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AUTOMATIC NAVIGATION OF USV FOR FLOATING AQUATIC WEED REMOVAL IN LAKE

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Abstract

The inland water bodies play a crucial role in human lives by providing water for various purposes. Infestation of these water bodies with invasive floating aquatic weeds impairs their usefulness to fulfill their envisaged functionalities. Hence, removal of the floating aquatic weeds is essential to maintain the envisaged functionalities of the water bodies. The present paper proposes a novel method for steering unmanned surface cleaning machines, such as surface cleaners and trash skimmers, automatically towards floating individual and small-size clusters of aquatic plants, for collection. A video camera is fitted on the front side of the USV vehicle. The front view camera is utilized to periodically capture sample color videos of the water surface lying in front of the vehicle. The sample video containing specified number of frames is separated into individual frames. Each color video frame is processed to segment the regions covered by the floating green color weeds based on the green color of the weeds. Each frame is divided along the image width to create 3 equal vertical partitions, which represent the left, straight and right directions of the vehicle movement. In each frame, the percentage of pixels covered by the green weeds is determined separately for all the 3 partitions. The USV vehicle is directed towards the left, straight or right directions depending on the partition exhibiting highest percentage of green coverage. The proposed method was implemented on an embedded hardware setup consisting of Raspberry Pi Model *B* processor using Open CV Python 3.8.0 software tool.

1. Introduction

Inland water bodies, such as rivers, canals, lakes and ponds, play a crucial role in human lives. They provide water for drinking, irrigation and

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industry usage, help navigation, allow aquatic sports and recreational activities. However, these water bodies usually get infested with different types of invasive aquatic weeds, including floating type aquatic weeds. The floating aquatic weeds include algae, duckweed, water meal, star duckweed, water lettuce, water hyacinth, clasping-leaf pondweed, curly-leaf pondweed, hydrilla, milfoil, coontail, cattails, water lily, water shield. Some of these plants, such as water hyacinth, water meal, water lettuce, after a certain growth stage, tend to form into matted cluster of plants. This infestation of inland water bodies with invasive floating aquatic weeds impairs the envisaged functionalities of the water bodies. Thus, removal of the floating aquatic weeds is essential to maintain the useful functionalities of the inland water bodies [9].

The unwanted aquatic weeds are removed using mainly three methods, namely biological, chemical and physical methods. A highly infested water body is subjected to an initial major cleaning procedure which is usually a combination of the above three methods. The physical methods carry out separation, collection and transport of weeds using a variety of machines, such as harvesters, cutters, shredders, etc. Additionally, surface cleaners and trash skimmers are used to collect floating individual and small-sized clusters of plants [3]. Several models of surface cleaners are available commercially. Most of these commercial models are manually controlled by human operators seated inside the machines. On the other hand, several research prototypes of remote-controlled unmanned surface cleaners are reported in literature [4]. All these unmanned models use a slanted conveyor to pick up the floating weeds from the water surface, move them up and drop them into an elevated collection bin. Some models also provide cutters to cut the matted plants [1].

The unmanned surface cleaners exhibit several advantages for control of infestation. However, maximum operational distance of these remote-controlled vehicles is limited by the visibility range of the operator situated on the bank. The vehicle may be added with more autonomous features for extending the operational distance by utilizing additional sensory inputs, such as GPS coordinates from a GPS module, live video display of the vehicle's surroundings from an on-board camera and visual details of the surroundings using automated analysis of the video of the surroundings. The

GPS capability allows way-points based navigation mode where the vehicle navigates sequentially through user specified way points. However, navigation along the limited number of waypoints may not assure efficient collection weeds in a lake. Also, the GPS capability is usually utilized to develop a grid-type navigation pattern for systematic scanning of the entire water body. The GPS based navigation along the grid-type path pattern can be satisfactory if the weeds are distributed uniformly over the entire water body. However, navigation may become quite inefficient, if the weeds are randomly and sparsely distributed over the water body. Thus, for unmanned surface cleaners, the navigation scheme critically influences the collection performance. Hence, there is a need for development of more efficient automated navigation methods for improving the collection of weeds.

