Talent and Creativity Center

MBZIRC 2023 White Paper Phase

31 Jan 2022

KAU Team

Table of Contents

Team Information

King Abdulaziz University (KAU) put together a team of 33 members with a diverse range of expertise to meet the challenge's demands. Programming, communication, mechanical, aerospace, and power are the five sub engineering teams that makes up the team. Each sub team is led by a supervisor who is either an engineer, a member of the faculty or both. We aim to advance in the world of robotics and contribute in an age of autonomous systems, to learn and solve this real-world problem using our knowledge, prior experiences, and the simulating environments that we have. Such as KAU, the Talent and Creativity Center.

Undergraduates

The university offered the team with 23 of its brightest undergraduates, all of whom are competent and have demonstrated knowledge in the brainstorming and creation of the technical approach.

✳ Undergraduates' technical capabilities and experience highlights:

- Knowledge in computer vision, neural networks, AI & machine learning, Gazebo, image processing, and object detecting.
- WRO, AUV, IEEEXtreme, Savola hackathon, and Hajj hackathon participation.
- CV projects using YOLO algorithms and GANs, NLP projects involving bidirectional RNN and LSTM cells, and a Micro-Air-Vehicle design

Engineers

Five University graduates with drone experience have joined to help the team thrive. They assisted in the development of the technical approach and will continue to assist in seeing it through.

✳ Engineers' technical capabilities and experience highlights:

- Expertise in ROV, autonomous robots, DSP, control systems, antenna design, microwave circuit design, RF electronics. radar systems, 5G communication technologies, multirotor and fixed wings automated systems, and additive manufacturing.
- Participation in Mate ROV, Formula Student, and the Eco Shell Marathon

Faculty members

Five members of the Faculty of Engineering will aid the team by guiding and refining their work: -

- **Dr. Saud Wasly:**
  Dr. Saud Wasly is an associate Professor in the department of Electrical and Computer Engineering at King Abdulaziz University. He is eager to employ creative teaching strategies to enhance the learning experience for students. Actively participating in continued learning through conferences and academic research. Interested in embedded real-time systems including embedded systems architecture, real-time programming languages, real-time operating systems, timing analysis, and architectural simulation. Love to contribute to the open-source communities through developing free and open software and hardware designs. Open to crazy ideas that might positively impact the future.
- **Dr. Muhammad Bilal:**
  Dr. Muhammad Bilal is an educator, researcher, and a maker. His research interests include Digital Image/Signal Processing, Machine Learning/AI, Digital/Analog circuit design, embedded systems, and Robotics. He is an Associate Professor in the Department of Electrical and Computer Engineering, KAU. Prior to joining KAU in 2014, he worked as a post-doctoral researcher at KAIST, South Korea. He has published in top journals such as IEEE Transactions on Intelligent Transportation Systems, IEEE Transactions on Circuits, Systems & Video Technology, and IEEE Transactions on Circuits & Systems. He has led student teams to compete in WRO Robotics competition 2019 (First place nationally, Seventh internationally), AI NEOM competition 2020 (Third place nationally) and OpenCV AI competition 2021 (finalists).
- **Dr. Muhammed Hanif:**
  He is an Associate Professor at the Department of Electrical and Computer Engineering, King Abdulaziz University. His research interests include machine learning, computer vision and information fusion. He has published in various journals related to image processing and computer vision proposing solutions of various vision tasks such as object detection and recognition, object tracking, image similarity computation.
- **Dr. Sultan Alghamdi:**
  Dr. Sultan Alghamdi in an Assistant Professor in the department of Electrical and Computer Engineering at King Abdulaziz University. His current research interests include distributed control and time-delay systems with application to microgrids and power systems, low inertia power system dynamics, and control. Open to innovative ideas that might positively improve life and humanity.

