



**The 26<sup>th</sup> Annual Intelligent  
Ground Vehicle Competition  
(IGVC)  
&  
Self-Drive  
(formerly Spec 2)**

**June 1<sup>st</sup> – 4<sup>th</sup>, 2018  
Oakland University  
Rochester, Michigan**

*In memory of Paul Lescoe*

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# I. COMPETITION INFORMATION

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## I.1 TEAM ENTRIES

Teams may be comprised of undergraduate and graduate students, and must be supervised by at least one faculty advisor. Interdisciplinary (Electrical, computer, mechanical, systems engineering, etc.) teams are encouraged. Students must staff each team. Only the student component of each team will be eligible for the awards. Faculty supervisor will certify that all team members are bonafide students on application form and will also provide contact information (telephone number and e-mail address) for him and the student team leader on the form. Business/Non-Engineering students are encouraged to join teams to promote marketing, sponsorships, and other program management functions. For a student to be eligible to compete as a team member, they are required to have attended at least one semester of school as a registered student between June 2017 and June 2018.

Team sponsors are encouraged. Sponsors' participation will be limited to hardware donation and/or funding support. Sponsors logos may be placed on the vehicle and may be displayed inside of the team maintenance area. Teams should encourage sponsor attendance at the IGVC.

Schools are encouraged to have more than one entry; but are limited to a maximum of three per school, and each vehicle must have a separate team of students and a design report in a defined format. See design rules for format. Each entry must be based on a different chassis and software and must be documented by a separate application form and design report, submitted in accordance with all deadlines. All entries must have a team name and each application form must be **TYPED** and accompanied with a \$300.00 non-refundable registration fee made payable to *Oakland University*. Intention to compete must be received no later than **February 28, 2018**, by mailing your application form to:

**Prof Ka C Cheok**  
446 EC SECS-ECE Dept.  
Oakland University  
Rochester, MI 48309-4478

Also PDF version of the registration must be e-mailed along with any questions to [IGVCquestions@yahoo.com](mailto:IGVCquestions@yahoo.com).

For 2018 IGVC will include Spec 2 Challenge employing street legal FMVSS-500 vehicle with automotive quality driving sensors See Section VI for Demonstration event details.

### International Teams Note

International (non-United States Teams) requiring Visa invitation letters must limit team participation to a maximum of twelve students and two faculty. Changes and additions to original submission entry are not permitted after March 30<sup>th</sup>, 2018.

## I.2 VEHICLE CONFIGURATION

The competition is designed for a small semi-rugged outdoor vehicle. Vehicle chassis can be fabricated from scratch or commercially bought. Entries must conform to the following specifications:

- **Design:** Must be a ground vehicle (propelled by direct mechanical contact to the ground such as wheels, tracks, pods, etc. or hovercraft).
- **Length:** Minimum length three feet, maximum length seven feet.
- **Width:** Minimum width two feet, maximum width four feet.
- **Height:** Not to exceed 6 six feet (excluding emergency stop antenna).
- **Propulsion:** Vehicle power must be generated onboard. Fuel storage or running of internal combustion engines and fuel cells are not permitted in the team maintenance area

(tent/building).

- **Average Speed:** Speed will be checked at the end of a challenge run to make sure the average speed of the competing vehicle is above one (1) mph over the course completed. Vehicle slower than the minimum average speed will be disqualified for the run.
- **Minimum Speed:** There will be a stretch of about 44 ft. long at the beginning of a run where the contending vehicle must consistently travel above 1 mph. A vehicle slower than this speed is considered to “hold-up traffic” and will be disqualified.
- **Maximum Speed:** A maximum vehicle speed of five miles per hour (5 mph) will be enforced. All vehicles must be hardware governed not to exceed this maximum speed. No changes to maximum speed control hardware are allowed after the vehicle passes Qualification.
- **Mechanical E-stop location:** The E-stop button must be a push to stop, red in color and a minimum of one inch in diameter. It must be easy to identify and activate safely, even if the vehicle is moving. It must be located in the center rear of vehicle at least two feet from ground, not to exceed four feet above ground. Vehicle E-stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop.
- **Wireless E-Stop:** The wireless E-Stop must be effective for a minimum of 100 feet. Vehicle E-stops must be hardware based and not controlled through software. Activating the E-Stop must bring the vehicle to a quick and complete stop. During the competition performance events (Autonomous Challenge and Navigation Challenge) the wireless E-stop will be held by the Judges.
- **Safety Light:** The vehicle must have an easily viewed solid indicator light which is turned on whenever the vehicle power is turned on. The light must go from solid to flashing whenever the vehicle is in autonomous mode. As soon as the vehicle comes out of autonomous mode the light must go back to solid.
- **Payload:** Each vehicle will be required to carry a 20-pound payload. The shape and size is approximately that of an 18" x 8" x 8" cinder block. Refer to section I.3 Payload.

### I.3 PAYLOAD

The payload must be securely mounted on the vehicle. If the payload falls off the vehicle during a run, the run will be terminated. The payload specifications are as follows: 18 inches long, 8 inches wide, 8 inches high and a weight of 20 pounds.

### I.4 QUALIFICATION

All vehicles must pass Qualification to receive standard award money in the Design Competition and compete in the Auto Nav performance events. To complete Qualification the vehicle must pass/perform all of the following criteria.

- **Length:** The vehicle will be measured to ensure that it is over the minimum of three feet long and under the maximum of seven feet long.
- **Width:** The vehicle will be measured to ensure that it is over the minimum of two feet wide and under the maximum of four feet wide.
- **Height:** The vehicle will be measured to ensure that it does not to exceed six feet high; this excludes emergency stop antennas.
- **Mechanical E-stop:** The mechanical E-stop will be checked for location to ensure it is located on the center rear of vehicle a minimum of two feet high and a maximum of four feet high and for functionality.
- **Wireless E-Stop:** The wireless E-Stop will be checked to ensure that it is effective for a minimum of 100 feet. During the performance events the wireless E-stop will be held by the Judges.
- **Safety Light:** The safety light will be checked to ensure that when the vehicle is powered up the light is on and solid. When the vehicle is running in autonomous mode, the light goes from solid

to flashing, then from flashing to solid when the vehicle comes out of autonomous mode.

- **Speed:** The vehicle will have to drive over a prescribed distance where its minimum and maximum speeds will be determined. The vehicle must not drop below **the minimum of one mile per hour and not exceed the maximum speed of five miles per hour**. Minimum speed of one mph will be assessed in the fully autonomous mode and verified over a 44 foot distance between the lanes and avoiding obstacles. No change to maximum speed control hardware is allowed after qualification. If the vehicle completes a performance event at a speed faster than the one it passed Qualification at, that run will not be counted.
- **Lane Following:** The vehicle must demonstrate that it can detect and follow lanes.
- **Obstacle Avoidance:** The vehicle must demonstrate that it can detect and avoid obstacles.
- **Waypoint Navigation:** Vehicle must prove it can find a path to a single two meter navigation waypoint by navigating around an obstacle.

During the Qualification the vehicle must be put in autonomous mode to verify the mechanical and wireless E -stops and to verify minimum speed, lane following, obstacle avoidance and waypoint navigation. The vehicle software cannot be reconfigured for waypoint navigation qualification. It must be integrated into the original autonomous software. For the max speed run the vehicle may be in autonomous mode or joystick/remote controlled. Judges will not qualify vehicles that fail to meet these requirements. Teams may fine tune their vehicles and resubmit for Qualification. There is no penalty for not qualifying the first time. Vehicles that are judged to be unsafe will not be allowed to compete. In the event of any conflict, the judges' decision will be final.

## I.5 INDEMNIFICATION AND INSURANCE

Teams will be required to submit an Application Form prior to **February 28, 2018**. The Application Form can be downloaded from [www.igvc.org](http://www.igvc.org).

Each Team's sponsoring institution will also be required to submit a Certificate of Insurance at the time the Application Form is submitted. The certificate is to show commercial general liability coverage in an amount not less than \$1 million.

In addition, each individual participating at the competition will be required to sign a Waiver of Claims when they arrive at site and before they can participate in the IGVC events.

***NOTE:*** *The IGVC Committee and Officials will try to adhere to the above official competition details, rules and format as much as possible. However, it reserves the right to change or modify the competition where deemed necessary for preserving fairness of the competition. Modifications, if any, will be announced prior to the competition as early as possible.*

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## II AUTO-NAV CHALLENGE COMPETITION

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***All teams must pass Qualification to participate in this event.***

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### II.1 OBJECTIVE

A fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while maintaining a minimum of speed of one mph over a section and a maximum speed limit of five mph, remaining within the lane, and avoiding the obstacles on the course.

Judges will rank the entries that complete the course based on shortest adjusted time taken. In the event that a vehicle does not finish the course, the judges will rank the entry based on longest adjusted distance traveled. Adjusted time and distance are the net scores given by judges after taking penalties, incurred from obstacle collisions and boundary crossings, into consideration.

### II.2 VEHICLE CONTROL

Vehicles must be unmanned and autonomous. They must compete based on their ability to perceive the course environment and avoid obstacles. Vehicles cannot be remotely controlled by a human operator during competition. All computational power, sensing and control equipment must be carried on board the vehicle. No base stations allowed for positioning accuracy is allowed. Teams are encouraged to map the course and use that information to improve their performance on the course.

### II.3 Auto-Nav COURSE

The Auto-Nav Challenge is laid out on a grassy area. The Course will be approximately 600 feet long in an area 100ft wide and 200 feet deep. This distance is identified so teams can set their maximum speed to complete the course pending no prior violations resulting in run termination. Track width will vary from ten to twenty feet wide with a turning radius not less than five feet.

Outer boundaries will be designated by continuous or dashed white lines approximately three inches wide, painted on the grass. Track width will be approximately ten feet wide. Alternating side-to-side dashes will be 15-20 feet long, with 10- 15 feet separation. A minimum speed will be required of one mph and will be a requirement of Qualification and verified in each run of the Auto-Nav Challenge. If the vehicle does not average one mph for the first 44 feet (30 seconds) from the starting line, the vehicle run will be ended. The vehicle will then need to average over one mph for the entire run.

