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Red Palm Weevil (*Rynchophorus Ferrugineous, Olivier*) Recognition by Image Processing Techniques

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Abstract: Problem statement: Red palm weevil is the most destructive insect for palm trees all over the world. This research is part of developing an automated wireless red palm weevil detection and control system. The focus for this study was to develop red palm Weevil recognition system which can detect RPW in an image and can be used in wireless image sensor network which will be part of entire proposed system. **Approach:** Template based recognition techniques were used. Two general recognition methods i.e., Zernike and Regional Properties and an algorithm combining them were used. Besides that, a novel technique for detecting Rostrum of RPW named as 'Rostrum Analysis' was proposed and used for recognition, a conclusive algorithm based on all three techniques was also proposed, 319 test images of RPW and 93 images of other insects which found in RPW habitat were used. **Results:** It was found that both general techniques i.e., Regional Properties and Zernike Moments methods perform reasonably in recognizing RPW. The algorithm based on both these methods performs better than individual methods. The Rostrum Analysis outperforms better than both the earlier methods and proposed algorithm using all three analytical techniques gives best results among all discussed techniques in recognizing RPW as well as other insects. **Conclusion:** The most balanced and efficient recognition technique is to use the proposed conclusive algorithm which is combination of Regional Properties, Zernike Moments and Rostrum Analysis techniques. The maximum time for processing an image is 0.47 sec and the results obtained in recognizing the RPW and other insects are 97 and 88% respectively.

Key words: Insects identification system, Red Palm Weevil (RPW), image processing, automated recognition system, wireless image sensor network, Integrated Pest Management (IPM)

INTRODUCTION

During the last two decades, Red Palm Weevil (RPW), scientifically known as *Rynchophorus Ferrugineous* (*Olivier*), became one of the most dangerous threats to the Palm trees in most parts of the world. RPW was first identified in start of twentieth century in South and Southeast Asia (Lefroy, 1906; Brand, 1917). In later part of the twentieth century, the existence of RPW was also reported in Middle-east Asia, North Africa and Europe (Buxton, 1920; Abraham *et al*., 1998; Al-Ayedh, 2008). At the end of the twentieth century, RPW was reported in Australia (Li *et al*., 2009; Faleiro, 2006). Currently, it is also reported in some parts of United States of America (Nisson *et al.*, 2010). The geographical spread of RPW is mainly due to the transportation of infested plants from infected regions to other places.

RPW mostly attacks young Palm trees under the age of 20 years (Abraham *et al*., 1998; Nirula, 1956). The life cycle of RPW is reported to vary from 45-139 days depending on the environmental and geographical conditions and is spent inside the palm tree itself (Faleiro, 2006; Esteban-Duran *et al*., 1998; Murphy and Briscoe, 1999). The four stages of its life cycle are described in Fig. 1. These four stages are: egg, larva, pupa and adult as shown in Fig. 1a-d respectively.

The female RPW lays eggs, ranging from 58-531 in quantity, in the cracks, wounds or crevices on the trunk of the tree. The grubs which is white-yellow larvae hatches from the eggs in a week and starts feeding itself by chewing the tissues of the plant and starts moving towards the interior of the plant. The grub leaves behind the chewed-up tissues of the plant which is usually visualized as thick brown fluid from the tunnels. The grub lives for 25-105 days and it becomes a pupa in a cocoon which is made up of chewed-up

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tissues of the plant. The developmental state of pupa usually takes 11-45 days (Abraham *et al*., 1998; Faleiro, 2006). After that, the adult RPW emerges. Mostly RPW has several generations inside the infested plant. Therefore, the RPW infestation is detected at such a later stage that it is not possible to save the infested palm. The RPW stays in the infested plant till it is hollow from inside and dead. After the death of infested plant, the RPW moves (flies) to the neighboring plants. The rate of multiplication of RPW is very high due to the reason that female lays egg continuously throughout the year.

The existing methods for managing and controlling the RPW involve detecting their existence/origination and then applying insecticides if the attack is in early stage otherwise burning the infested plants or infested part of the plants. The remedial actions depend on the stage of attack of RPW. Currently, there is no standardized technique for eliminating RPW without damaging the palm tree. The only possibility to save palm tree with minimum damage is to detect the existence of RPW in early stages.

The most successful way of controlling and managing RPW is reported from India by using Integrated Pest Management (IPM) program (Abraham *et al*., 1989). It includes monitoring and taking care of palm trees regularly, trapping adult RPW, treating cuts and infections in palm trees, detecting RPW at early stage, treating plant in early stages if infected with RPW, eradicating infested plants, proper cutting of fronds and training and educating farmers and agriculture officers (Faleiro, 2006). In IPM program, the early detection of RPW is ensured to save the palm tree which plays a critical role.