Dr. Hamza Diken:

Dr. Hamza Diken is an Associate Professor in the Mechanical Engineering Department of King Abdulaziz University. He teaches dynamics, machine dynamics, system dynamics control, and vibration. His main research area is applied mechanics. He worked on robot dynamics, rotor-blade vibrations and currently working on vibration of horizontal axis wind turbines.

Affiliates

The Talent and Creativity Center at King Abdulaziz University will provide the team with all the expertise they want and will offer their labs and facilities to them.

Talent and Creativity Center:

- Winning the Semi-Grand Prix as the second-best invention in the International Warsaw Invention show 27th October 2021.
- Obtaining more than 100 medals and special awards at international invention fairs.
- Placing 7th at the World Robot Olympiad in 2019.

Main point of contact

Name	Email	Phone number
Omar Alghamdi	Omar.Alghamdi.Gnosis@gmail.com	+966 544 156 510

Alternative point of contact

Name	Email	Phone number
Dr. Saud Wasly	swasly@kau.edu.sa	+966 540 648 189

Team roaster

No.	Name	Email	
1	Dr. Saud Wasly	Swasly@kau.edu.sa	Faculty Members
2	Dr. Muhammad Bilal	Meftekar@kau.edu.sa	
3	Dr. Muhammed Hanif	Mshanif@kau.edu.sa	
4	Dr. Sultan Alghamdi	Smalgamdi1@kau.edu.sa	
5	Dr. Hamza Diken	Hdiken@kau.edu.sa	
6	Yousuf Alotaibi	Yalotaibi0038@stu.kau.edu.sa	Engineers
7	Hani Abdulsalaam	Hnoabdulsalam11@gmail.com	
8	Hussain Qasem	Hussain.Ad.qasem@gmail.com	
9	Mutaz Aljafari	Aljafari.mutaz@gmail.com	
10	Nawaf Rasheed	Nawaf200817@gmail.com	
11	Omar Alghamdi	Omar.Alghamdi.Gnosis@gmail.com	Undergraduates
12	Adahm Alquthami	Amalquthami@stu.kau.edu.sa	
13	Waleed Althqfe	Althqfe@gmail.com	
14	Ahmed Aljuaid	A2000081@hotmail.com	
15	Amjad Aljarallah	Amjed.kmj@outlook.com	
16	Anas Alzahrani	Anas.zh1@gmail.com	
17	Abdulrahman Alsbhani	Alsbhani2@hotmail.com	
18	Meshal Alshehri	Malshehri0692@stu.kau.edu.sa	
19	Bader Alghamdi	Badrrdab1@gmail.com	
20	Mohammed Bamrdah	Mahmedbamrdah@stu.kau.edu.sa	

21	Abdullah Taleb	Ataleb0012@stu.kau.edu.sa	Undergraduates
22	Alfahad Felmban	Afelemban0052@stu.kau.edu.sa	
23	Faisal Bin Hassan	Fabdulazizbinhassan@stu.kau.edu.sa	
24	Mahmued Alardawi	Mmalardawi@stu.kau.edu.sa	
25	Faris Alahmady	Falahmadi0043@stu.kau.edu.sa	
26	Yousef Alsayegh	Yalsayegh@stu.kau.edu.sa	
27	Ahmed Alkhayal	Amahmoudalkhayal@stu.kau.edu.sa	
28	Abdullah Alkatheri	Aalkatheri0029@stu.kau.edu.sa	
29	Abdallah Alhissy	Abdallahalhissy@gmail.com	
30	Abdulaziz Ebrahim	Aahmedibrahim@stu.kau.edu.sa	
31	Wael Alqarni	Waeal2040@gmail.com	
32	Ali Almousa	Aalialmousa@stu.kau.edu.sa	
33	Khaled Al Juaid	K.t.aljuaid@gmail.com	

Technical Approach

We organized the technical approach into three parts. Part 1 will outline our fleet of unmanned aerial vehicles (UAVs) and unmanned surface vehicle (USV). Part 2 will discuss our scenario for solving the inspection and intervention tasks problems. Part 3 will present uniqueness of the approach, risk and mitigation actions, and safety considerations.