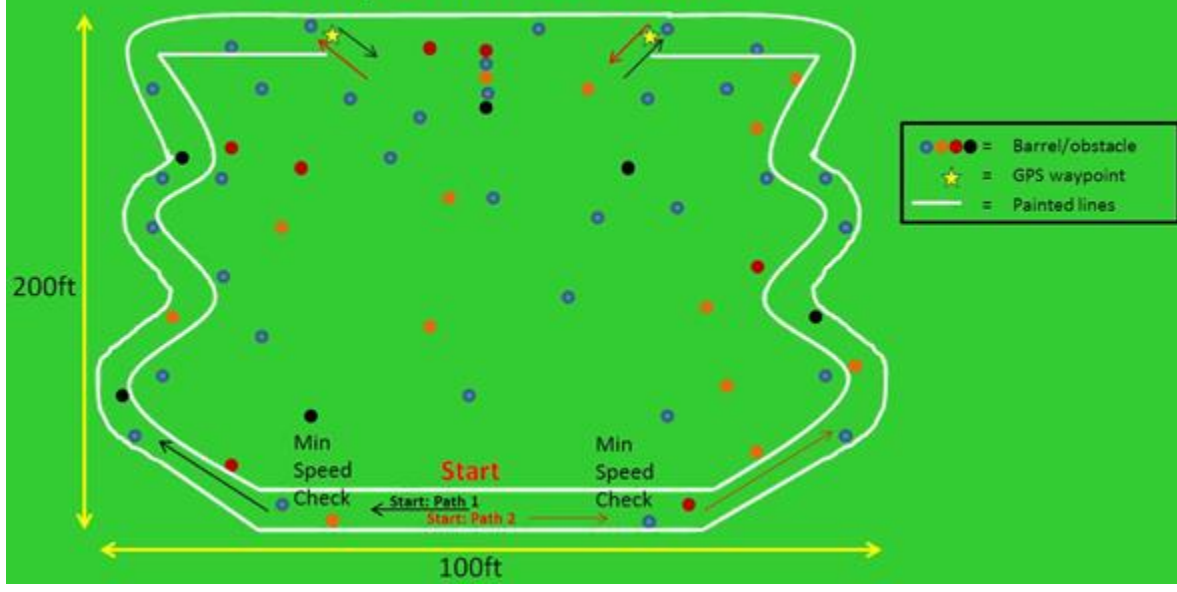
Competitors should expect natural or artificial inclines (ramps) with gradients not to exceed 15% and randomly placed obstacles along the course. The course will become more difficult to navigate autonomously as vehicle progresses. Obstacles on the course will consist of various colors (white, orange, brown, green, black, etc.) of construction barrels/drums that are used on roadways and highways. Natural obstacles such as trees or shrubs and manmade obstacles such as light posts or street signs could also appear on the course. The placement of the obstacles may be randomized from left, right, and center placements prior to every run. **Simulated potholes of 2 foot diameter solid white circles may be inserted. These simulated pot must be avoided or an end of run will occur.**

There will be a minimum of five feet clearance, minimum passage width, between the line and the obstacles; i.e., if the obstacle is in the middle of the course then on either side of the obstacle will be **five** feet of driving space. Or if the obstacle is closer to one side of the lane then the other side of the obstacle must have at least five feet of driving space for the vehicles.

The Course will be primarily sinusoidal curves with series of repetitive barrel obstacles. Two waypoint pairs for the course will be provided prior to competition. One waypoint pair will be the entrance and exit of the course in No Man's Land. There will be two additional waypoints in No-Man's Land.

Six (6) minutes will be allowed for course negotiation.

# Example Auto-Nav Course





## II.4 COMPETITION RULES & PROCEDURES

- The competition will take place in the event of light rain or drizzle but not in heavy rain or lightning.
- Each qualified team will have up to two runs (time permitting) in each of three heats.
- Starting order will be based on order of qualification. Teams will setup on-deck in that order. Failure to be on-deck will place you at the end of the order for the run and may forfeit you final (second) run in a heat based on heat time completion.
- No team participant is allowed on the course before the team's first run, and only one student team member is allowed on the course during a run. This shall in no case be the faculty advisor.
- At the designated on-deck time, the competing team will be asked to prepare their vehicle for an attempt. On-deck teams start in the order they arrive in the starting area unless they give way to another team.
- A Starting Official will call teams to the starting line. The Starting Official's direction is final. The Starting Officials may alter the order to enhance the competition flow of entries; e.g. slower vehicles may be grouped together to allow successive running of two vehicles on the course simultaneously.
- A team will have one minute in the starting point to prep the vehicle at the starting line and point out to the Competition Judges the buttons to start and stop the vehicle,
- The Competition Judge will start the vehicle by a one touch motion; i.e. pushing a remote control button, hitting the enter key of a keyboard, a left mouse click, lifting the e-stop up, flipping a toggle switch, etc. The Competition Judge will also carry the E-Stop.
- An attempt will be declared valid when the Competition Judge initiates the start signal at the designated competing time. An attempt will continue until one of the following occurs:
  - The vehicle finishes the course.
  - The vehicle was E-Stopped by a judge's call.
  - The team E-Stops the vehicle.
  - Six minutes have passed after the vehicle run has started for the Auto-Nav Course.
  - The vehicle has not started after one minute after moving to the start line or at the judges' discretion.
  - Time for each heat will be strictly observed.
  - Tactile sensors will not be allowed.
- Based on the above allowable run times, if the vehicle has not completed the course in the 10 minute time period, the attempt will be ended by a judge's choice E-stop, with no additional penalty for that run.
- Each vehicle must navigate the course by remaining inside the course boundaries and navigating around course obstacles. Crossing internal lines is not allowed and will be judged an E-Stop end of run with penalty. For the following Traffic Violations, the appropriate ticket will be issued and deducted from the overall distance or time score. Refer to section II.5 Traffic Violation Laws.

## II.5 TRAFFIC VIOLATION LAWS

	Traffic Violations	Ticket Value	E-Stop	Measurement
1	Hold-up Traffic	End of Run	Yes	>60 secs. to 88 ft
2	Leave the Course/Scene	- 10 Feet	Yes	Yes
3	Crash/Obstacle Displacement	- 10 Feet	Yes	Yes
4	Careless Driving	- 5 Feet	No	No
5	Sideswipe/Obstacle Touch	- 5 Feet	No	No
6	Student's Choice E-Stop	- 10 Feet	Yes	Yes
7	Judge's Choice E-Stop	0 Feet	Yes	Yes
8	Blocking Traffic	- 5 Feet	Yes	Yes
9	Loss of Payload	0 Feet	Yes	Yes
10	Too slow, did not average 1 mph	Disqualified	No	No

- **Hold-up traffic:** Must maintain 1 mph, there will be a speed check at 44/88 foot mark of the course, will result in end of run with time recorded
- **Leave the scene\course:** All portions of the vehicle cross the boundary. The overall distance will be measured from the starting line to the furthest point where the final part of the vehicle crossed the boundary edge.
- **Crash:** The overall distance will be measured from the starting line to the collision point with the obstacle.
- **Careless Driving:** Crossing the boundary while at least some part of the vehicle remains in bounds.
- **Student E-Stop:** Student e-stop is used if the team feels that there may be damaged caused to their vehicle or they know that it is stuck and want to end their time.
- **Judge E-Stop:** The overall distance will be measured from the starting line to the front of the vehicle or where the final/furthest remaining part of vehicle if stopped, crossed the boundary outside edge.
- **Obstacle Displacement:** Defined as displacing permanently the obstacle from its original position. Slightly rocking/Tilting an obstacle with no permanent displacement is not considered obstacle displacement. An obstacle that rocks or tilts significantly but with no displacement will still be considered a end of run. Judges calls are final.
- **Blocking Traffic:** Vehicles stopping on course for over one minute will be E-Stopped and measured.
- **Loss of Payload:** If the payload falls of the vehicle the run will be ended.
- **Too Slow:** If the vehicle does not maintain 1 mph minimum average speed limit throughout the course this run is disqualified.

## **II.6 HOW COMPETITION WILL BE JUDGED**

- A team of judges and officials will determine compliance with all rules.
- Designated competition judges will determine the official times, distances and ticket deductions of each entry. At the end of the competition, those vehicles crossing the finish line will be scored on the time taken to complete the course minus any ticket deductions. Ticket values will be assessed in seconds (one foot = one second) if the vehicle completes the course within the run time.
- The team with the adjusted shortest time will be declared the winner.
- In the event that no vehicle completes the course, the score will be based on the distance traveled by the vehicle minus the ticket deductions. The team with the adjusted longest distance will be declared the winner.
- For standard award money consideration, entry must exhibit sufficient degree of autonomous mobility by completing the Auto-Nav course. If a tie is declared between entries, the award money will be split between them.
- If your vehicle is overtaken by a faster vehicle you will be commanded to stop and your time will be recorded and allowed to be restarted with remaining time after the faster vehicle passes. Total distance will be assessed at the 10 minute mark.

## **II.7 GROUNDS FOR DISQUALIFICATION**

- Judges will disqualify any vehicle which appears to be a safety hazard or violate the safety requirements during the competition.
  - Intentional interference with another competitor's vehicle and/or data link will result in disqualification of the offending contestant's entry.
  - Damaging the course or deliberate movement of the obstacles or running over the obstacles may result in disqualification.
  - Actions designed to damage or destroy an opponent's vehicle are not in the spirit of the competition and will result in disqualification of the offending contestant's entry.
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### III. DESIGN COMPETITION

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**All teams must participate in the Design Competition and submit design report in mandatory format.**

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#### III.1 OBJECTIVE

Although the ability of the vehicles to negotiate the competition courses is the ultimate measure of product quality, the officials are also interested in the design strategy and process that engineering teams follow to produce their vehicles. Design judging will be by a panel of expert judges and will be conducted separate from and without regard to vehicle performance on the test course. Judging will be based on a written report, an oral presentation and examination of the vehicle.

Design innovation is a primary objective of this competition and will be given special attention by the judges. Innovation is considered to be a technology (hardware or software) that has not ever been used by this or any other vehicle in this competition. The innovation needs to be documented, as an innovation, clearly in the written report and emphasized in the oral presentation.

#### III.2 WRITTEN REPORT

The IGVC report (15 page maximum) shall follow a modified version of the American Astronautical Society (AAS) paper format that is used by the Association for Unmanned Vehicle Systems International (AUVSI). **The report must follow the outlined format provided in section III.6 (DESIGN REPORT FORMAT – MANDATORY) located at the end of this Written Report section.** Each vehicle must have a complete report in defined format below of its own (a report cannot cover more than one vehicle). All reports, both for new vehicles and for earlier vehicles with design changes, must include a statement signed by the faculty advisor certifying that the design and engineering of the vehicle (original or changes) by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

Participants are required to submit an electronic copy in PDF format along with a scanned copy of the statement in PDF format by **May 15, 2018**. Everything must be e-mailed along with any questions to [IGVCquestions@yahoo.com](mailto:IGVCquestions@yahoo.com). Reports arriving after that date will lose 10 points in scoring for each day late, statements arriving after that date will lose 5 points in scoring for each day late. Teams are encouraged to submit reports even several weeks early to avoid the last minute rush of preparing vehicles for the competition, and there will be no penalty for last minute changes in the vehicle from the design reported. The electronic copy of the report will be posted on the competition's web site in PDF format after the completion of the competition.

The paper should present the conceptual design of the vehicle and its components. Especially important to highlight are any unique innovative aspects of the design and the intelligence aspects of the vehicle. Also included must be descriptions of:

Electronics	Design Planning Process
electrical system	signal processing
actuators	plan for path following (both solid & dashed lines)
software strategy	failure point & mode
sensors	plan for control decisions
computers	system integration plan
mapping	high speed operations

Design of the lane following and obstacle detection/avoidance systems must be specifically described. Along with how the vehicle uses mapping techniques to perceive and navigate through its environment. Describe how the system uses GPS for waypoint navigation and localization.

Components acquired ready-made must be identified, but their internal components need not be described in detail. The steps followed during the design process should be described along with any use of Computer-Aided Design (CAD). How considerations of safety, reliability, and durability were addressed in the design process should be specifically described, as well as problems encountered in the design process and how they were overcome. Identification of Failure Points and Modes of hardware is required. Furthermore, description of how failure points are addressed and resolved if they should occur during the days of the competition. The analysis leading to the predicted performance of the vehicle should be documented, specifically:

- Speed
- Ramp climbing ability
- Reaction times
- Battery life
- Distance at which obstacles are detected
- How the vehicle deals with complex obstacles including switchbacks and center islands dead ends, traps, and potholes)
- How the team identifies and addresses vehicle failure points and modes (Not an FMEA)
- Accuracy of arrival at navigation waypoints
- Comparison of these predictions with actual trial data is desirable.

