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Proposal of a marine protected area surveillance system against illegal vessels using image sensing and image processing

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ABSTRACT

Conservation of marine fauna is a great concern in the present days for a number of reasons. Implementation of marine protected area is considered to be a common practice for the conservation of marine fauna at a specific area. However, in many cases, the present management system of the marine protected areas fails to protect marine fauna. This paper proposes a marine protected area surveillance system that uses airborne image sensing and digital image processing to monitor the marine protected area against illegal vessels efficiently. The system architecture, including the system structure, execution planning, and algorithm, has been described for the proposed surveillance system. It is apparent from this study that the currently proposed marine protected area surveillance system is better than the previously proposed ones.

1. Introduction

Marine biodiversity is an essential element of the environmental ecosystem [1]. According to Food and Agriculture Organization of the United Nations, more than 16% of animal protein consumed by the human beings is covered by the marine fisheries [2]. Besides, it is evident that the economic significance of natural marine biodiversity is tremendous [3]. Moreover, marine biodiversity compensates the ecological connectivity and works as a dominant resistance as well as a strong resilience to climatic change [4]. However, studies show that human beings, by fishing as well as hunting and by provisioning of services, have already instigated a few marine defaunation and have profoundly escalated the defaunation threat to some marine fauna [5].

Implementation of marine protected areas (MPAs) is often considered to be a forefront strategy for conserving marine biodiversity [6]. That is why MPAs have been implemented in a large number and with a wide coverage for the last several years [7,8]. However, the failure of MPAs to instigate positive ecological outcome is evident in many cases—mainly because of ineffective management processes of those MPAs [9]. The author of this article presumes that an integrated system of airborne image sensing and digital image processing can be an expedient resolution to this predicament.

Typically, human patrolling is used in the conventional marine protected areas for conservation purpose [10]. Though image sensing and image processing are being employed in a vast number of applications in other fields, literature related to their specific applications to MPA is very rear. Sudarsan et al. previously proposed image processing to be used for marine protected zones, but the study lacks a proper description of the system architecture [11]. Recently Kachelriess et al. made an elaborated argument that image sensing has the potential to be implemented for the management of MPAs, but the study was carried out by reviewing the aspect of the terrestrial protected areas which typically utilize satellite remote sensing for image sensing [12].

This paper proposes an MPA surveillance that uses an integrated system of airborne image sensing by an unmanned aerial vehicle (UAV) system in the air and digital image processing by a control system at the ground station. This proposed system is supposed to be an efficient system for monitoring of the MPAs. Moreover, since the UAV monitoring is replacing the need for human patrolling, the resource optimization, i.e. minimization of human labor as well as fuel expenditure of patrolling vessels, might be a potential advantage.

2. System architecture

2.1. System structure

The proposed MPA system is a system of systems—that is it consists of two subsystems; namely: unmanned aerial vehicle (UAV) system and control system. These two systems will be connected with a communication data link. There is a lot of equipment available within the range of present technology that can construct the proposed architecture. For this reason, this description endeavors to exclude the specifications of the equipment and thus generalizes the idea. Note that the idea includes only what is available with present technology.

The UAV system will be comprised of a single UAV or more than one UAV. The number of UAV(s) used for a UAV system will depend on the

Abbreviations: MPA, marine protected area; UAV, unmanned aerial vehicle; RGB, Red Green Blue; GPS, global positioning system.

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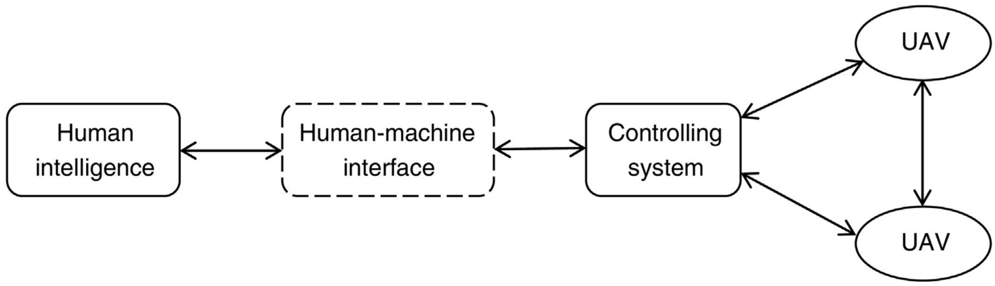

Fig. 1. Communication between the components of the proposed system.

coverage of the considered MPA and the risk level of the MPA. If a single UAV is used, the UAV might be operated by a preprogrammed autopilot, or it might be controlled manually from the control station. More the number of UAV, the more recommended it is to control the UAVs with preprogrammed autopilot. More than three UAV might require swarm control of the UAVs.