Considering the above circumstances, the present paper proposes a color vision- based method for efficient collection of free floating aquatic weeds. The method assumes that the weeds are green in color and are available as free-floating individual or small-clusters of plants. The unmanned vehicle is fitted with a camera mounted at a height on the front side. Thus, for unmanned surface cleaners, the navigation scheme critically influences the collection performance. Hence, there is a need for development of more efficient automated navigation methods for improving the collection of weeds. As the vehicle moves, the camera captures continuous video of the water-surface lying at a distance in front of the vehicle at a slow frame rate. The individual video frames are analyzed to detect the regions covered by the weeds based on their green color. The frame is considered to be divided into 3 equal partitions along its width, namely left, straight and right partitions. The percentage of pixels covered by green weeds is determined for the left, straight and right partitions. The vehicle is directed to left, straight or right direction, based on which partition exhibits maximum weed coverage. The method will be useful for collection of free-floating individual and small sized clusters of plants on the water surface. The matted plants can also be collected, after dividing the mats into smaller clusters using a cutter. The proposed method saves battery life & time, and also improves collection performance.

The proposed method is implemented on an embedded hardware setup using Open CV software environment. The functionality of the developed setup is tested in off-line mode by analysis of sample images of floating aquatic weeds growing in lake environment. The embedded setup consisted of a video acquisition device, a processor, LEDs, a display device. The setup is used to analyze a sample image, determines the image partition having the highest weed coverage and gives an indication of the result by glowing a corresponding LED. This paper is structured as follows. Literature survey of related work is provided in Section II. The proposed method is described in Section III. The results of our method are provided in Section IV. Finally, our conclusions and summary are given in Section *V*.

2. Literature Survey

The development of Unmanned Surface Vehicles (USVs) with advanced Guidance, Navigation, and Control (GNC) capabilities were discussed which are used in commercial, scientific, and military issues associated with both oceans and shallow waters were discussed in [12]. In this paper, authors provided an overview of both historical and recent USVs development and outlined existing USVs GNC approaches and classified according to various criteria, such as their applications, methodologies, and challenges. In [5], authors provided an overview of more effective, compact, commercially available and affordable navigation equipment, including Global Positioning Systems (GPSs) and Inertial Measurement Units (IMUs), as well as more powerful and reliable wireless communication systems. In [11], authors developed a USV platform for autonomous navigation in the paddy field. A radio controlled air propeller and a GPS compass system for navigation was attached to the top of the USV. The USV platform can autonomously navigate to the predefined navigation map for autonomous weeding, intelligent fertilization or paddy growth management. For autonomous map navigation, turning control method was used which is easy to implement but cannot accurately control the turning radius. If vehicle captures sky-land-water image in lake environment, the horizon line detection methods will helpful to segment the water region from sky-land regions. In [2] [7], authors proposed different techniques to detect horizon line. But detected line is straight line and is not exactly meet lake environment shore line nature. To detect exact shore line, as in [9], we proposed a K-means clustering followed by seed based region growing using Fast Marching method. The water region is separated from sky and land regions in lake environment. Hence the vehicle concentrates on green color weed appearing in water region only and not on the green color based trees, grass etc., on shoreline. In case the color of the lake water is similar to the color of the weed, the determination of weed coverage percentage will be quite complex. So, the method for detection of objects floating on water surface is considered as a primary step. In [6], authors proposed an obstacle-detection system for small, lake-deployed Autonomous Surface Vehicles (ASVs) that relies on a low-cost, consumer-grade camera and runs on a single-board computer. Their proposed method was used to detect obstacles in lake environment by using gradient-based image processing algorithm. By using this algorithm, water region is segmented and obstacles are detected and hence weeds were easily identified.

3. Methodology

The USV based surface cleaner vehicle is fitted with a camera on its front side. The camera is mounted at a height, oriented in forward direction at a known tilt angle. The height and tilt angle are chosen to image a region located at a specified distance in front of the camera. In the captured image, the bottom region corresponds to water surface region is closer to the camera.

The vehicle continuously captures the video of the water surface region lying in front of the vehicle. The video is separated into a number of individual video frames. Each frame is analyzed separately. However, the basic functionality of the proposed method is demonstrated in off-line mode by analyzing a few sample images showing the growth of aquatic weeds over water surface of a water body. In this, vehicle captures a video and it is converted to frames. These frames undergo preprocessing techniques for proper segmentation of green pixels. Finally, this processed frame is divided into three parts for weed calculation and the vehicle is directed to the more weedy direction. The block diagram and schematic diagram of proposed system is shown in figure (1) and (2).