Although cost itself is not a factor in judging (these are considered research vehicles), the report should include a cost estimate (not counting student labor) for the final product if it were to be duplicated. A breakdown of the cost by component is helpful.

The team organization and the names of all members of the design team, with academic department and class, should be included along with an estimate of the project's total number of person-hours expended.

Vehicles that have been entered in IGVC in earlier years and have not had significant changes in design are ineligible in either the design or performance events. Vehicles that have been changed significantly in design (hardware or software) from an earlier year are eligible, but will require a completely new design report treating both the old and new features, thus describing the complete vehicle as if it were all new.

<b>Judges will score the written reports as follows:</b>	<b>Maximum Points</b>
<b>1.</b> Conduct of the design process and team organization (including decision-making & software development)	50
<b>2.</b> Failure points identification and resolution methods to be used if this failure occurs. (Not an FMEA)	100
<b>3.</b> Quality of documentation (English, grammar, completeness, and style)	50
<b>4.</b> Effective innovation represented in the design (as described above)	150
<b>5.</b> Description of mapping technique	100
<b>6.</b> Description of mechanical design	100
<b>7.</b> Description of electronic design	100
<b>8.</b> Description of software strategy	150
<b>9.</b> Description of systems integration <u>Descriptions to include:</u> lane following, obstacle detection/avoidance, and waypoint navigation (GPS or other)	150
<b>10.</b> Efficient use of power and materials	50
<b>11.</b> Attention given to safety, reliability, and durability and failure modes	50
<b>Total</b>	<b>1050</b>

### III.3 ORAL PRESENTATION

The technical talk should relate the highlights of the written report described above and include any updates of the design since the written report. Audio or video tape presentations of the text are not allowed, but graphic aids may be presented by video, slide projection, computer projection, overhead transparencies, or easel charts. The presentation must be made by one or more student members of the team to the judges and other interested members of the audience and should last not more than 10 minutes. A penalty of 5 points will be assessed for each minute or fraction thereof over 11 minutes. After the presentation, judges only may ask questions for up to 5 minutes. The audience should be considered as a senior management group of generally knowledgeable engineers upon whom the project is dependent for funding and the team is dependent for their employment. Scoring will be as follows:

<b>Judges will score the oral presentations as follows:</b>	<b>Maximum Points</b>
1. Clear, well planned and understandable explanation of the innovations	50
2. Logical organization and subject knowledge of the talk	50
3. Effective use of graphic aids	30
4. Articulation and eye contact during presentation	40
5. Demonstrated simulation of vehicle control in performance events	10
6. Response to questions	10
7. Salesmanship	10
<b>Total</b>	<b>200</b>

Effective use of graphic aids includes not blocking the view of the screen by the presenter and simple enough graphics that are large enough to read (block diagrams rather than detailed circuit diagrams). Articulation refers to the clarity and loudness of speaking. Eye contact refers to speaking to the audience and judges (not reading notes or screen or looking above audience heads). Response to questions means short answers that address only the question. Salesmanship refers to the enthusiasm and pride exhibited (why this vehicle is the best).

Participants are responsible for providing their own visual aids and related equipment (the vehicle itself may be displayed). A computer-connected projector will be made available. Projectors may also be supplied by the participants.

During the oral presentation, the following question period and the examination of the vehicle, team members sitting the audience may participate by assisting the oral presenters, but at no time is the faculty advisor to participate in this part of the design competition.

### III.4 EXAMINATION OF THE VEHICLE

The vehicle must be present and will be examined by the judges preferably immediately after the oral presentation or at another convenient time the time during the competition. Software is not included in this judging. Judging will be as follows:

<b>Judges will score the vehicle examinations as follows:</b>	<b>Maximum Points</b>
1. Packaging neatness, efficient use of space	20
2. Serviceability	20
3. Ruggedness	20
4. Safety	20
5. Degree of original content in the vehicle (as opposed to ready-made)	50
6. Style (overall appearance)	20
<b>Total</b>	<b>150</b>

### III.5 FINAL SCORING

The number of points awarded by the individual judges will be averaged for each of the 23 judging areas above, and these results will be offered to each participating team for their edification. The total of the average scores over all 23 areas (max 1300) will be used to determine the ranking.

When two (or three) teams of judges are used (due to a large number of entries) each judging team will determine the top three (or two) winners in their group, and the resulting six contestants will participate in a runoff of oral presentations and vehicle examinations judged by all judges to determine an overall Design Winner. The six teams will be judged in random order.

For the Finals competition four criteria from the written report judging will be added to the normal oral presentation scoring shown above for preliminary judging. Thus, the Finals Oral presentation scoring will have maximum points as below:

<b>Judges will score the final presentations as follows:</b>	<b>Maximum Points</b>
1. Clear explanation of the innovations	50
2. Description of mapping technique	30
3. Description of Electronic Design	30
4. Description of Software Strategy	30
5. Description of System Integration	30
6. Logical organization of the talk	50
7. Effective use of graphic aids	25
8. Articulation	25
9. Demonstrated Simulation of Vehicle Control	10
10. Response to questions	10
11. Salesmanship	10
<b>Total</b>	<b>300</b>

The vehicle examination scoring will be the same as in the preliminary judging, as shown above.

### III.6 DESIGN REPORT FORMAT - MANDATORY

1. Title Page
  - University/College Name
  - Vehicle/Team Name
  - Vehicle Photo/Sketch/Symbol
  - Date Submitted
  - Team Captain's Name and E-Mail
  - Team Members Names and E-Mails
  - Faculty Advisors Name and Statement of Integrity
2. Conduct of design process, team identification and team organization
  - Introduction
  - Organization
  - Design assumptions and design process
3. Effective innovations in your vehicle design
  - Innovative concept(s) from other vehicles designed into your vehicle
  - Innovative technology applied to your vehicle
4. Description of mechanical design

- Overview
  - Decision on frame structure, housing, structure design
  - Suspension
  - Weather proofing
5. Description of electronic and power design
- Overview
  - Power distribution system (capacity, max. run time, recharge rate, additional innovative concepts)
  - Electronics suite description including CPU and sensors system integration/feedback concepts
  - Safety devices and their integration into your system
6. Description of software strategy and mapping techniques
- Overview
  - Obstacle detection and avoidance
  - Software strategy and path planning
  - Map generation
  - Goal selection and path generation
  - Additional creative concepts
7. Description of failure modes, failure points and resolutions
- Vehicle failure modes (software, mapping, etc) and resolutions
  - Vehicle failure points (electronic, electrical, mechanical, structural, etc) and resolutions
  - All failure prevention strategy
  - Testing (mechanical, electronic, simulations, in lab, real world, etc.)
  - Vehicle safety design concepts
8. Simulations employed
- Simulations in virtual environment
  - Theoretical concepts in simulations
9. Performance Testing to Date
- Component testing, system and subsystem testing, etc.
10. Initial Performance Assessments
- How is your vehicle performing to date
-



## IV. INTEROPERABILITY PROFILES CHALLENGE

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***Participation in the IOP Challenge is recommended. IOP participation must be with the IGVC robot vehicle.***

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### IV.1 TECHNICAL OVERVIEW

The Interoperability Profiles (IOPs) have been developed by the Robotic Systems Joint Project Office (RSJPO) to help facilitate interoperability between controller, robotic platforms, and payloads. There are four IOPs defined that help facilitate this interoperability – the Overarching IOP, the Communications IOP, the Payloads IOP, and the Controls IOP. These IOPs cover overarching platform requirements, communications requirements, payloads requirements, and controller (i.e. Operator Control Unit) requirements, respectively. These documents are formed using something called IOP attributes, which defines a specific way that a certain function needs to be achieved, usually in terms of interfaces. For example, Overarching Profile defines a Mobility attribute that specifies different types of mobility like Teleoperation or waypoint following, and those attributes specify the requirements for interfacing with those capabilities. The four IOPs listed above are supported by two additional IOP documents – the JAUS Profiling Rules IOP, and a Custom Services, Messages, and Transports document. These two additional documents profile the SAE Joint Architecture for Unmanned Systems (JAUS) and define how JAUS services, messages, and transports are used to implement IOP compliant interfaces.

This challenge focuses on successful implementation of a number of IOP attributes, primarily from the JAUS Profiling Rules document. Each entry will interface with the Judges Testing Client (JTC) as specified in the sections that follow. The JTC will be running testing software called the Conformance Verification Tool (CVT), which evaluates JAUS services interfaces, and will also be running Common Operating Picture (COP) software that will display information coming from the entrant's platform while it is executing the tasks defined by the Interoperability Profiles Challenge. There will be two parts to this challenge – a test of JAUS interfaces using the CVT, and a local waypoint navigation challenge that will be monitored by the COP.

### IV.2 CONFORMANCE VERIFICATION TOOL

The Conformance Verification Tool (CVT) is a piece of software that runs on the Judges Test Client (JTC). The purpose of the CVT is to test the JAUS interfaces provided by the entrant's system. The CVT will execute tests based on IOP attribute definitions, and will primarily send messages from the input message set of the required JAUS services and will look for appropriate responses or changes in state. The CVT is the primary tool used to evaluate an entrant's system, and will be supported through the review of Wireshark logs.

### IV.3 COMMON OPERATING PICTURE

The Common Operating Picture (COP) will provide a high level view of the systems in operation that successfully implement the JAUS protocol as profiled by the IOPs. This software is a simple reporting and recording tool for the Judges to use while the entrant's system performs the tasks required for this challenge. It will provide information such as the reported pose, location, and speed of the entrant's system.

### IV.4 COMMUNICATIONS PROTOCOLS

The teams will implement a wireless 802.11 b/g or hardwired Ethernet data link. The interface can be implemented at any point in the student team's system including the control station or mobility platform.

The Internet Protocol (IP) address to be used will be provided at competition. For planning purposes, this address will be in range of 192.168.1.100 to 192.168.1.200. The JTC will have both hard-wire and 802.11 b/g capabilities. The IP address of the JTC will nominally be 192.168.1.42, but can be changed in case of IP address conflicts. All teams will be provided an IP address to be used during the competition. The last

octet of the IP address is significant, as it will also be used as the subsystem identifier in the team's JAUS ID. The JTC and the team's robot will be on the same flat network (i.e. there shall be no router. The port number for all JAUS traffic shall be 3794.

## IV.5 REQUIREMENTS – IOP ATTRIBUTTES

### 1.5.1 Overarching Requirements

Overarching requirements define the high level requirements for the entrant system. These requirements will not directly be scored, but reference attributes within the other IOP documents.

IOP Attribute	Value	Description	Comments / Parameters
<b>Platform Databus</b>	None	No platform databus is mandated.	There will be bonus points awarded for providing an Ethernet connector.
<b>Transport</b>	UDP	The entrant's shall use JAUS communications over the UDP protocol.	All UDP traffic shall be on the JAUS port, 3794.
<b>Mobility</b>	Basic Navigation	This attribute value specifies that the entrant's system shall provide an interface for doing waypoint navigation.	Local waypoint navigation shall be used.
<b>Mobility</b>	Teleoperation	This attribute value specifies that the entrant's system shall provide an interface for remote control of the system.	