Part 1

In this segment, we discuss the UAV's capabilities and equipment, followed by a discussion of the USV and the mechanisms we equipped it with.

UAV

There are four types of UAVs used, in this section we will describe the capabilities, such as the flight time and payload capacity, as well as the equipment used by each type, focusing on the processing unit and the camera.

Type-1 (Deployer drone)

Capabilities

The deployer multirotor drone will place buoys (floating devices at sea) at key locations. It can stay in the air with a fully charged battery for 75 – 55 minutes depending on the payload. It can reach a speed of 15 m/s (54 km/h), and an altitude of 150m. It also has a maximum payload of up to 1 kg. [1]

Equipment

Raspberry Pi board will be the processing unit that controls the data input/output from and to the camera. We will also use a thermal camera to collect information and send it to the Raspberry Pi.

Type-2 (Scanner drone)

Capabilities

We will use vertical take-off and landing (VTOL) fixed-wing planes for locating and verifying the target vessels. It comes with four lift motors and one fixed-wing motor, which will allow the VTOL drone to ascend like a helicopter. For the scanning or security mission, the fixed-wing motor will make the drone fly like a plane. It can fly up to 112 minutes while carrying 600g payload. Due to its modular airframe and foldable motor arm design, a single man can set up this VTOL in less than 3 minutes. [2]

Equipment

Jetson Nano board will be the main processing unit. It is a small, powerful computer board that has the performance and capabilities we need to run modern AI workloads and multiple neural networks in parallel for jobs like image processing, image classification, and object detection. We will also use a thermal camera to collect information and send it to the Jetson Nano.

Type-3 (Carrier drone)

Capabilities

The package carrier multirotor drone can stay in the air with a fully charged battery for up to 45 minutes depending on the payload, and it can reach a flying speed of 10m/s and lifting speed up to 5m/s. The maximum payload it can carry is up to 5kg. The drone has a closed fuselage structure with high strength and rain resistance, and the drone is designed to withstand temperatures from -10 to 55°C.

Equipment

The Same choice of processing unit as Type-2. We will use a stereo camera for the drone to be able to precisely pick up objects

Carrying mechanism

The approach we are following in designing the mechanism, is to design a vice-like gripping mechanism, where we have two jaws that are connected through a power screw, which delivers the force from an electric motor to the jaws. Moreover, a further addition that we would like to consider in our design, is to install springs located between the end of the power screws and the back of the jaws. This addition's main purpose is to maintain the clamping force when the jaws are closed. Another advantage is that it will use less power because we will use less energy trying to close the jaws and hold the load, and the motor will only have to work at full capacity when the jaws open to grip or drop the load. We will be using position sensors to confirm that the payload is successfully clamped. Also, we will be using 3D printed parts in the mechanism to save weight. [3], [4]

Type-4 (Pusher drone)

Capabilities

Multirotor drones have a maximum angle of inclination around 45 degrees, the thrust produced by the drone can push 10 kg object. The drone has a stable flight system with high strength structure and a high-efficiency power system.

Equipment

The Same choice of processing unit and camera as Type-3.

Thrust Mechanism

Pushing a heavyweight with multiple drones is a complicated task. To solve the problem, we will use an aluminum profile to design a piece 1.8 m in length, which will be carried by drones to achieve enough strength to move 10 kg over the required distance. We choose aluminum profiles because they have the flexibility that allows them to be bent and extruded into various shapes, provide strength that makes them highly weather-resistant, and are also lightweight.

USV

This section will discuss variety of elements that the USV is equipped with, such as mechanisms, sensors, cameras, computers, antennas, and drones

Robotic arm

For the arm, we consider renowned robots in the market such as UR16e (figure1), which has a payload capacity of 16kg, with the aim that it can hold the gripping system along with the targeted object.