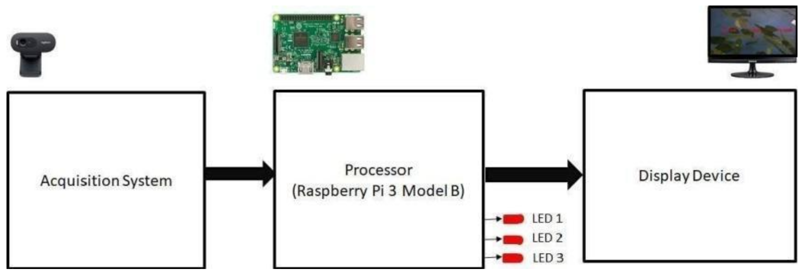


Figure 1. Block Diagram of Proposed system.

The proposed method is implemented on an embedded setup, which mainly consists of video acquisition system, processor LED's, and display device.

The video acquisition system consists of a Logitech C270 HD webcam with its technical specifications given as fluid HD 720p video calling and recording in 16:9 widescreen, max resolution: 720p/30fps, FoV: 60°, crisp 3 MP photos, automatic light correction, video capture: up to 1280×720 pixels, built-in mic with noise reduction, hi-speed USB 2.0, universal clip fits laptops, LCD or CRT monitors. The processor consists of a third generation Raspberry Pi 3 Model B. This has more powerful processor, which is 10x faster than the first-generation Raspberry Pi. It also has wireless LAN and Bluetooth connectivity facility. As shown in the figure 2, the Logitech C270 HD Webcam is connected to the processor using a Universal Synchronous Bus (USB) through the one of the 4 available USB ports. The three LED's which indicate the moving direction of the USV are connected to the GPIO pins of the processor. The LED1, LED2 and LED3 are connected to the pin 11, pin 7 and pin 3 of the processor and they are commonly connected to the pin6 which is the Ground pin of the processor [8].

An Open CV Python program is developed to implement the image processing algorithm. The flow chart of image processing algorithm, as shown in Figure 3, consists of various blocks which represent the various tasks that are performed on the input samples in order to obtain the desired output. First the video is taken by using the acquisition system and this video is converted into frames. Then each frame undergoes some preprocessing operations for removing noise. For this purpose, Gaussian filter is used. After that the RGB frames are converted into HSV and based on Hue value, the threshold based segmentation is performed in order to separate weed and others such as water and other obstacles. Each frame is divided into three equal partitions along the image width and weed percentage is calculated in each partition. Based on highest weed percentage value, the processor "ON" the corresponding LED. Consider LED1 for left movement, LED2 for straight movement and LED3 for right movement of the USV. Example is shown in Figure 4 which explains input image and output image of the proposed method. The weed percentage is displayed on image in three parts that represents left, straight, and right movement of the USV. From example it is clear that the USV should be moved in the right direction only so as to minimize navigation path length. Such that the vehicle saves time and battery life. Figure 5 explains the proposed method step to step procedure for one sample image.

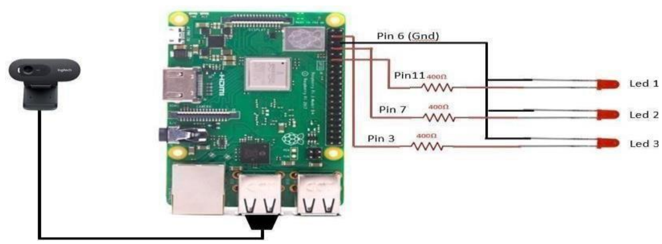


Figure 2. Schematic diagram of proposed method.

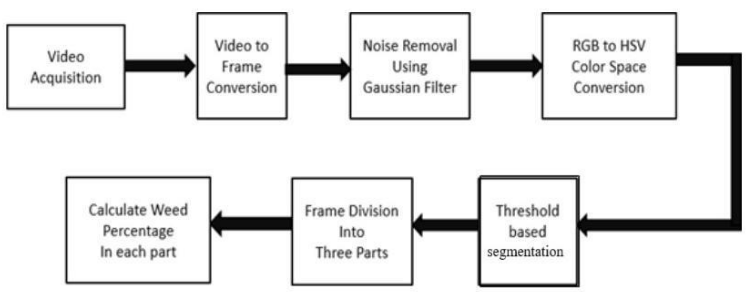
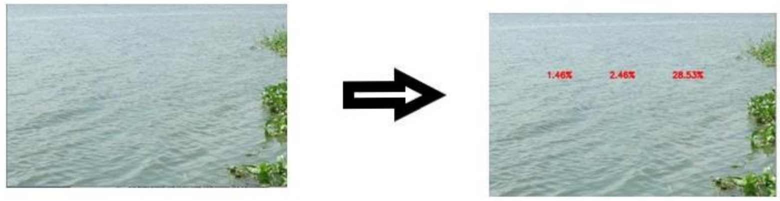


Figure 3. Flow chart of proposed method.