### 1.5.2 Payloads Requirements

There are currently no payloads requirements.

### 1.5.3 Communications Requirements

There are currently no communications requirements.

### 1.5.4 JAUS Profiling Rules Requirements

The attributes required from the SAE JAUS Profiling Rules IOP will in most cases define JAUS services that must be implemented by the entrant's system. JAUS services define a message interface and a state protocol that must be followed.

#### 1.5.4.1 Core Interoperability Attributes

These attributes are from the Core Interoperability Attribute group.

IOP Attribute	Value	Description
<b>Core Requirements</b>	Default	Specifies core services that must always be implemented for any JAUS component. Mandated JAUS Interoperability Attribute Options are Core::Core Services, Core::Access Control, and Core::Liveness. The following parameter values will be used: Access Control Timeout = 0 (no timeout)
<b>Subsystem ID Assignment</b>	Static	Specifies a static JAUS subsystem ID will be assigned.
<b>Node ID Assignment</b>	Static	Specifies that a static JAUS node ID will be assigned.
<b>Transport</b>	JUDP	Specifies that the JAUS over UDP transport protocol will be used, as specified in AS5669A.

#### 1.5.4.2 Platform Management Attributes

These attribute are from the Platform Interoperability Attribute Group.

IOP Attribute	Value	Description
<b>Platform Management***</b>	Basic	Defines platform management services such as Discovery, Liveness, PlatformMode, HealthMonitor, and

PlatformState.

\*\*\* The HealthMonitor, PlatformMode, and PlatformState services will not be tested and are not required to be implemented for this challenge.

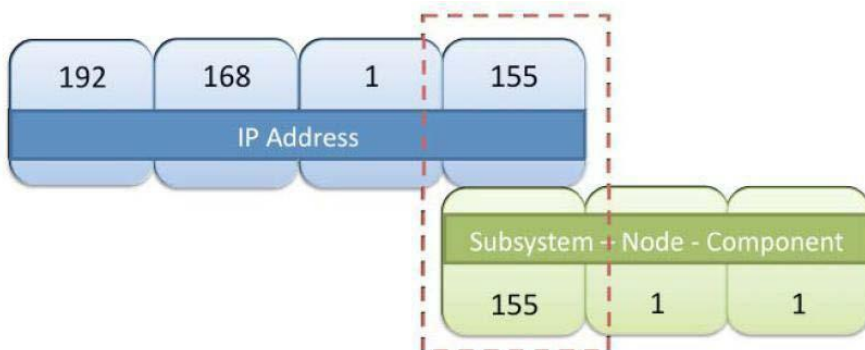
### 1.5.4.3 Entrant Navigation and Reporting Capabilities

This capability attribute and added options describes the navigation and reporting capabilities that the entrant must provide.

IOP Attribute	Value	Description
<b>Global::Capability (“Navigation and Reporting”)</b>	Default	The Interoperability Options in the rows below are added to this Capability attribute.
IOP Attribute Option	Value	Description
<b>Autonomy and Behaviors :: Basic Navigation</b>	Local	Requires the use of the Local Waypoint Driver and Local Waypoint List Driver services that provide an interface for setting up and commanding local waypoint navigation.
<b>Global :: Local Position and Attitude</b>	Default	Requires the use of the Local Pose Sensor service that provides an interface for querying the Local Position of the platform, in reference to a local coordinate frame. The default rate of 1 Hz for reporting local pose applies.
<b>Global :: Velocity State Sensor</b>	Default	Requires the use of the Velocity State Sensor service that provides an interface for reporting the velocity (rotational and translational) of the platform. A 10 Hz reporting rate shall be supported.
Remote Control	Default	The Remote Control Interoperability Attribute provides the capability to control a platform via line of sight remote control.

### 1.5.5 Competition Setup

All teams will be assigned a JAUS Subsystem ID based on their assigned IP address. The JAUS Subsystem ID is part of the JAUS ID which consists of three elements: a Subsystem ID, a Node ID, and a Component ID. The Subsystem ID uniquely identifies a major element that is an unmanned system, an unmanned system controller, or some other entity on a network with unmanned systems. A Node ID is unique within a subsystem and identifies a processing element on which JAUS Components can be found. A Component ID is unique within a Node and represents an end point to and from which JAUS messages are sent and received. The last octet of the assigned IP address will be used as the team’s JAUS Subsystem ID. For example, the team assigned the IP address of 192.168.1.155 will use the JAUS Subsystem ID of 155. A team will provide two JAUS Components - a Navigation and Reporting JAUS Component that contains all the services defined by the Navigation and Reporting capability, and platform management JAUS Component specified by the Platform Management attribute basic value. A team may use any valid JAUS Node ID and JAUS Component ID for their Navigation and Reporting Component, and shall use a JAUS Node ID of 1 and a JAUS Component ID of 1 for their platform management component. As an example, the team with JAUS Subsystem ID 155 would use the full Subsystem-Node-Component ID of 155-1-1 for their Platform Management Component (see figure below).



**Figure 1-1: IP and JAUS ID Assignment Example**

The team’s subsystem and the JTC will run on the same communications network as described in the Communications Protocol section. The JTC will be running software tools that will present at least three separate JAUS components. The most important element running on the JTC will be the Conformance Verification Tool (CVT). The CVT will be used to test the IOP interfaces required for this JAUS challenge. It will run a series of automated tests that send a message to a team’s subsystem and look for expected responses. The CVT presents one primary JAUS Component, and creates a second JAUS Component for certain access control tests. The CVT may be at any valid JAUS Node ID and JAUS Component IDs on the JTC Subsystem.

The JTC will also be running the Common Operational Picture (COP) process. This process is a monitoring process that will be used to evaluate the performance requirements of the IOP Challenge. The COP will run in a separate component from the CVT and will send query messages to the team’s Navigation and Reporting Component, as well as create certain periodic events to monitor information from the team’s platform. The COP will display information on platform velocity, position, liveness, and status to the judges, and will be used for evaluation of these elements.

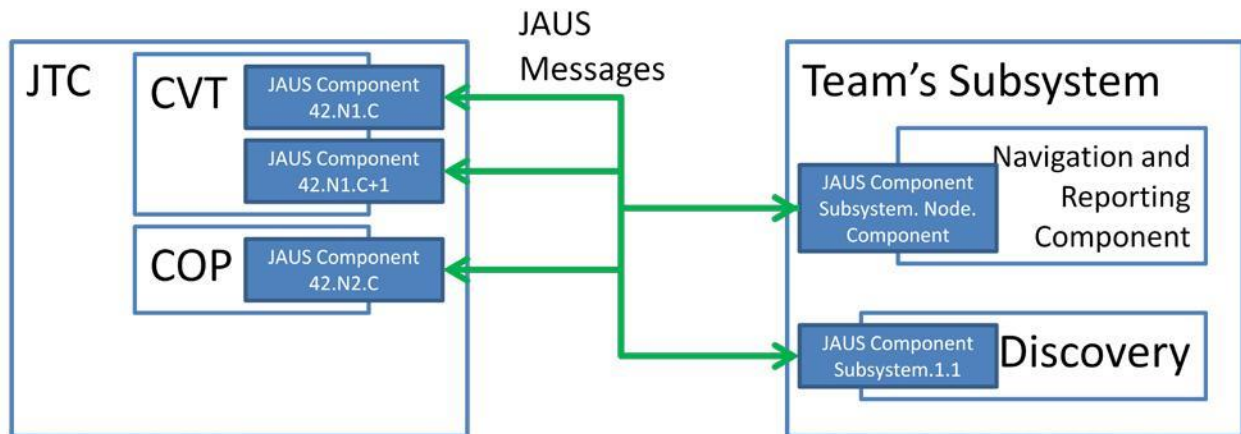


Figure 1-2: JAUS Challenge Setup

In summary, each team will be assigned an IP address by the judges. The last octet of that IOP address will be the team’s subsystem identifier. The Judges Testing Computer (JTC) will be a subsystem as will each team’s entry into the competition. The JTC will run the CVT and the COP. The Team’s Subsystem will run a single Navigation and Reporting JAUS Component and a Platform Management Component (these may be combined into a single component). The JAUS port 3794 shall be used for all JAUS communications.

## IV.6 COMPETITION TASK

### 1.6 Competition Task Description

Messages passed between the JTC and the team entries will include data as described in the task descriptions below. The JTC will initiate all requests subsequent to the discovery process described as Task 1. A single Navigation and Reporting Component is required of all teams. This interface will implement all of the messages for the services defined in the Requirements – IOP Attributes sections, and expanded upon below. All messages from all services implemented will be tested.

The judges will evaluate each team’s ability to meet the IOP Challenge for the tasks described below in accordance with the scoring chart. Note that the tasks specified with “Tie-Breaker” points are only used to break ties.

Task	Maximum Points
<b>Qualification (Network Setup and Transport Discovery)</b>	N/A – Must qualify before proceeding with other tasks.
<b>IOP Interfaces Tasks</b>	
Capabilities Discovery	5
Core Services	5
Events	5
Platform Management	5
Navigation and Reporting	5
<b>IOP Interfaces Tasks SUB-TOTAL:</b>	<b>25</b>
<b>Performance Tasks</b>	
Safe Operation	5
Remote Control	10
Waypoint Navigation	10
Position and Orientation Report	5
Velocity State Report	5
<b>Performance Tasks SUB-TOTAL:</b>	<b>35</b>
<b>All Tasks TOTAL:</b>	<b>75</b>
<b>Tie-Breaker Tasks</b>	
<b>Waypoint Navigation Course Total Run-Time</b>	<b>(6 – rank)* Tie-Breaker Points</b>
<b>Maximum Tie-Breaker Points Possible:</b>	<b>10</b>

\* Ranking is determined by completing all waypoints in the shortest amount of time. The team that finishes in the shortest amount of time gets a rank of 1, and therefore would get  $(6 - 1) = 5$  Tie-Breaker points. Tie-Breaker points for total run time only apply to teams who successfully achieve all waypoints on the course. If more than 5 teams achieve all waypoints, the teams with rank lower than 5 will be awarded 0 tie- breaker points. If after the tie-breaker points are evaluated, there are still teams tied, shortest run-time will be used as the final tie-breaker.

### 1.6.1 Qualification (Network Setup and Transport Discovery)

For any two elements in the system to communicate meaningful data, there must first proper network and communications configuration and a handshake to ensure that both sides use the same protocol and are able to communicate with one another.

The first part of this qualification task is to ensure that the JTC and the team's subsystem can communicate with each other over a flat network. There are up three possible options a team may choose for communications: wired network, judge hosted wireless network, and team hosted wireless network. A team must qualify for every network type that it will use during the IOP Challenge. For example, if a team plans to do only its IOP interfaces tasks on its first run using a wired network, and then plans to do its performance tasks in its next run using a judge hosted wireless network, then it must qualify for both networks.

#### 1.6.1.1 Wired Network

For the Wired Network, the judges will provide a Gigabit Ethernet switch that a team may plug their subsystem into using a standard RJ-45 Ethernet connector. Both the team's subsystem and the JTC will be plugged into the Ethernet switch and assigned their respective static IP addresses.