To find a suitable gripping mechanism, we must keep in mind the variety of shapes and materials that the object can be made of. To overcome this issue, we are planning to use a vacuum gripping mechanism attached to a foam pad (figure 2). The vacuum gripper is a flexible solution for handling products with different shapes and dimensions with an integrated vacuum pump, meaning it doesn’t need an external generator. The foam pad will help in minimizing the vacuum pressure loss which can be caused by deformed and arched surfaces. Also, the pad takes the object’s surface shape to increase the coverage, and more coverage results in more gripping force (figure 3). In addition, stabilizing the arm will be solved by maintaining the stability of the whole USV, which will be subject to discussion in the next part.

Figure 1: UR16e robot [5]

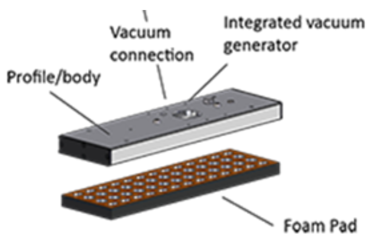

Figure 2: shows vacuum gripper parts connection [6]

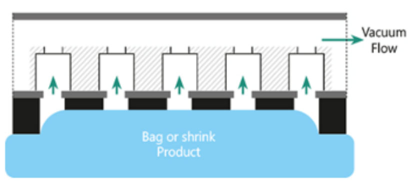

Figure 3: Shrinkage on the foam-pad caused by the object’s surface [6]

Robotic arm mount

An Intelligent platform, which we called biaxial platform (BP) has a camera for guidance and mechanisms to mount the robotic arm. BP has the ability to move the robotic arm in two directions (azimuth, vertical) using a scissor-like mechanism that enables the arm to ascend to its desired height, this mechanism is attached to a sliding mechanism which will facilitate movements and enables the arm to cross a small distance for it to reach and pick up the object.

Moreover, BP is positioned across the USV making the distance of the torque arm between the target object and the rotation of the axis as minimum as possible. So, the job can be done safely.

The mount and the USV have different interfaces, so an adapter should be designed and manufactured with taking into consideration vibration, joint stress analysis, and positioning accuracy. A screw with 8.8 grade and Loctite 242 will be used to improve resistance to vibration for the bolts and seals against corrosion. Moreover, mounting pins will be used to accommodate shearing stresses and avoid any misalignment.

Stability

Many devices rely on stability, such as the robotic arm. We have encountered many solutions to solve the problem of stability. We discovered that large ships use a system that consists of two tanks filled with water, and as the ship swings from side to side, one tank would have a higher water level, therefore, stabilizing the ship. Aanother solution we found was to use two fins at the bottom side of the ship, where it is possible to adjust the angle of attack according to the waves and stabilize the ship, however, to have any significant effect, the ship must be moving so that lift can be generated at the fins.

In the end, we found that the best solution for our application is to have a gyroscopic stabilizer, we would manufacture a high-speed rotating flywheel, which would have angular momentum pointing upward, and therefore stabilizing our ship. This is the best solution since does not need large tanks (extra weight) in the first solution, and it does not need to be moving in order to stabilize the ship as in the second solution. [7], [8], [9]

Connection Mechanism

One problem that appears when the USV approaches the target vessel is that they must be rafted up and connected together, so that the robotic arm can complete its mission. A mechanism consisting of a pipe, socket joint, and a heavy-duty suction cup will be attached to the USV.

The pipes own the tolerance to be compressed with the aid of springs. The socket joint will address the problem of the curvature and allow the cups to rotate to the optimum angle. Finally, the suction cups that will be used are battery powered and can lift a good amount of mass. Several the discussed mechanism will be used along the boat as shown in Figure 4.

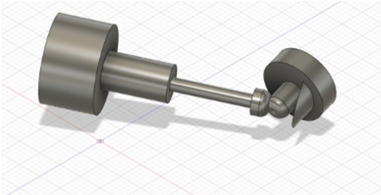

Figure 4: Rafting mechanism

Cameras

General Camera (ESP32-CAM)

These types of cameras are used for the general purpose, collecting general insights about the surface of the water. The ESP32-CAM is a very small camera module equipped with the ESP32-S chip. Along with the OV2640 camera, and variant GPIOs to connect peripherals, it also features a microSD card slot that can be utilized to store images taken with the camera or to store files in the USV.