For this system, the main assignment of the UAV is to continue the task of image sensing by the digital image sensor which will be included in the sensing payloads. The image sensor will be equipped with night vision mode for the surveillance at night. The UAV will also be equipped with navigation sensors for positioning of the UAV and with a wireless system for communicating with other UAVs as well as the ground station.

The ground station is the place where the control system will be situated. Note that ground station does not necessarily mean it will be a ground place—i.e. it can be a floating ground station if required for a specific MPA. The control system comprises a set of devices which will run on hardware-software interaction. These devices will be used for monitoring, analyzing and controlling of the UAVs. The control system will also be used for image processing and for monitoring the MPA. Human operators are needed at the ground station for manual control or taking any action in case human intelligence is required.

The wireless data communication can be used for maintaining the communication of the UAVs among themselves and with the control system. The human-machine interface maintains communication of human intelligence and the machine at the ground station linked to the controlling system.

Fig. 1 shows the conceptual diagram of the communication process between the components of the proposed MPA system where the number of UAV is considered to be two. The UAVs will work for image sensing whereas the control system will work for image processing.

2.2. Execution planning

Fig. 2 shows a possible mapping of the proposed MPA surveillance. The dotted line defines the area to be protected. The surveillance path of the UAVs is determined such that it has a close end with a perimeter that resembles an ellipse or a circle depending on the shape of the MPA. Fig. 3 shows a possible mapping of the MPA surveillance where the surveillance path perimeter resembles a circle. As illustrated by Fig. 3, an additional surveillance layer can be arranged for a more protected MPA, especially if the threat level is high for a large MPA.

The position of the ground station should be optimized for a specific MPA. The more elliptical rather than circular the path perimeter is, the better it is to position the ground station near the minor axis of the elliptical perimeter. This point is more important for large MPA zones—as it is required to take action from the ground station as soon as possible if needed.

2.3. Algorithm

The live stream of the UAV image sensor is sent to the ground station. This live stream is then converted to particular frames at the rate of 10 frames per second. The visibility time range of human eyes is 0.1 s, which is why the rate of 10 frames per second is recommended. However, a frame rate of 24 frames per second to 29 frames per second would seem to be more animated to human eyes.

When the edge detection is done, the system can check if the structure resembles a vessel and marine wave created by the vessel. If the system finds it to be an illegal vessel, it will mark the vessel with the global positioning system (GPS) coordinate and start tracking the object of interest, i.e. the illegal vessel. The steps of the algorithm, as proposed by the author, are as below:

Step 1: Read RGB image.
Step 2: Convert from RGB image to grayscale image.
Step 3: Use edge detection operator for detecting the edge.
Step 4: Check if any illegal vessel is present.
Step 5: If any illegal vessel is present, notify human intelligence and track the vessel.
Step 6: Go back to step 4.

This algorithm is further illustrated by a flowchart in Fig. 4.

Although the presented algorithm, as well as the flowchart, represents the main process, step 3 and step 4 should be applied as