#### 1.6.1.2 Judge Hosted Wireless Network

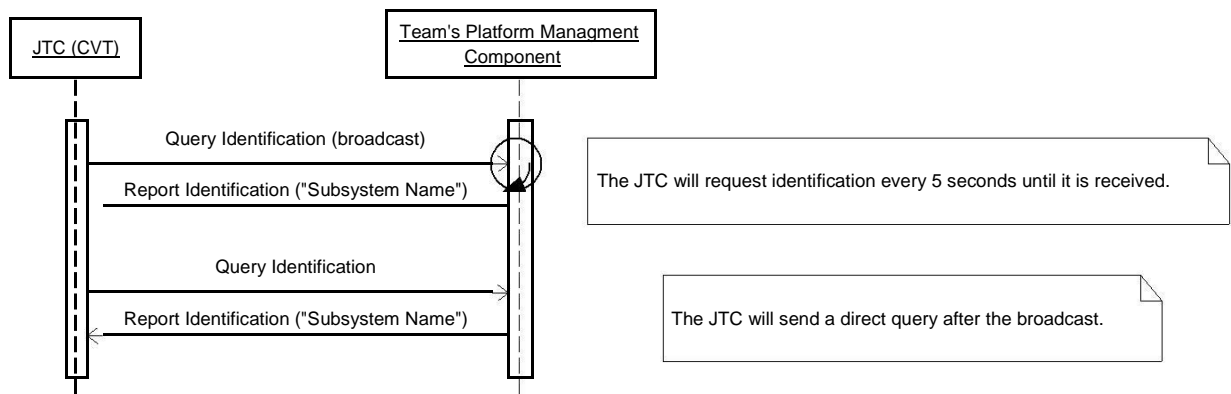
For the Judge Hosted Wireless Network, the judges will a 2.4 GHz b/g wireless router that the JTC will be connected into through a wired connection. The team's subsystem shall connect to the Judge Hosted Wireless Network using information provide to each team. In order to help facilitate secure communications and prevent accidental presence of other teams on the wireless network, the SSID of the wireless network will be unique for each team in the form of "JAUSXXX", where XXX is the three-digit Subsystem ID assigned to the team. Each team will also be given a randomly generated passphrase to use with commercial standard wireless encryption of the network.

### 1.6.1.3 Team Hosted Wireless Network

For the Team Hosted Wireless Network, the judges will connect the JTC to a team’s wireless network using information provided by the team. The default wireless capabilities of the JTC computer will be used, and possibly augmented by an external antenna solution to improve communications. If choosing this option, it is the responsibility of the team to ensure that the judges are properly able to connect the JTC to the team’s network, so use of commercial standard wireless network practices is highly encouraged.

Once the networking portion of qualification is completed, the transport discovery qualification task begins. The discovery process, shown in the figure below, will occur at the application layer. The process begins with the JTC broadcasting a QueryIdentification message using the default multicast address 239.255.0.1. This multicast address shall be used by both the JTC and the team’s Subsystem to implement all JAUS logical broadcast semantics. The JTC will send a QueryIdentification message every 5 seconds until it receives a response from the Team’s Platform Management Component. Once a response is received showing an appropriate subsystem name, the JTC will send a Query Identification directly to the address of the Discovery service to ensure proper direct communications. Once this has happened, the system is qualified on the network type or types chosen and may proceed with the rest of the IOP challenge.

**Note: Other messages may be multicast using 239.255.0.1 – do not assume QueryIdentification is the only message that might be multicast!**



**Figure 1-3: Transport Discovery Process**

### 1.6.2 IOP Interface Tasks

IOP interface tasks involve implementing JAUS services and messages as defined in the SAE JAUS Profiling Rules IOP document. IOP Interface tasks are scored using the Conformance Verification Tool (CVT), which exercises the interfaces of each JAUS service defined for an attribute. The CVT will send out a sequence of messages to the team’s Subsystem, and will look for expected responses within a given amount of time. In general, the messages sent out by the CVT are queries, but there will also be messages sent that cause a change in the state of the platform (note: during interface testing, no messages that should cause movement of a platform will be sent). The results of most CVT tests will be a simple pass/fail based on if an expected message response was received in response to a specific query, but there are some responses where the presence of certain fields or the values of fields will also be evaluated.

One test that will be performed over for multiple tasks is a presence vector test. A presence vector in JAUS is a field (usually 1-4 bytes) that indicates whether a specific field within a message is present (or when sending a query with a presence vector, what fields are requested). For example, with a one-byte presence vector, a value of “1” in the Nth bit indicates the field N of the message is present or



requested. The CVT will be used to test proper use of the presence vector for messages that are required to report certain fields – at least these fields must be supported when requested. Other fields may be supported. When a presence vector is included in a query, the returned fields is determined by a bit-wise or of the requested presence vector and the required presence vector (i.e. the fields that the JAUS component / service must actually report). A team may support fields in addition to the ones required and should report those fields if requested. Some examples using the Query Velocity State and Report Velocity State messages are shown below:

**Table 1-1: Fields in Presence Vector**

Field Number	Field Name
0	Velocity X
1	Velocity Y
2	Velocity Z
3	Velocity RMS
4	Roll Rate
5	Pitch Rate
6	Yaw Rate
7	Rate RMS
8	Time Stamp

**Table 1-2: Correct Response - All fields requested and only the required fields are returned.**

	Presence Vector (unsigned short integer)															Value (Hex)	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14		15
Required Fields	X						X		X								0x0141
Requested Fields	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0xFFFF
Reported Fields	X						X		X								0x0141

**Table 1-3: Incorrect Response – Did not return the timestamp field when requested.**

	Presence Vector (unsigned short integer)															Value (Hex)	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14		15
Required Fields	X						X		X								0x0141
Requested Fields	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	0xFFFF
Reported Fields	X						X										0x0041



**Table 1-4: Correct Response – Returned the required field that was requested.**

	Presence Vector (unsigned short integer)																Value (Hex)
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Required Fields	X						X	X									0x0141
Requested Fields	X	X	X	X													0x000F
Reported Fields	X																0x0001

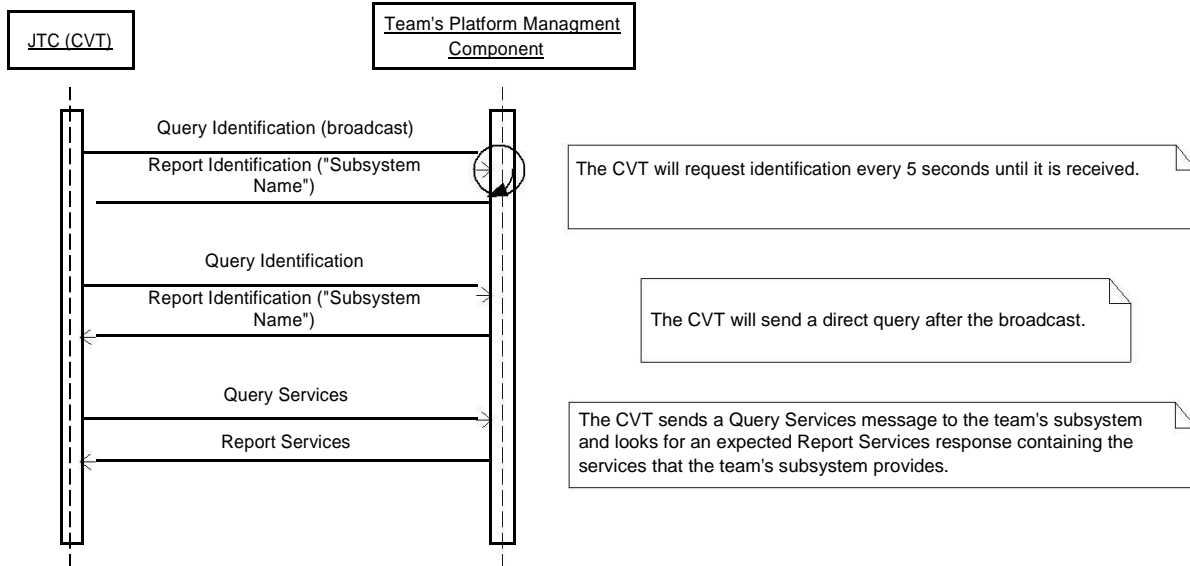
**Table 1-5: Incorrect Response – Returned the Yaw Rate and Timestamp fields when they were not requested.**

	Presence Vector (unsigned short integer)																Value (Hex)
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Required Fields	X					X		X									0x0141
Requested Fields	X	X	X	X													0x000F
Reported Fields	X					X		X									0x0141

The sections that follow describe the individual IOP interface tasks and how they will be tested, including how the task points are assigned.

### 1.6.2.1 Capabilities Discovery Task

For the Capabilities Discovery Task, the CVT will find the team's Discovery Service in the same way done in the Qualification Task and will then send a Query Services message to the team's Discovery Service. This is actually a test that must be performed before any CVT test since the location of services must be known in order to test them. If service discovery is not completed, other tests can still be performed by specifying the location of the other services. The service discovery sequence is done as shown below:



**Figure 1-4: Capabilities Discovery Procedure**

**Note: The CVT may broadcast (using the multicast address 239.255.0.1) the QueryServices message instead of doing discovery using Query Identification.**

The two tables below show the fully qualified service names, including service version, that the CVT will be expecting to find for each JAUS Component provided by the team's subsystem.

**Table 1-6: Platform Management Component Required Services**

Platform Management Component		
Service Name	Fully Qualified Service Name	Service Version
Transport	urn:jaus:jss:core:Transport	1.0
Events	urn:jaus:jss:core:Events	1.0
Access Control	urn:jaus:jss:core:Access Control	1.0
Liveness	urn:jaus:jss:core:Liveness	1.0
Discovery	urn:jaus:jss:core:Discovery	1.0

**Table 1-7: Navigation and Reporting Component Required Services**

Navigation and Reporting Component		
Service Name	Fully Qualified Service Name	Service Version
Transport	urn:jaus:jss:core:Transport	1.0
Events	urn:jaus:jss:core:Events	1.0
Access Control	urn:jaus:jss:core:AccessControl	1.0
Management	urn:jaus:jss:core:Management	1.0
Liveness	urn:jaus:jss:core:Liveness	1.0
Waypoint Driver	urn:jaus:jss:mobility:LocalWaypointDriver	1.0
Waypoint List Driver	urn:jaus:jss:mobility:LocalWaypointListDriver	1.0
Velocity State Sensor	urn:jaus:jss:mobility:VelocityStateSensor	1.0
Local Pose Sensor	urn:jaus:jss:mobility:LocalPoseSensor	1.0
Primitive Driver	urn:jaus:jss:mobility:PrimitiveDriver	1.0

Scoring for this task is performed by deducting points from the maximum task score based on missing services or incorrect services versions.

Scoring Starting Points = 5	
Deduction	Points Deducted
Missing Service (includes misspelling)	-1 per missing service
Incorrect Service Versions	-1
No response to Query Services message	-10

### 1.6.2.2 Core Services Task

For this task, the team's subsystem must demonstrate proper implementation of the services defined by the Core Requirements Interoperability Attributes. These services are Transport, Events, Access Control, Management, and Liveness. All five services are required for the Navigation and Reporting JAUS Component, and all but Management are required for the Platform Management Component.