Specialized Camera (FPV system)

The specialized type is utilized for a more in-depth scanning of the targeted region. Such cameras come with a double antenna to stabilize the signal more efficiently. Furthermore, they will be equipped with LiDAR technology (Light Detection and Ranging) which is a remote sensing method applied to examine the surface of interest. With low power consumption, these cameras can operate for a longer period compared with the general ones.

Computer

The computer will be responsible for almost all the orders given for both the drones and the USV itself. These orders are classified as:

Order assignment

The computer will be responsible for almost all the orders given for both the drones and the USV itself. These orders are classified as:

Proactive orders

Such orders look to seek information to act upon. These orders include sending Type-1 drones to deploy the Buoys. Another example is directing Type-2 drones for the scanning process. And many more.

Reactive orders

These kinds of orders revolve around the response to be driven according to observed events. Examples of this are coordination of drones, and task transition and initiation.

Localization

The system will contain a virtual map that will support the buoys in the localization process (more information in Chapter 02). Such a map will be used to direct operating drones and keep track of the location of detected objects.

Communication

The computer will be the common link between the drones and the USV. It will communicate the location of the drones and their destination to the USV. It will also handle the communication between the fleet and the operator.

Video streaming

The system will transmit the live feed obtained from the drones to the base station for the confirmation process.

Antennas

The USV will be equipped with multiple mechanically steered Rotating Directional Antenna.

Drones

For intervention purposes, the USV will carry a Type-3 drone and multiple Type-4 drones.

Crashing zone (safety net)

A net-like structure will be designed for emergency landing. The design consists of four steel columns and support (ribs), and a net in the middle. Moreover, analysis will be done to avoid potential problems and ensure that it will work in tough environmental conditions.

Part 2

In this segment, we will first clarify some important information regarding communication, video streaming, and antennas. Then we will look at the inspection and intervention tasks. Afterwards, we will view the simulation we have done.

✳ Communication & video streaming

The communication and video streaming methodology will be done by using frequency division multiple access (FDMA). The process of FDMA is to assign individual channels to each drone. So, each UAV will communicate with the USV by using its unique channel with guard bands between channels to prevent interference. Also, there will be another dedicated channel between the USV and the base station, which will facilitate transmitting the video stream from the UAV to the base station. As for communication between UAVs, they will communicate through a mediator which is the USV. Then, the USV will relay the messages to the appropriate drone. The control signal and video streaming will be split between two different frequencies. [10]

Omnidirectional Antenna (ODA)

ODAs broadcast radio signals in all directions (360°). The advantage is that the UAVs and USV can know how far away from the antenna they have traveled (distance) through Friis's equation, the disadvantage is that they will not know where the signal came from since the antenna transmitted the signal everywhere. However, we can solve this by placing multiple ODAs strategically, they will transmit signals at consecutive time slots. The signals will be powerful enough for them to overlap in the mission area then the swarm can know how far it has traveled and at what direction (distance + direction).

Rotating Directional Antenna (RDA)

The advantage of RDA is that the UAVs can locate the USV (distance + direction), but this will happen at specific intervals.

Inspection Task

To solve the localization (know where the UAVs+USV are) problem, The RDAs that are placed in the USV will be directed to the lower corners of the area, allowing Type-1 drones to launch from the base and navigate their way to these corners and deploy the buoys (Devices that has an ODA). In the meantime, the USV starts moving towards the center of the area, allowing faster transition to the intervention task once the target vessel is located. We now have two buoys and an RDA in the area; the buoys will signal Type-1 drones of their distance so they can travel straight, and once they enter the range of the RDA – that is now directed to the top corners - the drones will be able to deploy the buoys. After the RDAs finish helping Type-1 drones in their mission, each antenna will begin scanning 180° broadside to assist the ODAs achieve greater precision.