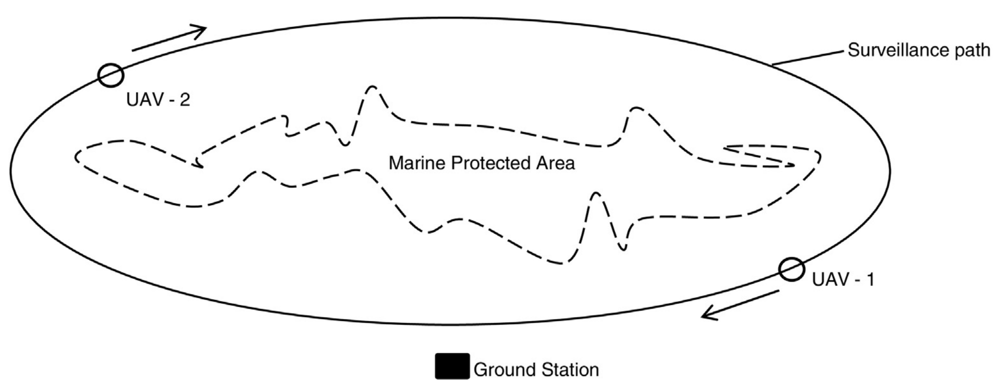

Fig.2. A possible mapping of the MPA surveillance.

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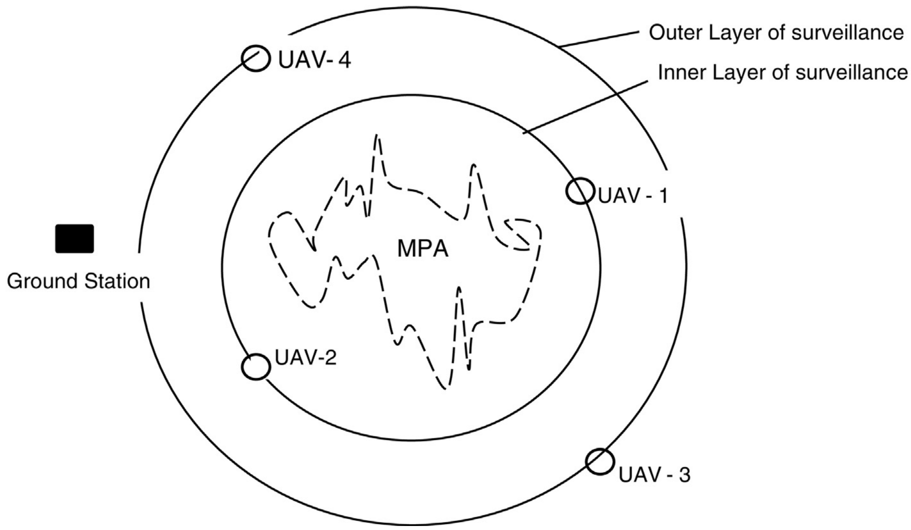

Fig.3. A possible mapping of the MPA with two layers of surveillance.