The following messages input-output pairs must be supported:

Service	Input Message	Expected Response	Required Fields (Presence Vector)
<b>Events</b>	Query Events	Report Events	N/A
	Create Event	Confirm Event Request	N/A
		Reject Event Request	N/A
	Update Event	Confirm Event Request	N/A
		Reject Event Request	N/A
	Cancel Event	Confirm Event Request	N/A
		Reject Event Request	N/A
	[Event Triggered]	Event	N/A
<b>Access Control</b>	Request Control	Confirm Control	N/A
	Release Control	Reject Control	N/A
	Query Control	Report Control	N/A
	Query Authority	Report Authority	N/A
	Query Timeout	Report Timeout	N/A
	Set Authority	[set authority internal event]	N/A
<b>Management</b>	Shutdown		N/A
	Standby		N/A
	Resume		N/A
	Reset		N/A
	Set Emergency		N/A
	Clear Emergency		N/A
	Query Status	Report Status	N/A
<b>Liveness</b>	Query Heartbeat Pulse	Report Heartbeat Pulse	N/A

The following is an example test pattern the CVT may perform – final test plan may vary and will be released prior to the competition.

**Table 1-8: Core Services Test Patterns**

Service	Message Sent	Expected Response	Fields or Values Expected
<b>Events</b>	Query Events	Report Events	If team uses events there may be existing events in here.
	Create Event (for supported event)	Confirm Event Request	
	Query Events	Report Events	Created event is found with proper parameters.
	Update Event (for supported event)	Confirm Event Request	
	Query Events	Report Events	Created event has been properly updated.
	Cancel Event (for supported event)	Confirm Event Request	
	Query Events	Report Events	Created Event is not present.

	Create Event (unsupported parameters or message)	Reject Event Request	
<b>Access Control</b>	Query Control	Report Control	J AUS ID = 0.0.0
	Request Control (default authority greater)	Confirm Control	ResponseCode = insufficient authority.
	Query Control	Report Control	J AUS ID = 0.0.0
	Request Control (default authority NOT greater, control available)	Confirm Control	ResponseCode = control accepted.
	Query Control	Report Control	J AUS ID = CVT first component ID
	Set Authority (valid authority)		
	Query Authority	Report Authority	Authority = set authority
	Query Timeout	Report Timeout	Timeout = 0
	Request Control (different source component, authority less than or equal to current controller)	Confirm Control	ResponseCode = Insufficient Authority
	Query Control	Report Control	J AUS ID = CVT first component ID
	Request Control (different source component, authority greater than current controller)	Reject Control (to first component) Confirm Control (to second component)	ResponseCode = Control Accepted for second component
	Query Control	Report Control	J AUS ID = CVT second component ID
	Release Control	Reject Control	ReponseCode = Control Released
	<b>Management</b>	Set Emergency (Emergency Code = STOP)	
Query Status		Report Status	Status = Emergency
Request Control (authority valid)		Confirm Control	Response Code = Not Available
Clear Emergency (Emergency Code = STOP)			
Request Control (authority valid)		Confirm Control	Response Code = Control Accepted
Query Status		Report Status	Status = Standby
Set Status (status = Resume)			
Query Status		Report Status	Status = Resume
Set Status (status = Reset)			
Query Status		Report Status	Status = Init or Standby
Set Emergency (Emergency Code = STOP)			
Query Status		Report Status	Status = Emergency
Request Control (from		Confirm Control	Response Code = Not

	any component)		Available
	Release Control	Reject Control	Response Code = Not Available
	Clear Emergency (Emergency Code = STOP)		
	Query Status	Report Status	Status = Standby
<b>Liveness</b>	Query Heartbeat Pulse	Report Heartbeat Pulse	

Points for this task will be awarded based on successfully passing each service test for each of the two components. Points will be deducted for presence vector test (can't go below 0 points).

<b>Scoring Maximum Points = 5</b>	
<b>Test</b>	<b>Points</b>
Events Service	2
Access Control Service	1
Liveness Service	1
Management Service	1
Incorrect Presence Vector Use	-2 (deduction)

### 1.6.2.3 Events Task

The team's subsystem is required to support periodic events for reporting certain information. These events will be tested with a special tool within the CVT defined to create and test events. The required periodic events are:

<b>Event (Report Message)</b>	<b>Service</b>	<b>Component(s)</b>	<b>Required Rate</b>
<b>Report Heartbeat Pulse</b>	Liveness	Platform Management Navigation and Reporting	1 Hz
<b>Report Velocity State</b>	Velocity State Sensor	Navigation and Reporting	1 Hz
<b>Report Local Pose</b>	Local Pose Sensor	Navigation and Reporting	1 Hz
<b>Report Status</b>	Management	Navigation and Reporting	1 Hz
<b>Report Control</b>	Access Control	Platform Management Navigation and Reporting	1 Hz

The following procedure will be used to test successful implementation of each event:

1. The CVT sends a Create Event message, specifying the report message, the required rate, and the type of event (periodic).
2. The team's event service (on the receiving component) handles the Create Event message and creates an event.
3. The team's event service send back a Confirm Event response to the CVT indicating successful creation of the periodic event at the requested rate.
4. The team's event service sends periodic events to the CVT, at the required rate (a +/- 20% variation is acceptable).
5. The CVT monitors the events to check for proper rate.
6. The CVT sends a Cancel Event message with the proper event ID when it is done with its test.

Scoring will be based on properly implementing the full sequence above for each event specified.

A maximum of 10 points may be awarded.

<b>Scoring Maximum Points = 5</b>	
<b>Test</b>	<b>Points</b>
Report Heartbeat Pulse Event	1
Report Velocity State Event	1
Report Local Pose Event	1
Report Status Event	1
Report Control Event	1

### 1.6.2.4 Platform Management Task

For this task, the team's subsystem must demonstrate proper implementation of the services defined by the Platform Management Interoperability Attribute's Basic Value, with the exception of Platform State, Platform Mode, and Health Monitor. The required services are Discovery and Liveness. Liveness is tested as part of the Core Services task, so it will not be tested separately as part of this task.

The following messages input-output pairs must be supported:

Service	Input Message	Expected Response	Required Fields (Presence Vector)
<b>Discovery</b>	Register Services	[Services specified are registered and will show up in subsequent Report Services messages]	N/A
	Query Identification	Report Identification	N/A
	Query Configuration	Report Configuration	N/A
	Query Subsystem List	Report Subsystem List	N/A
	Query Services	Report Services	N/A
<b>Liveness</b>	Query Heartbeat Pulse	Report Heartbeat Pulse	N/A

The first part of the test for this task is identical to that in the Capabilities Discovery Task – a query identification message will be broadcast and used to find the Discover Service, and a Query Services message will be used to get a Report Services message. The other query messages will also be sent and the expected report messages looked for by the CVT. For this test, the content of the report messages will not be inspected.

The second part of testing for this task is proving proper handling of the Register Services message. The CVT will perform this test by sending a Register Services message that contains a set of unique service names to the team's Discovery Service, and then using Query Services to find out if those services were properly registered. The CVT will try two more times to successfully register its services if the first time fails.

Scoring for this task is based on successful responses for each of the queries, and successfully handling the Register Services message.

Scoring Maximum Points = 5	
Test	Points
Query Identification	1
Query Configuration	1
Query Subsystem List	1
Query Services	1
Register Services	1 point will be awarded if all services are verified to have been properly registered

### 1.6.2.5 Navigation and Reporting Task

The navigation and reporting task tests the services that are found on the Navigation and Reporting Component, other than those already tested in the Core Services Task. The services tested are Velocity State Sensor, Local Pose Sensor, Local Waypoint Driver, and Local Waypoint List Driver. The following input / output message pairs are required to be implemented:

Service	Input Message	Expected Response	Required Fields (Presence Vector)
<b>Velocity State Sensor</b>	Query Velocity State	Report Velocity State	Velocity X, Yaw Rate, and Timestamp (0141h)
<b>Local Pose Sensor</b>	Query Local Pose	Report Local Pose	X, Y, Yaw, Timestamp (0143h)
<b>Local Waypoint Driver</b>	Set Travel Speed	[ Team sets its travel speed to that specified ]	N/A

	Set Local Waypoint	[ Team sets its current waypoint to that specified ]	X, Y (0003h)
	Query Travel Speed	Report Travel Speed	N/A
	Query Local Waypoint	Report Local Waypoint	X, Y (0000h)
<b>Local Waypoint List Driver</b>	Set Element	Confirm Element Request	N/A
	Query Element List	Report Element List	N/A
	Query Element Count	Report Element Count	N/A
	Execute List	[ Team's platform starts executing waypoint list if in proper state ]	Speed (01h)
	Query Active Element	Report Active Element	N/A
	Query Travel Speed	Report Travel Speed	N/A
	Query Local Waypoint	Report Local Waypoint	X, Y (0003h)

The Execute List message will not be sent during the IOP Interfaces portion of the tasks – it will not be sent until the performance tasks are started.

Scoring for this task is based on successfully passing the test for each service, and is a maximum of 10 points. Points will be deducted for improper use of presence vectors.

<b>Scoring Maximum Points = 5</b>	
<b>Test</b>	<b>Points</b>
Velocity State Sensor Service	1
Local Pose Sensor Service	1
Local Waypoint Driver Service	1
Local Waypoint List Driver Service	2
Incorrect Presence Vector Use	-2 (deduction)

### 1.6.3 Performance Tasks

Performance tasks demonstrate the ability of a team's platform to properly use the IOP interfaces that have been implemented in a practical situation. The Performance Tasks portion of this challenge will test the ability of the team's platform to properly report information and execute on commands, using IOP interfaces. **All tasks in the Performance Tasks portion of the IOP Challenge will be initiated by the judges – students may not interact with the platform after the Performance Tasks begin other than to emergency stop the platform if needed or to manually drive the platform to a starting point as instructed by a judge.**

**IOP Performance Tasks MUST be done with an actual robot – no simulations may be used for this portion of the IOP challenge.**

Performance tasks will be performed on the IOP Challenge course. The IOP challenge course consists of two areas – a "Safety" area and a "Navigation" area. The "Safety" area is where the Safe Operation Task is performed – it is a simple straightaway stretch alongside the "Navigation" area. The "Navigation" area will contain between 4 and 10 local (X, Y coordinate frame) waypoints, where each waypoint is defined by a center (X, Y) location and a waypoint tolerance of 1 meter (radius). The Navigation area is where the Waypoint Navigation, Velocity State Report, and Pose and Orientation Report tasks will be performed. The figure below shows a notional concept of what the IOP Challenge course will look like.