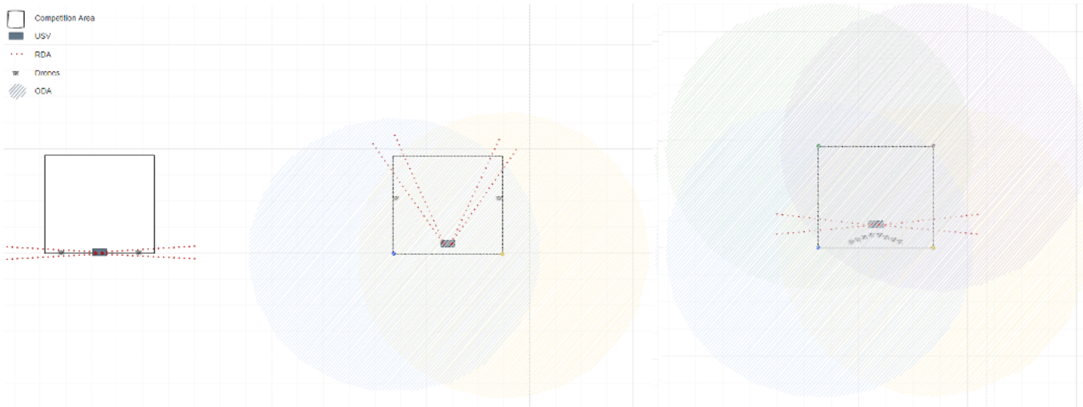

Figure 5: Localization process

Now the localization system is complete and Type-2 drones will be released to search and locate the vessels using an image processing navigation system that can detect the vessels. After a drone finds a vessel, it will execute appropriate maneuvers to enable the camera to take pictures from various angles and create a model of the vessel to verify whether it is the target or not. If it is not the target vessel, then the drone will carry out its search. If it is the target vessel, then the USV will head towards the verified vessel to start its intervention task while the drone continues to search for the second target vessel (If there were 2 target vessels).

Once the target vessels are verified or all the vessels in the area are located and verified whether they are the target or not, all type-2 drones will head back to the base.

✳ Intervention Task

The USV will head towards the target vessel after verifying it, and four drones will be launched as it approaches. One Type-3 drone will transmit a live video to the operator while searching for the smaller object, once the operator verifies which object to be picked up, the drone will use the gripping mechanism to carry and transfer the object. For the larger object, three type-4 drones will transmit a live video to the operator while searching for the larger object, once the operator verifies which one is the desired object, the drones will push the larger object and prepare it for the robotic arm.

In the meantime, the USV will approach the target vessel and orient itself using the guiding cameras and connect both ships to increase stability so that the orientation and connection will facilitate the process of picking up the large object by the robotic arm. However, if a second target vessel is detected, then the USV will repeat the intervention task after the first vessel is cleared.

✳ Simulation

Flight performance

To estimate the flight condition, we considered a worst scenario, best scenario, and moderate scenario to cover any possible condition of the environment. The flight simulation is needed to detect the required parameters of flight and meet the flight mission requirements such as lift-to-drag ratio for computing the range and moments for UAVs stability.

Image detection

The image preprocessing algorithm used for the USV, and vessels detection Is a deep neural network for detecting the vessels by putting a box around the vessel. The tools used are, Detectron 2, Pytorch, openCV, Python programming language, NumPy.

Figure 5: Sample of the simulation output [11]

As shown in figure 5, the system can detect low resolution and far away vessels, making it suitable for our need.

✳ Virtual map

Before the mission starts, details regarding the area of the map will be given. Once given, the parameters in the function of the virtual map will be easily altered. Meaning that the scenario can work with various dimensions of the 10 .