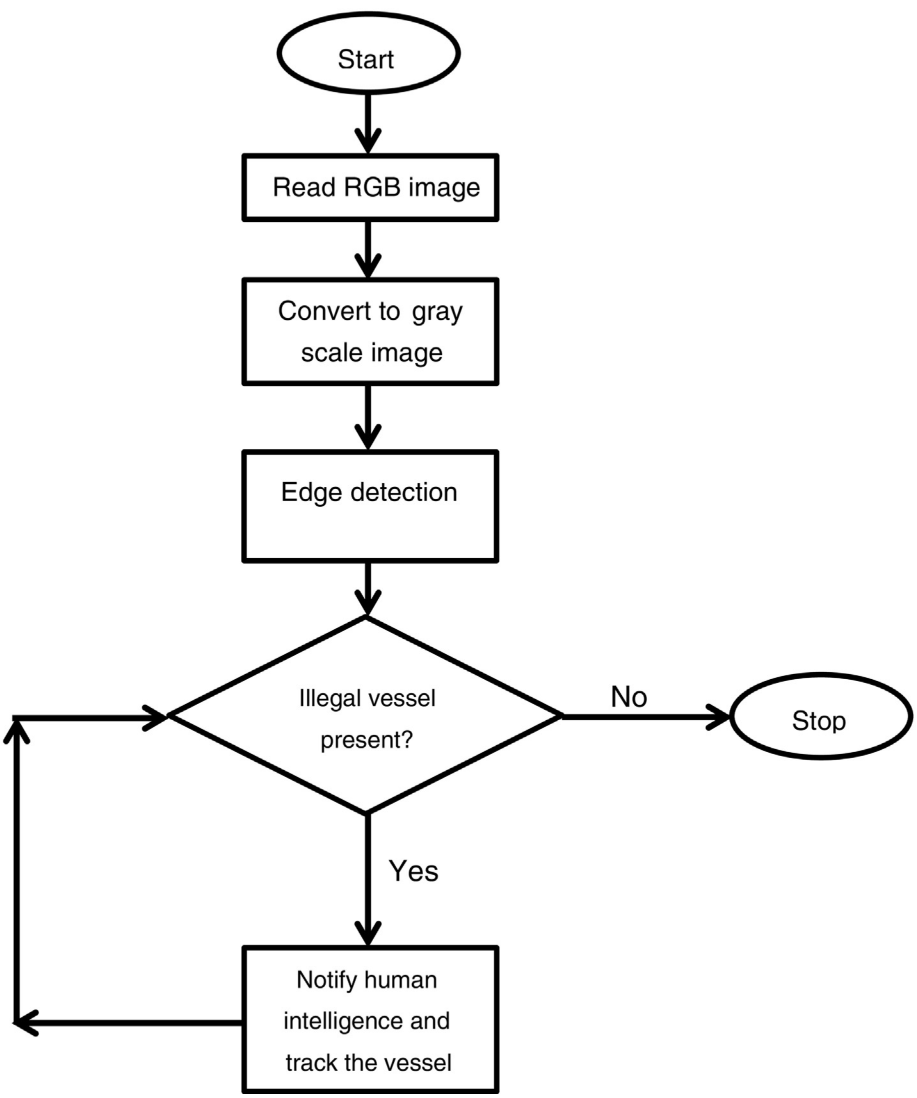

Fig. 4. Flowchart of the proposed algorithm for the MPA surveillance.

combinations of multi-stage operations. This is why these steps are discussed here as sub-algorithms.

Step 3 uses an edge detection operator for detecting edges—it is used not only for detection but also for tracking of the vessels. This involves elimination of unnecessary information and using the remaining structural information for determining the presence of any object of interest. While using the edge detection operator for detecting and tracking the object of interest in an MPA, it will detect two of the largest structural information—presence of vessel-like objects and presence of wake created by the vessel-like objects.

An edge detection operator, which is a mutation like an image edge to test the edge, is applied for edge detection. There are two fundamental sorts—one of them is the first derivative-based edge detection operator to detect edges by processing the gradient values. The first derivative based edge detection operators can be classified into two sections; the first one is Canny edge detection operator and the second one