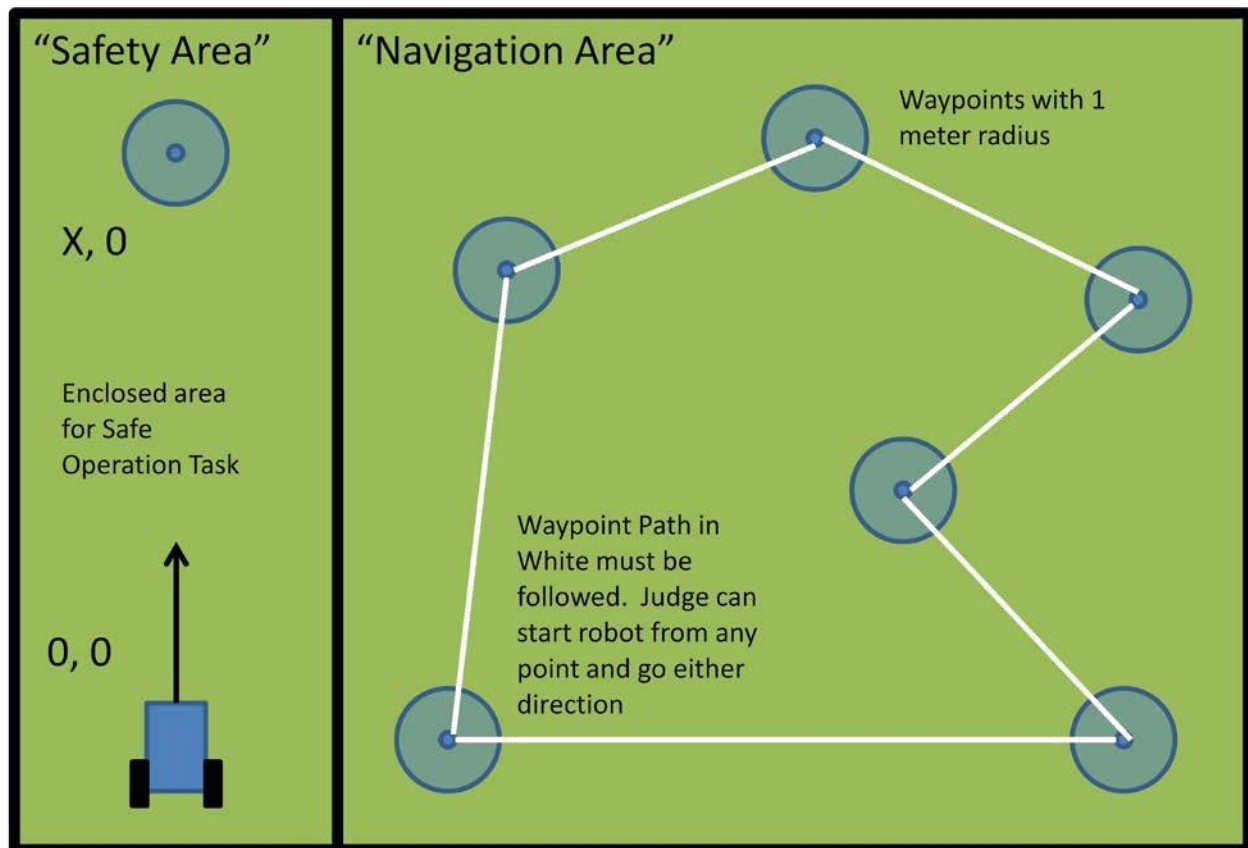


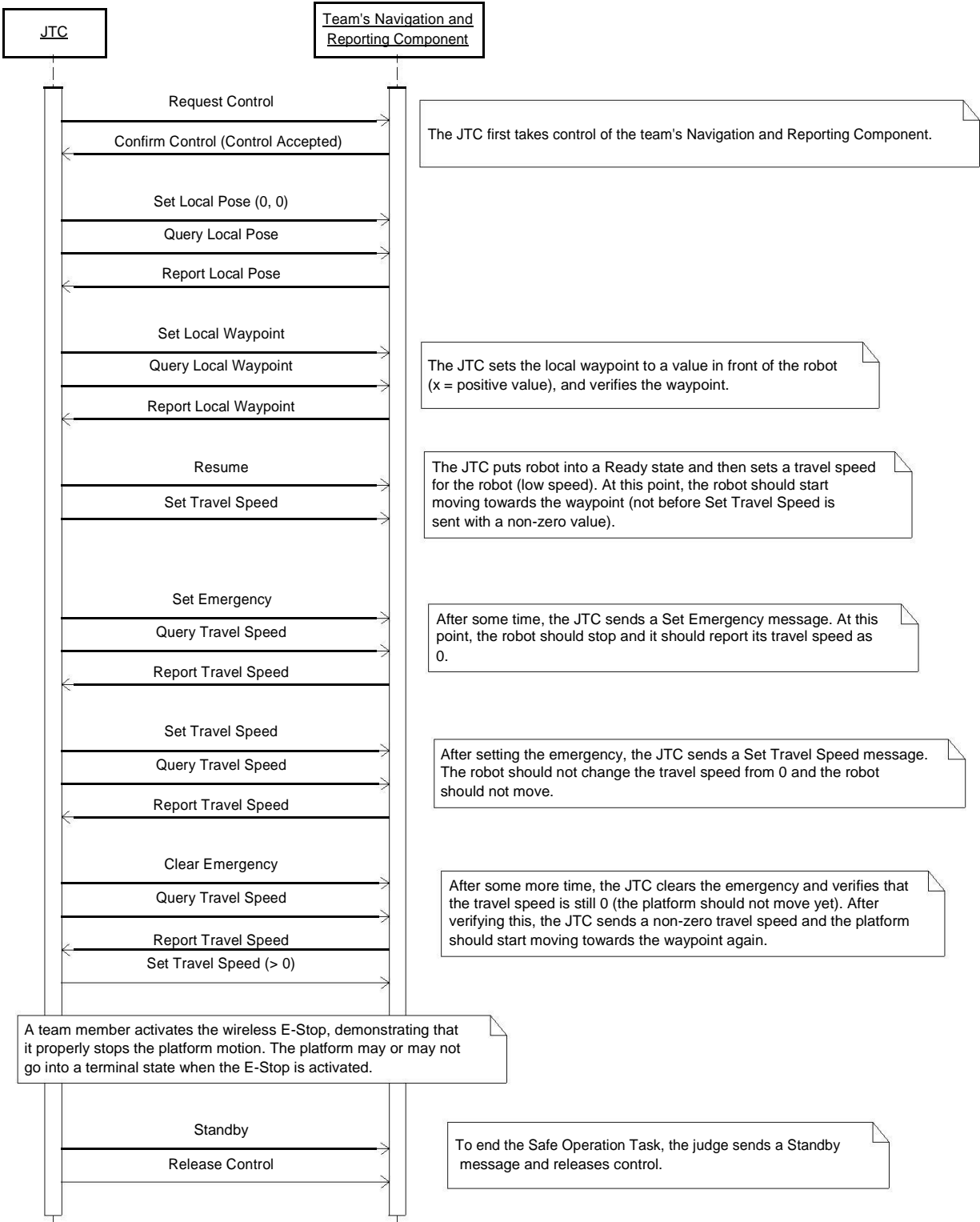
Figure 1-5: Notional Concept of IOP Challenge Course

### 1.6.3.1 Safe Operation Task

**Note: The use of the Set Emergency JAUS message is NOT a substitute for an independent, wireless E-Stop. All teams must have an independent wireless E-Stop.**

The Safe Operation Task will be used to demonstrate a team's platform's ability to properly respond to a Set Emergency command during operation. The Safe Operation Task is run in the "Safety" area of the IOP challenge course. The JTC will take control of the robot and command it to go at low speed to a waypoint in the direction that it is pointing. At some point during the Safe Operation task, the judge will send a Set Emergency message to the robot – when this happens, the robot should stop executing its current waypoint and safely stop. The judge then confirm that the reported travel speed (Report Travel Speed message) is 0 and that attempts to set a travel speed other than 0 while in the emergency state do not succeed. After verification that the robot has successfully handled the Set Emergency message, the judge will clear the emergency and set a new travel speed, at which point the robot should resume heading towards its waypoint. Finally, the judge will tell the team to initiate their wireless E-stop to demonstrate that it is capable of stopping the robot. The figure below shows the exact sequence diagram for this test.





**Figure 1-6: Safe Operation Task Sequence Diagram**

A team's robot must pass all aspects of the test for this task in order to receive the full 5 points. Failure of this task for any reason results in 0 points. **Also, if a team's robot is unable to pass this test, it may not perform the Waypoint Navigation Task and must be remotely controlled for the Velocity State Report and Position and Orientation Report tasks. If the reason for failure is a non-working wireless E-Stop, no further performance tasks may be performed.** Reasons why this test may be failed include:

- The team's robot does not give the JTC control
- The team's robot does not correctly set a 0, 0 local pose
- The team's robot does not correctly set the local waypoint
- The team's robot starts moving while in a non-ready state
- The team's robot does not start moving while in a ready state and commanded a non-zero travel speed (travel speed will be approximately 0.5 meters/second)
- The team's robot does not stop after the Set Emergency message is sent (approximately 1 second will be given for the robot to stop)
- The team's robot does not move after the emergency has been cleared and a travel speed sent
- The team's robot does not stop after the wireless E-Stop has been activated

### **1.6.3.2 Remote Control Task**

**A team may only do the Remote Control Task if it successfully completes the Safe Operation Task.**

The Remote Control Task is run in the "Navigation" area of the IOP challenge course. The Remote Control Task is performed as follows:

1. The team places their robot at a location within the Navigation area specified by the judges.
2. The JTC will send a series of SetWrenchEffort messages to the team's robot (after taking control and commanding it to the Ready state). These SetWrenchEffort messages will command translational motion in the X direction (forward and back) and / or rotational motion in the Z direction (clockwise / counter-clockwise).
3. The judges will observe the motion of the platform and evaluate its proper response to the SetWrenchEffort messages.

Scoring for this task is based on proper response to the SetWrenchEffort message – the maximum score for this task is 10 points. 5 points will be removed if the platform turns or drives in the wrong direction. Another 5 points will be removed if the platform does not move consistent with the commanded effort percentage, as determined by the judges. No points are awarded if the platform does not move.

### **1.6.3.3 Waypoint Navigation Task**

***A team may only do the Waypoint Navigation Task if it successfully completes the Safe Operation Task.***

The Waypoint Navigation Task is run in the "Navigation" area of the IOP Challenge course. The Waypoint Navigation Task is performed as follows:

1. The team places their robot at a starting point designated by the judges. The judges may specify any waypoint in the "Navigation" area of the IOP Challenge course as the starting point, and may instruct the team to face its platform towards either of two adjacent waypoints.
2. The JTC will send a Set Local Pose message with the X, Y value for the waypoint that the team's robot starts at. Note that this position is not necessarily the origin of the local coordinate system.
3. The JTC will take control of the team's robot and send it a list of local waypoints, with the starting point being the head of the list. The list of waypoints will be setup such that each team will travel to all waypoints along a path that is the same distance, regardless of the starting position and orientation.
4. The JTC will send Resume command to the robot to take it to a Ready state, and will then send an Execute List message to start execution of the local waypoint list.
5. The robot will continue to run until it either reaches the final waypoint, the team calls an end to the

run, the judges call an end to the run for safety reasons, or the allotted run time runs out.

The number of waypoints that a team's robot successfully achieves will be recorded. A waypoint is successfully achieved if approximately one-half or more of the team's robot, subject to the judge's judgment, crosses into the 1 meter waypoint radius. **Waypoints must be achieved in order - the run stops if the robot reaches another waypoint before reaching the next one in its list.** For teams that successfully achieve all waypoints, a time will be recorded to be used as final tie-breaker in case all other tie-breakers are insufficient.

Scoring for this task will be based on the number of waypoints achieved – the maximum score is 10 points. Since the number of waypoints may vary, the score per waypoint will be  $10 / N$ , where  $N$  = number of waypoints on the course.