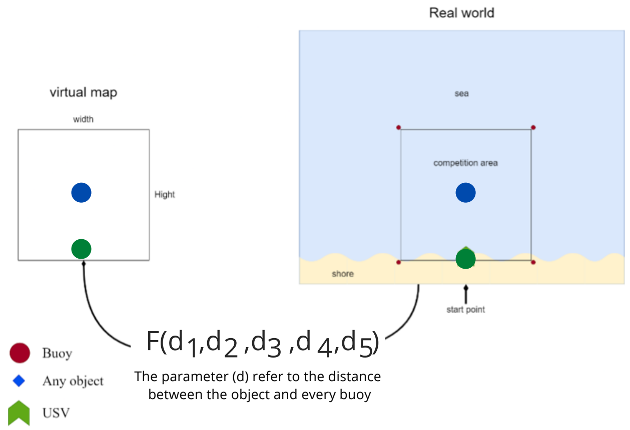

Figure 6 shows a simple component diagram for the virtual map that shows how the real map relates to the virtual map via the mapping function.

Part 3

In this segment, we will set out more information such as the approach's uniqueness, risk and mitigation actions, and safety considerations.

✳ Uniqueness of the approach

Antennas
Using narrow beam directional antennas to direct units to specific areas and then use Omnidirectional antennas to make UAVs + USV locate themselves in an area that has no GPS or GNSS coverage.

Detection
Our detection system can identify and log previously discovered targets, as well as deliver reports detailing where the items were identified and when, as well as visual reports that show what the objects detected looked like and assigning IDs to them.

Rotating Directional antennas (RDA)
Using RDA, our system in specific conditions can send drones to a distance exceeding 10km, outside the coverage of the buoys (outside the 10 km2 area).

Materials
The frames and drone arm materials will deteriorate over time, especially under humid conditions, therefore we chose materials that are easy to maintain.

VTOLs
We are using the versatile VTOLs to act as fixed wing to scan and reach vessels as fast as possible, and then switch to loiter around the vessel for the verification process.

Risk and Mitigation approach

UAVs hit each other
The unique frequency of the IR LEDs allows the drones to communicate with each other and keep their distance.

Loss of signal (coverage)
By positioning the buoys in the corners of the area and increasing the power transmitted.

Drone hijacking
Hard coding to instruct the drones not to leave the operation area.

Jamming
All communication is ID'd.

System communicate in unintended frequency
By selecting equipment that does not exceed the allowable frequency range.

Engine failure
Falling fixed wing can glide to approach the shore as much as possible.

Drone sink in the sea
By putting a small floating device under the UAV that will do the inspection task.

The corrosion of equipment's
Use of composite material.

Adverse reactions of electrical components
Equipment isolation.

Packages fall in the sea
The gripper is designed with a feedback control to ensure the package will not drop.

Drone losing signal
By using a compass to navigate back to the shore and send a distress signal.

USV hit the target vessel
Rubber bumper to minimize the impact force and prevent damage.

Low to no visibility
Use thermal camera for the drones that will do the inspection task.

Buoys explode
The material used for the buoys are suitable against high pressure from the wind.

UAV returns to base in command

The system provides an integrated overwrite command that terminates the mission and returns it to the base.

Commercial and societal impact

Increase productivity, and safety of commercial activities due to our automated system. The system can help with search and rescue at sea with minimal changes. It can also be used in areas that have no boundary marking mechanisms such as the ones provided in the competition.

Conclusion

KAU team consists of Professors with research interests that align with the competition's purpose. Engineers with drone, communication, and mechanism experience. Undergraduate students from 5 different engineering fields who have worked on many small projects and have competed in several competitions.

The team has devised a scenario in which two types of drones are used for inspection and another two types of drones are used for intervention. The mission is based on the antennas that will be spread out from the start, which addresses the GNSS denial in a cost-effective manner. Our overall system has been thoroughly thought out, and we have evaluated potential hazards as well as ways to mitigate them. Our technology will be tested and simulated in a variety of locations in the future to guarantee that it can withstand harsh environmental conditions.

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