(a) input image (b) output image

Figure 4. Example for proposed method input and output images.

Proposed method image processing algorithm is described below as

1. Acquiring video using camera at a specified frame rate and writing it as .avi.

2. Converting the video into individual frames at frame rate one frames per second.

3. On each frame the following operations are performed:

- Frame is resized
- The height and width of the frame are noted.
- The frame is smoothened using 5x5 size Gaussian filter function of the Open CV library.
- The frame is converted from RGB to HSV color space.
- Green color region is segmented by selecting pixels exhibiting H, S, V values lying between two specified limits in [H S V] values. Here [H, S, V] range is from [20, 50, 50] to [80, 255, 255].
- Morphological operations are performed.
- Frame is partitioned along the width into 3 equal blocks.
- In each block weed percentage is calculated.
- The percentage is marked on the resized image.

4. Based on the highest weed percent value the LED glows.

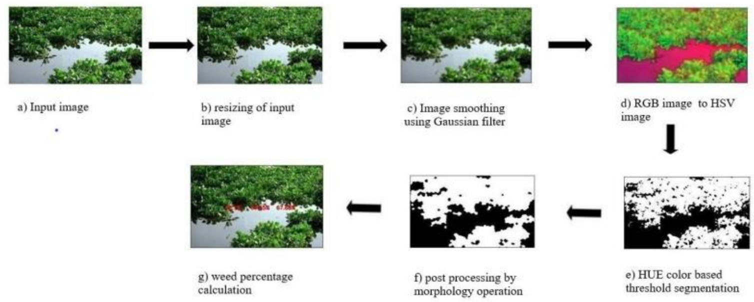


Figure 5. Proposed method step to step procedure for one sample image.

5. Results and Discussions

The proposed method was implemented using Open CV software executed on the computer and Raspberry Pi based embedded board. Videos stored on the computer were read and analyzed. The input image of size 640×480 is converted to sample image of 800×500 pixels size. After resizing the sample image undergoes some smoothing techniques for the purpose of removing noise. Here Gaussian Blur is used for smoothing. After smoothing, the sample image in RGB color space is converted into HSV color space. The green colored objects in the image are segmented by selecting the pixels lying within a specified range of HSV values. Based on the Hue value of green color the weed and others are segmented. Here the resulting image is a binary image in which the weed region is represented in white. In this step the sample image undergoes morphological transform in order to remove the imperfections of the binary sample. Based on the number of white pixels present in the binary sample the weed percentage is calculated as in equation (1) in left, middle and right parts of the sample image.

Weed

$$\text{percentage} = \frac{\text{total number of white pixels}}{\text{total number of pixels}} * 100\%. \tag{1}$$

Case 1. In Table 2, by comparing the ground truth image of the sample and its corresponding output binary image obtained from the algorithm, the performance metrics are calculated and tabulated in table 5. For good appearance, for an image two percentages only considered.

Case 2. Without Water Segmentation: In Table 3, the algorithm is completely based on the threshold-based color segmentation and hence, it failed in calculating the weed percentage appropriately.

Case 3. In Table 4, the water is segmented by using the edge segmentation techniques like gradient based segmentation, as in [6], prior applying the sample to the algorithm.

Case 4. If the sample image comprises Sky-Land-Water regions, then this algorithm failed to detect accurate weed percentage. Hence, it is necessary to eliminate Sky-Land region by using the shore line detection, as in [9] prior applying it to the algorithm as in Figure (6).

Table 2. Comparison table for ground truth and output binary images obtained from the algorithm.

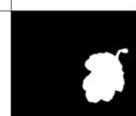
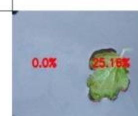
Sample NO.	Input	Ground Truth Image	Output Binary Image of proposed algorithm	Result (Calculates White Percent)
1.				
2.				
3.				
4.				

Table 3. Output images are obtained based on color segmentation without segmenting water.