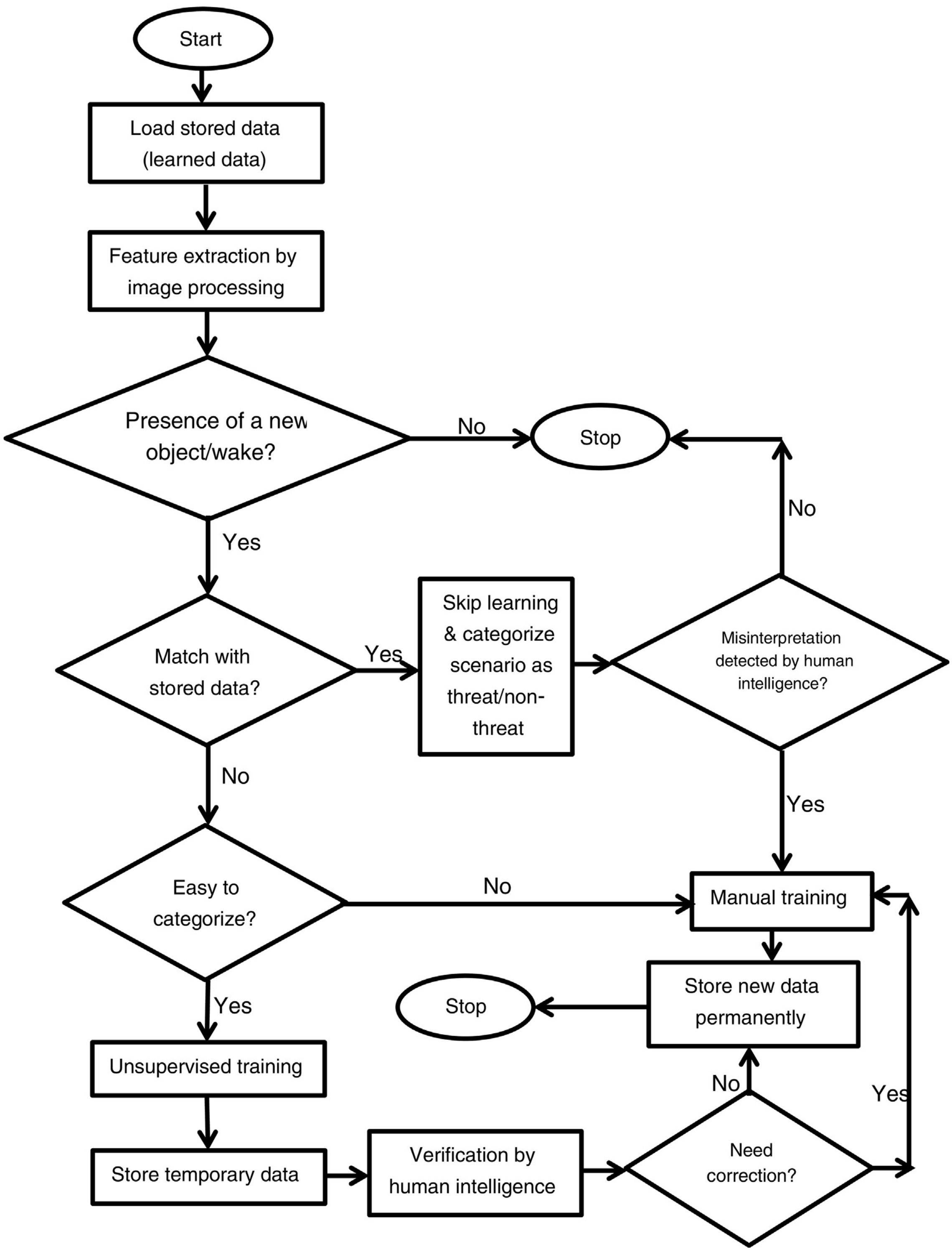

Fig. 5. Flowchart of the proposed sub-algorithm for detecting real-threat.

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is classical edge detectors: such as—Roberts operator, Sobel operator, Prewitt operator. The edge detection operator other than the first derivative-based one is the second derivative-based operator. It detects the edge by seeking the second derivative zero-crossing. This operator is categorized as Laplacian based operator—a typical example is Marr-Hildreth edge detector. Each edge detection operators have their pros and cons; for instance, classical edge detection operators are normally faster than the other ones, but normally include more disturbance than Canny edge detection operator.

Considering these issues, Canny edge detection operator is proposed, mainly for two reasons; the first one—natural marine wave and marine sunlight reflection may cause noise enough to face disturbance if the classical edge detectors are used and the second one—today's computers have speed enough to cope with the time-cost of Canny edge detector for MPA surveillance image processing.

Canny edge detection operator uses a multi-stage algorithm to detect a broad range of edges in an image. The process of Canny edge detection algorithm can be broken down into 5 different steps. So these steps can be considered as the steps of the sub-algorithm of Step 3. The sub-algorithm is presented here.

Step 3 (a): Read the grayscale image.
Step 3 (b): Apply Gaussian filter to smooth the image, i.e. to remove the noise.
Step 3 (c): Detect the intensity gradient.
Step 3 (d): Apply non-maximum suppression to avoid false interpretation.
Step 3 (e): Apply double threshold to find missing edges.
Step 3 (f): Suppress the weak edges.
Step 3 (g) Finalize the detection.

Since this sub-algorithm does not contain any decision-making step, and thus a well-known straightforward algorithm, the illustration by flowchart is skipped for this one.

Step 4 checks if there is any illegal vessel present in the analyzed image. However, note that any moving object including the marine fauna may cause marine wake enough to cause misinterpretation and detection of a false threat. This glitch can be eliminated by providing structural example data—the system will compare the detected object-wake with the available data stored in it. To make the system more efficient and compatible with real situation scenario, an artificial intelligence should be added to the system so that the system, itself can identify the object-wake situation to be a threat or non-threat category. This is why step 4 of the main algorithm should be run with a multi-stage sub-algorithm. A possible sequence of operations of the sub-algorithm, as proposed by the author, is represented here.

