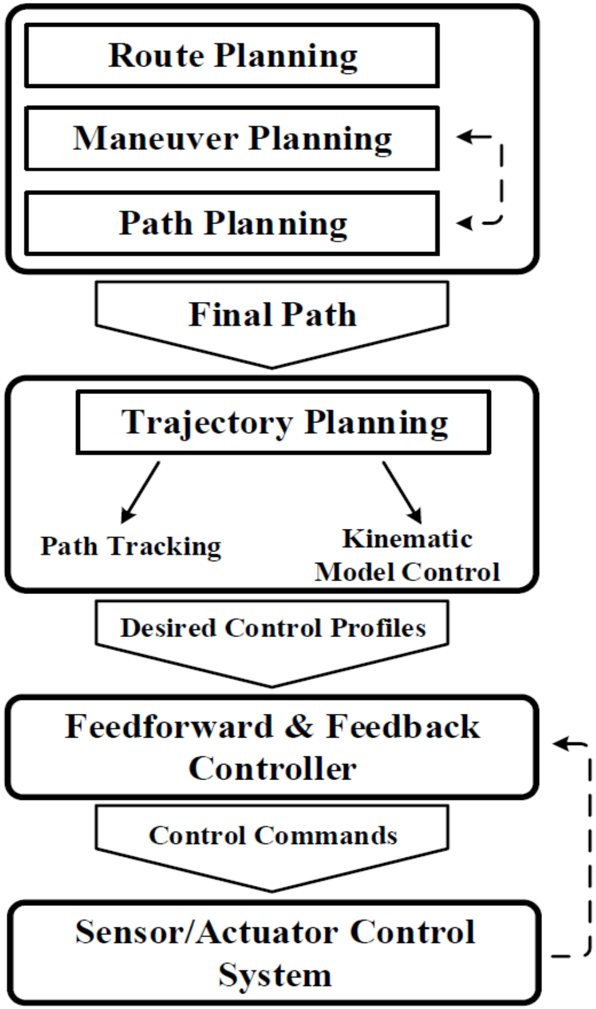
- **Trajectory planning problem:**
  "*Real-time planning of the actual vehicle's transition from one feasible state to the next, satisfying the vehicle's kinematic limits based on vehicle dynamics and constrained by the navigation comfort*"
  - From the trajectory planning perspective, the simplicity of the model is more favorable since there is no need to impose the computationally overhead of the complex models.

- **From the control aspect,**
  - Kinematic models are more simple and being used in low-speed applications
  - Dynamic models are more attractive in high speed applications since the slippage effect can be captured by them while they are suffering from a high computational complexity due to the identification of nonlinear unknown parameters e.g. mass, cornering stiffness, and tire-road friction.

Sample DoT Research Projects at ACIT…

Kinematic-based Framework for Autonomous Ground Vehicle Trajectory Planning

- **In trajectory planning,**
  - the framework generates the trajectory with the minimum tracking error (position, velocity, acceleration, heading).
  - motion constraints can be transformed into the form of vehicle configurations (states) inequality constraints (road boundaries, limitations on velocity, etc.)
  - the most important part is not presuming linearity of the trajectory planner and not restricting the input space and trajectory to any certain parametric class of functions, e.g. Bezier curves, splines, and polynomials which indeed avoid the sub-optimal solution
- **In control,**
  - we used the calculus of variation technique to find the optimal closed-form control inputs and states which make the method attractive for real-timed applications.