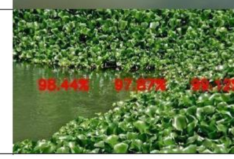
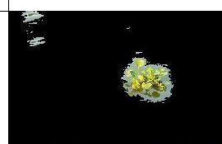
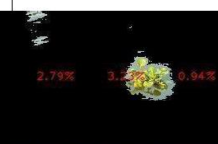
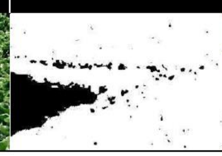
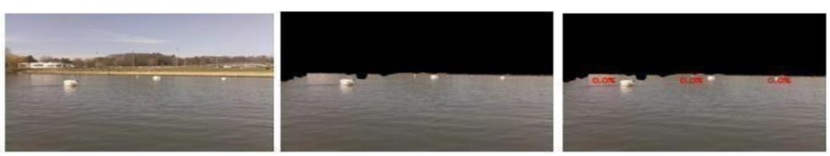
Samples	Input images	Binary Images	Result
Sample 1			
Sample 2			

Table 4. Output images are obtained based on color segmentation after segmenting water.

Samples	Input images	Binary Images	Result
Sample 1			
Sample 2			



(a) Image comprising sky, land and water (b) Image after shore line detection (c) weed percentage output image

Figure 6. Case 4 results.

The Table 5 gives the performance metric values for the samples mentioned in Table 2. The Table 6 gives the number of white and black pixels present in the ground truth images of the samples present in Table 2.

Table 5. Performance metrics values for the proposed algorithm.

S.No	Sample	True Positive (TP)	True Negative (TN)	False Positive (FP)	False Negative (FN)	Perfomance Metrics			
						Accuracy	Precision	Recall	F1-Score
1.	Sample 1	12705	146532	817	82	0.99438	0.93957	0.99358	0.96582
2.	Sample 2	94757	247172	1	6828	0.98041	0.99998	0.93278	0.96521
3.	Sample 3	13690	106916	692	4412	0.95939	0.95188	0.75627	0.84287
4.	Sample 4	74845	78170	7307	110	0.95376	0.91105	0.99853	0.95279

Table 6. Number of black and white pixels present in ground truth images of the given samples.

S.NO	Sample	True Positive (Number of White Pixels)	True Negative (Number of Black Pixels)
1	Sample 1	12787	147349
2	Sample 2	102780	247179
3	Sample 3	18102	107608
4	Sample 4	74955	85477

The difference in the values of the true positive and true negative values of the Table 5 and 6 indicates the error rate of the proposed algorithm. For example consider the case of sample 1, by using the proposed algorithm the value of true positive is 12705 and for the ground truth image we got 12787 so we are losing the information of 82 pixels. Even for the case of true negative also we lost 817 pixels information. All the false positive and false negatives of above samples are zeros for the case of ground truth image.

The proposed method has been demonstrated satisfactorily by using sample images. However, the performance is expected to be similar when the USV based surface cleaner employs the proposed method to analyze the real-life images obtained by the vehicle. In a real-life image, the pixel height of an object region from the bottom row corresponds to the distance of a weed object from the vehicle (camera). On the other hand, the pixel area of an object corresponds to a higher physical area due to image corrections resulting from camera tilting.

6. Conclusion

Infestation of water bodies with invasive floating aquatic weeds impairs the usefulness of the water bodies for their intended functionality. Control of infestation of inland water bodies requires periodic visual inspection of the water surface and physical removal of the floating aquatic weeds. A USV based surface cleaner fitted with a front camera can be used for systematic scanning of the water surface and collection and removal of floating aquatic weeds. Present paper proposed a vision based method for directing the vehicle towards the floating weeds, by detecting the weeds based on their green color. The water surface lying in front of the moving vehicle is videographed at frequent intervals. The individual video frames are analyzed to detect the presence of aquatic weeds based on their green color and determine their extent of coverage in the left, middle and right portions of the frame. Accordingly, the vehicle is directed towards left, straight or right directions depending on which image portion has the highest weed coverage. After collecting the detected weed, the procedure is repeated. In a lake having sparsely distributed weeds, the proposed method can significantly reduce the travel path of the vehicle for collection of the weeds, compared to the conventional grid pattern of navigation, As the proposed method detects weeds based on their green color, the method doesn't perform well in water bodies having greenish colored water, due to similarity in color. This problem could be solved by eliminating water by using the edge segmentation techniques. Another problem is that there exists some uncertainty when the sample image comprises land or sky along with the water body. Hence, it is necessary to eliminate the land and sky by using the shore line detection prior applying the sample to the algorithm.

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