Step 4 (a): Load previously stored data.
Step 4 (b): Read the extracted edge i.e. structural information of the image.
Step 4 (c): Check if there is the presence of a new object/wake.
Step 4 (d): If a new object/wake is present, check if it matches with stored data.
Step 4 (e): If there is a match, skip learning and categorize scenario as threat/non-threat.
Step 4 (f): Check if human intelligence has detected a misinterpretation.
Step 4 (g): If misinterpretation is detected by human intelligence, proceed to Step 4 (h).
Step 4 (h): Learn from human intelligence by manual training.
Step 4 (i): Store data permanently.
Step 4 (j): If there is no match with previous data (as checked in Step 4 (d)), check if it is still easy to categorize as threat or non-threat.
Step 4 (k): If it is not easy to categorize, go back to Step 4 (h).

Fig. 6. RGB image fed into the system.

Step 4 (l): If it is easy to categorize, learn data by unsupervised training.
Step 4 (m): Save temporary data.
Step 4 (n): Verify the categorization by human intelligence.
Step 4 (o): Check if any correction is needed.
Step 4 (p): If correction is needed, go to Step 4 (h).
Step 4 (q): If correction is not needed, go to Step 4 (i).

The algorithm shows that the system uses its stored data to categorize the presence of object-wake scenario as threat or non-threat. If it misinterprets data and detects a non-threat scenario as a threat or vice versa, it is trained manually. It is also trained manually if it cannot categorize the scenario itself, i.e. the scenario is not easy to interpret by the system itself because of inadequate data availability. Note that at a time, when sufficient data is stored in the system, this sub-algorithm will most likely complete its purpose at step 4 (e), and then will go back to the original algorithm. The sub-algorithm is also illustrated by a flowchart in Fig. 5.

3. Results and discussion

Fig. 6 is a possible example of a true-color image or Red-Green-Blue image (RGB image) that can be fed into the system. The original RGB image was taken from here: [13].

Fig. 7 shows the conversion of RGB image to grayscale image, whereas Fig. 8 shows the edges created by object-wake detected by the Canny operator. The author used Matlab for the image processing in the current study. However, the proposed system may use a different language for this purpose.

Fig. 7. Converted grayscale image.

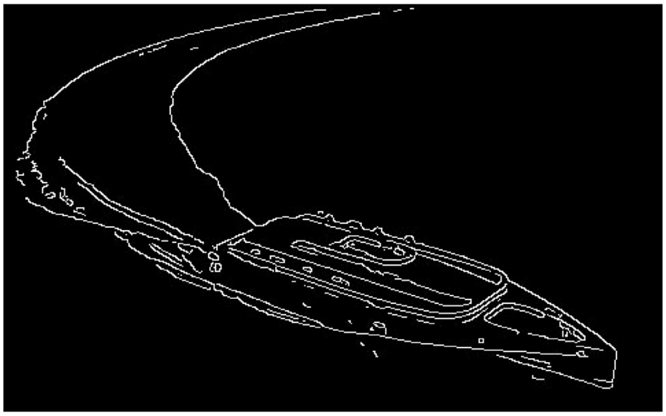

Fig. 8. Object-wake edge detected by Canny operator.

The artificial intelligence, as proposed in the algorithm section in this article, can be applied to this extracted feature to determine if it is a threat to the MPA. As it is a threat to the MPA, human intelligence will be notified accordingly with the specific GPS coordinate of the threat to take immediate action. The structure will also be tracked as long as the threat is not minimized.

The proposed MPA system in the current study is apparently better than the MPA management system proposed by Kachelriess et al. [12], mainly because of the utilization of airborne image sensing instead of satellite-based remote sensing. The main advantage is that airborne image sensing will maintain an unremitting surveillance of the MPA, whereas satellite remote sensing will not.

4. Conclusion

The current study proposes an MPA surveillance system that uses a UAV system for image sensing and a control system to analyze and interpret the data. The study proposes the system structure, execution planning and algorithm of the MPA surveillance system. Apparently, the proposed MPA system, integrated with human intelligence, ought to be an efficient MPA surveillance system. Implementation of the proposed MPA surveillance system can make an MPA management system much more efficient than the current ones.

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