Sample DoT Research Projects at ACIT…

A Fuzzy Danger Level Detection - applied on Collision Avoidance System

Motivation

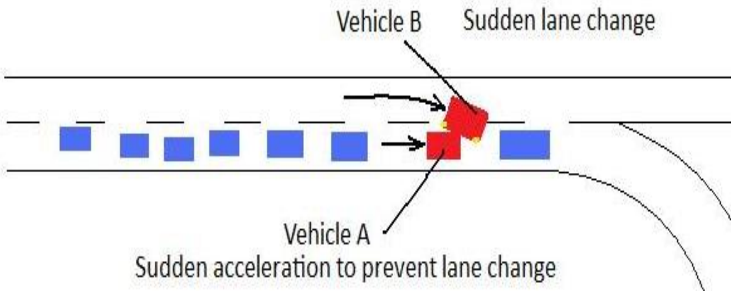
- Driver assistance systems have the potential to reduce the risk of accidents as the system will take over control of the vehicle in dangerous scenarios and prevent potential accidents.
- Therefore, detecting dangerous lane change events and modifying them to avoid accidents is essential in increasing traffic safety.

Goal:

- Develop a fuzzy danger-level detection system based on naturalistic driving data to perform risk assessment in lane-change scenarios
- Implement a collision avoidance system to modify the driving performance and reduce the level of danger

Challenges:

- Naturalistic driving data contain massive observation
- Complicated feature extraction, in order to capture real life factors which caused the accident



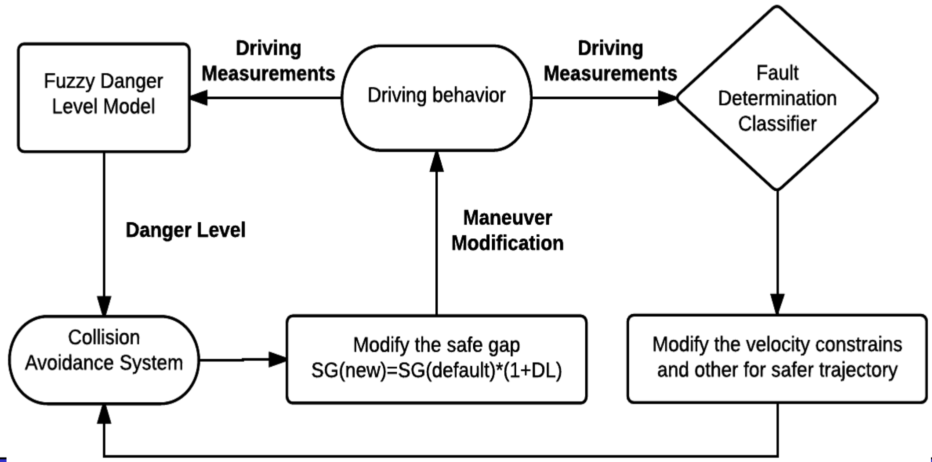
Sample DoT Research Projects at ACIT…

Fuzzy Danger Level Detection

- ***Estimate on Subject vehicle***
  - Based on Mamdani's fuzzy inference method
  - ***Inputs***: Velocity, Yaw-rate, Accelerations in Longitudinal & Lateral
  - ***Output***: Danger-level percentages
- ***Estimate on Surrounding vehicle***
  - Based on Mamdani's fuzzy inference method
  - ***Inputs***: Relative velocity of surrounding vehicle, Relative distance in Longitudinal & Lateral
  - ***Output***: Danger-level percentages

Collision Avoidance System

- **Based on model predictive control(MPC)**
- **Trajectory planning**
  - Optimize the accelerations in Longitudinal
  - Optimize the distance in Lateral
  - Danger level affect on Safe Gap constrain



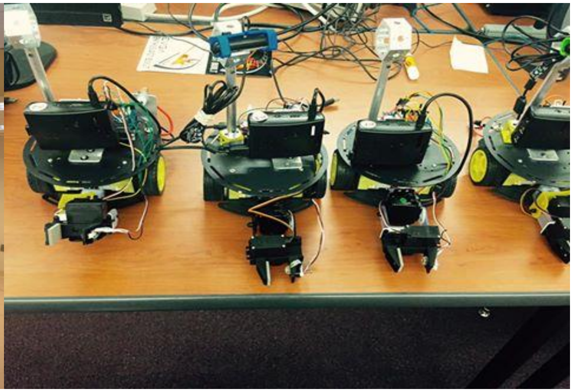
TECHLAV Outreach Activities at N.C. A&T

✓Hosted a Congressional Delegation (CODEL) visit to view DoD/HBCU partnerships on March 28, 2018, sponsored by Representative Anthony G. Brown (D-MD). Among the individuals present were also Representative Alma Adams (D-NC), and Dr. Michael Lomax, president and CEO of UNCF.