#### 1.6.3.4 Position and Orientation Report Task

***If a team does not successfully complete the Safe Operation Task, they may still perform this task by remotely controlling their robot around the waypoint course so long as their wireless E-Stop was demonstrated to function properly.***

The Position and Orientation Report Task requires the team's robot to report its position and orientation as it travels around the course, using the Report Local Pose message. The team must report its local X, Y position, yaw (heading), and timestamp. The COP on the JTC is responsible for establishing the message flow need to get local pose information from the team's Navigation and Reporting Component. The COP will either try to create a periodic, 1 Hz event, or send Query Local Pose messages at 1 Hz.

Five (5) total points are available for this task. Points will be awarded for accurately reporting the position and orientation around the course. Half points will be awarded if only pose or only orientation is reported. The accuracy of the timestamp sent back will not be evaluated for this task.

#### 1.6.3.5 Velocity State Report Task

***If a team does not successfully complete the Safe Operation Task, they may still perform this task by remotely controlling their robot around the waypoint course so long as their wireless E-Stop was demonstrated to function properly.***

The Velocity State Report Task requires the team's robot to report its translational (X direction) and rotational (yaw rate) velocity as it travels around the course, using the Report Local Pose message. The team must report its X direction velocity, yaw rate velocity, and timestamp. The COP on the JTC is responsible for establishing the message flow need to get velocity state information from the team's Navigation and Reporting Component. The COP will either try to create a periodic, 1 Hz event, or send Query Velocity State messages at 1 Hz.

Five (5) total points are available for this task. Points will be awarded for accurately reporting velocity state around the course. Half points will be awarded if only yaw rate or only X velocity is reported accurately.

#### 1.6.4 Tie-Breaker Tasks

Tie-Breaker tasks only apply in the case of ties. They provide tie-breaker points that are used for the sole purpose of breaking ties. There is currently only one tie-breaker task.

##### 1.6.4.1 IOP Compliant Payload Connector

The team shall provide one Connector Type A connector as specified in the Payloads IOP. This connector shall be provided at a location that is easily accessible to the judges. At some point in the future of this competition, this connector may be used to add a judges' or team payload to the platform. For the purposes of this IOP Challenge, the team does not need to provide Gigabit Ethernet at this connector – Fast Ethernet is acceptable. The team shall NOT connect power to this connector at this time – only the data lines shall be populated

#### 1.6.5 General IOP Challenge Rules and Information

##### 1.6.5.1 Qualification

A team must qualify by completing the Qualification Task for each network option it plans to use during its runs. A team will not be allowed to begin a run until it has qualified. Teams may attempt to qualify at any time. Time limits will only be applied to qualification if other teams are waiting.

##### 1.6.5.2 Runs

There are two types of official runs that a team may do after qualifying: an IOP Interface run and a Performance run.

An IOP Interface run only tests a team's IOP interface software and does not test the physical performance of their robot system. During an IOP interface run, the team does not need to use their actual robot system – they can bring a computer, a simulation, or any other device that is running their IOP interface software. The team's IOP software device will be put on the same network as the JTC, which will run a series of mostly automated tests against the team's IOP software interfaces. IOP interface runs have a time limit of 5 minutes, and a team may do up to 5 IOP interface runs per day.

A Performance run tests a team's robot performance in addition to its successful implementation of its IOP requirements. During a performance run, a team must use its actual robot – no simulations are allowed. A performance run begins with the same tasks as in an IOP interface run, and then proceeds to do the Performance tasks. The Performance tasks start with a Safety Operation Task – if this task is successfully completed, the team is allowed to do the Waypoint Navigation Task, during which the Position and Orientation Report and Velocity State Report tasks take place simultaneously. If the team's robot does not pass the Safe Operation task, it may still be remotely controlled to perform the Position and Orientation Report and Velocity State Report tasks, so long as its wireless E-Stop is working correctly, but will not be allowed to do the Waypoint Navigation Task. Since we cannot assess the safety impacts of changes that teams make between runs, the Safe Operation Task must be performed during each run. Also, since we cannot guarantee that the version of software a team ran during a IOP Interface test is the same as during a Performance test, the results of IOP interface tasks from IOP Interface tests cannot be combined with the results of Performance test results from a different run. For example, if a team scored 50 points on the IOP interface tasks during its first IOP Interface run, then got 40 points on the IOP interface tasks during a full Performance run, it does not get the original 50 points added to its performance results – each run is scored individually, and the team keeps the highest score it has achieved on any individual run. **Performance runs are limited to 15 minutes and 3 per day. A team may do no more than a total of 5 runs of any type in a day.**

### **1.6.5.3 Schedule Considerations**

If there are a lot of teams waiting to make a run or time is running short, judges may, at their discretion, take action to help ensure greater fairness and faster flow of the IOP Challenge. Actions taken may include, but are not limited to:

- Reducing allowed run times.
- Reducing number of total allowed runs on a given day.
- Prioritize teams waiting who have done less runs.
- Prioritize one type of run over another type
- Specify strict rigid time slots when teams can make a run

There will likely be three total days of runs. The days will likely be organized as follows:

- Day 1: Limited amount of time, judges setup testing equipment and course. May be limited to just qualification and IOP interface tests. Qualification and IOP interface tests may take priority over Performance tests.
- Day 2: Full day, likely no special restrictions on schedule
- Day 3: Full or extended day, later in day may see schedule restriction, time slots, prioritization, etc.

### **1.6.5.4 Scoring Considerations**

The judges will utilize the testing tools specified in this document to score all entries. In addition, Wireshark packet capture logs will be taken during each run. The judges reserve the right to make scoring corrections based on review of these packet capture logs.

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**V Self Drive formerly know as Spec 2 Rules and Awards is published in a separate volume**



## **VI. AWARDS AND RECOGNITION**

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***All schools are only eligible to win award money once per event (Auto-Nav Challenge, Design Competition and IOP Challenge); if more than one team from the same school places in the same event, only the highest placing team will be placed in a standing and receive money for that event.***

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### **VI.1 AUTO-NAV CHALLENGE COMPETITION**

#### **Award Money**

(Vehicle must complete course)

1 <sup>ST</sup> Place	\$ 3,000
2 <sup>ND</sup> Place	\$ 2,000
3 <sup>RD</sup> Place	\$ 1,500
4 <sup>TH</sup> Place	\$ 1,000
5 <sup>TH</sup> Place	\$ 750
6 <sup>TH</sup> Place	\$ 500

## Nominal Award Money

(Vehicle must attain one waypoint in No Man;s Land)

1 <sup>ST</sup> Place	\$ 1,000
2 <sup>ND</sup> Place	\$ 800
3 <sup>RD</sup> Place	\$ 600
4 <sup>I<sup>H</sup></sup> Place	\$ 500
5 <sup>I<sup>H</sup></sup> Place	\$ 400
6 <sup>TH</sup> Place	\$ 300

## VI.2 VEHICLE DESIGN COMPETITION

### Design Competition Standard Awards

Dr. William G. Agnew Awards

1 <sup>ST</sup> Place	\$ 3,000
2 <sup>ND</sup> Place	\$ 2,000
3 <sup>RD</sup> Place	\$ 1,000
4 <sup>TH</sup> Place	\$ 750
5 <sup>I<sup>H</sup></sup> Place	\$ 500
6 <sup>TH</sup> Place	\$ 250

### Nominal Award Money

(Vehicle did not pass Qualification)

1 <sup>ST</sup> Place	\$ 600
2 <sup>ND</sup> Place	\$ 500
3 <sup>RD</sup> Place	\$ 400
4 <sup>I<sup>H</sup></sup> Place	\$ 300
5 <sup>I<sup>H</sup></sup> Place	\$ 200
6 <sup>TH</sup> Place	\$ 100

## VI.3 IOP CHALLENGE

### IOP Competition Standard Awards

Robot Vehicle must perform IOP challenge and qualify for eligibility of Standard IOP Award

1 <sup>ST</sup> Place	\$ 1,500
2 <sup>ND</sup> Place	\$ 1,000
3 <sup>RD</sup> Place	\$ 500
4 <sup>I<sup>H</sup></sup> Place	\$ 350
5 <sup>I<sup>H</sup></sup> Place	\$ 250
6 <sup>TH</sup> Place	\$ 150

### Nominal Award Money

(Robot Vehicle must perform IOP challenge & Vehicle did not pass Qualification)

1 <sup>ST</sup> Place	\$ 600
2 <sup>ND</sup> Place	\$ 500
3 <sup>RD</sup> Place	\$ 400
4 <sup>I<sup>H</sup></sup> Place	\$ 300
5 <sup>I<sup>H</sup></sup> Place	\$ 200
6 <sup>TH</sup> Place	\$ 100

## VI.4 Self Drive formerly SPEC 2 Awards are listed in a separate volume

## VI.5 ROOKIE-OF-THE-YEAR AWARD

The Rookie-of-the-Year Award will be given out to a team from a new school competing for the first time ever or a school that has not participated in the last five competitions (for this year the team would be eligible if they haven't competed since the 2012 IGVC). To win the Rookie-of-the-Year Award the team must be the best of the eligible teams competing and perform to the minimum standards of the following events. In the Design Competition you must pass Qualification, in the AutoNav Challenge you must pass the Rookie Barrel and in the IOP Challenge you must be compliant. The winner of the Rookie-of-the-Year Award will receive \$1,000 in award money; in the case the minimum requirements are not met the best of the eligible teams competing will receive \$500.

## VI.6 GRAND AWARD

The Grand Award trophies will be, presented to the top three teams that perform the best overall (combined scores per below), in all **three** challenges. For each Challenge, points will be awarded to each team, below is a breakdown of the points:

### Standard Grand Award Points\*

Challenge	First	Second	Third	Fourth	Fifth	Sixth
Auto-Nav	24	20	16	12	8	4
Design	24	20	16	12	8	4
IOP	24	20	16	12	8	4

### Nominal Grand Award Points\*\*

Challenge	First	Second	Third	Fourth	Fifth	Sixth
Auto-Nav	12	10	8	6	4	2
Design	12	10	8	6	4	2
IOP	12	10	8	6	4	2

\* For Standard Grand Award Points, the team must complete the Auto-Nav course and qualify in Auto Nav for the Design Competition points and fully participate in all IOP Challenge aspects for IOP points.

\*\* For Nominal Grand Award Points in each Challenge, The team must qualify to be eligible in the Auto-Nav Challenge and have their vehicle present for the Design Competition and IOP Challenge.



## VII PUBLICATION AND RECOGNITION

International recognition of all participating teams through AUVSI publications.

Videos of the competition event will be distributed to sponsors, media and the public. All design reports, articles, videos and pictures will be post on the IGVC website [www.igvc.org](http://www.igvc.org).

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Name	Years as Editor
Jerry Lane & Andrew Kosinski	2014-2018
Bernard Theisen	2013-2014
Jerry Lane	2011-2013
Bernard Theisen	2006-2010
Greg Gill	2005-2006
Bernard Theisen	2004-2005
Dan Maslach	2003-2004
Bernard Theisen	2001-2003
Stephen W. Roberts	2000-2001
Scot Wheelock	1999-2000
Geoff Clark	1998-1999
G. Edzko Smid	1997-1998
Candy McLellan and G. Edzko Smid	1996-1997
Jerry Lane, Paul Lescoe and Ka C. Cheok	1992-1996

IGVC Rules Editors

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*All questions and concerns should be e-mailed to [IGVCquestions@yahoo.com](mailto:IGVCquestions@yahoo.com).*

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