✓Held the FIRST LEGO League and FIRST Tech Challenge State Championships in January and February.

- TECHLAV provided funding support for the equipment, registrations, and supplies of three rookie teams to participate in the 2017-2018 First Tech Challenge season. There were a total of 120 FLL teams and 36 FTC teams that participated.

✓Reached over 450 K-12 students through lab tours, workshops, and interactive demonstrations.



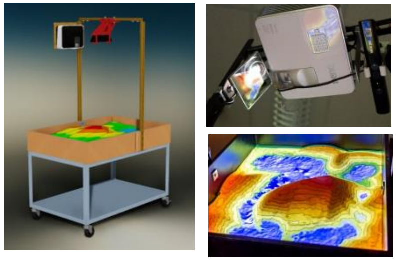
TECHLAV Outreach Activities at SIPI

High school tours at SIPI Labs

Bernalillo High school Collaboration

Using RoadRunner to teach programming skills

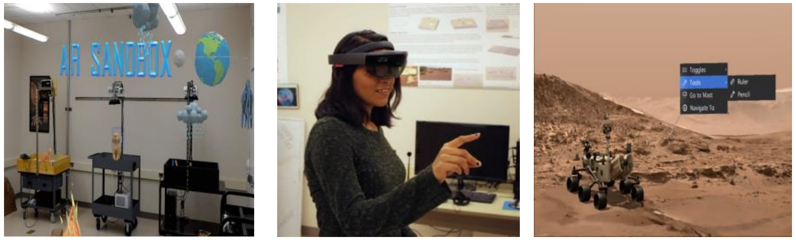
RoadRunner 5



AR Sandbox CAD Design & Simulation

ROV-S Model & Manufactured Prototype

Oculus Rift with motion controls



HoloLens as used in Mars Exploration & view holograms

TECHLAV Seminar Series

- TECHLAV Center and its affiliated partners and laboratories have jointly organized 25 bi-weekly seminar series.
- **Topics:** Different aspects of modeling, control, testing, and evaluation of large-scale systems of autonomous vehicles.
- **Goal:** To create this interactive forum as an environment for sharing recent research results and discussing various control, modeling, testing and evaluation problems from different angles by participants with different backgrounds and expertise.
- **Attendees:** Researchers from NCAT, UTSA, SIPI and other TECHLAV partners and collaborators.
- **Speakers:** TECHLAV Researchers and speakers from industry, government and academia.

The seminars are available to the public at:
http://techlav.ncat.edu/seminars.html

Sustaining the Center Activities

- **Developed 19 collaborative proposals totaling over $27 M, and secured over $19 M in funding**
- **Continuation of TECHLAV award for 2020-2025 –** To sustain the effort and maintain the created infrastructure and student pipeline for larger government and industry funding. (discussion ongoing)
- Secured funding from DoD/other government agencies and industries especially from the TECHLAV mentors and members of the SIAB.
- Began writing collaborative proposals with various academic institutions especially with the members of SIAB.

Acknowledgement

The TECHLAV Center would like to acknowledge the Department of Defense (DoD), the Office of the Secretary of Defense (OSD), and Air Force Research Laboratory (AFRL).

- Department of Defense (DoD)
- Office of the Secretary of Defense (OSD)
- Air Force Research Laboratory (AFRL)

Remark: The views and conclusions being discussed here are those of the presenters and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of Air Force Research Laboratory, OSD, or the U.S. Government.

Acknowledgement

- The N.C. A&T, UTSA, and SIPI leadership, faculty, staff, and students for their continued support, effort and contributions.

Thank you!