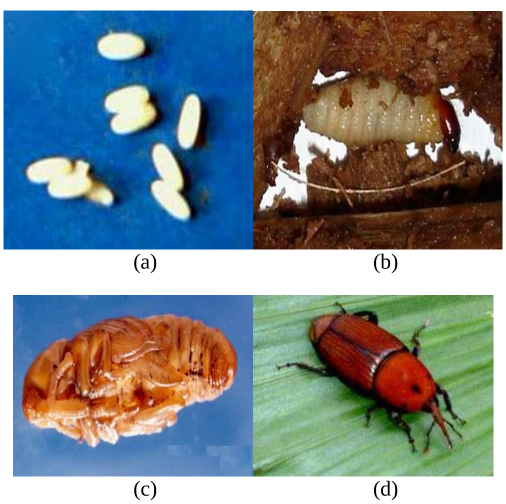

Fig. 1: The four life stages of the Red Palm Weevil (Red Palm Weevil Control for Date Palm Trees, 2010) (a) eggs (b) larva; (c) pupa fibrous cocoom removed and (d) adult RPW

The attack of RPW is usually detected by observing the symptoms described by Abraham *et al*. (1998). The infested plant is usually found by one of the below mentioned three generalized ways:

- Visual observation: the field staff surveys the field and regularly checks the symptoms of the infested plant.
- Listening observation: the sound generated by the chewing grub can be detected by endoscope (Hamad and Faith, 2004) or any other equipment which can detect the sound. Currently, Digital Signal Processing techniques are also used to identify the presence of RPW in the plants (Al-Manie and Alkanhal, 2005)
- Smelling observation: the infested plant produces a typical fermented odor which can be detected by sniffer dogs (Nakash *et al*., 2000)

It can be observed that all the above mentioned observation techniques are laborious, time consuming and depend on the skills and ability of field staff. Overall, it is observed that neither there is any efficient result-assured standardized mechanism to detect the existence of RPW in palm trees nor there is any efficient standardized mechanism to eliminate RPW without damaging the palm trees.

However, there is another technique which is commonly used is by using traps which needs lesser skills of field staff. This technique also plays a pivotal role in IPM to detect RPW presence.

In this methodology, traps are established by using pheromone which attracts RPW. Once RPW are attracted towards the traps, they will feed on food mixed with pesticides which will eventually kill them. Another useful aspect of traps is to find the existence of RPW in the area and use insecticide in entire area to eradicate them. There are different designs of traps used worldwide depending upon the regions. There is no specific trap which is having more success than others. In Saudi Arabia, the inverted bucket and upright bucket traps are commonly used. In United Arab Emirates, the fabricated plastic traps are used while in India the inverted bucket traps are mostly used (Faleiro, 2006; Faleiro *et al*., 1998).

The fundamental trap design is to have several windows in a container that allows RPW to enter. The outside of the container is usually made rough by wrapping it with rough material. The RPW is lured by pheromone and palm stems mixed with insecticides are used as bait in the traps. Figure 2 and 3 mentions two different designs of traps for RPW.

Fig. 2: Bucket trap (Russel IPM)

Fig. 3: RPW trap designed by (Zhangzhou Enjoy Agriculture Technology Co.)

The trap density varies from 1 trap per 2 h to 10 traps per ha (Faleiro, 2006). Normally, it is recommended to use at least 1 or 2 traps per ha. These traps must be inspected regularly by field staff and should not be used for trapping any other insects. This technique of trapping RPW is still laborious but needs lesser skills of field staff as compared to other techniques. Due to this reason, traps are mostly used worldwide against RPW. With the existing advancement in technology, this laborious work can be reduced to minimal by automating the system. Instead of field staff to survey and check the traps for the existence of RPW, the automated system may identify the RPW presence and alert the field staff to take appropriate actions or even take basic preventive measures. With the use of Wireless Sensor Networks, the information can easily be gathered and forwarded to the main server efficiently. Sensor networks are already used in field to measure the different environmental parameters and to take control decisions accordingly. Its usage in different fields has already been established such as in the fields of Agriculture (Burrell *et al*., 2004), poultry (Murad *et al*., 2009), industries (Jan *et al*., 2010).

There are already many automated systems, without using wireless sensor network, proposed for identification of insects such as Automated Bee Identification System (ABIS) for identification of Bees (Arbuckle *et al*., 2001); Digital Automated Identification System (DAISY) for identification of Ophioninae (Watson *et al*., 2004); Automated Insect Identification through Concatenated Histograms of Local Appearance System (AIICHLA) for identification of Stonefly larvae (Larios, 2007); Species Identification Automated and Web Accessible System (SPIWA) for identification of Spiders (Do *et al*., 1999); a software system developed for identification for Pecan Weevil (Ashaghathra, 2008).

Based on what we have studied in literature, all the proposed systems have some limitations in its working and cannot be implemented directly for identification of RPW. In all the studied automated identification systems, wireless sensor network was not used. Besides that, in most of the systems, insects are required to be placed in certain orientation and at certain distance from the camera or any other identification device. It has also been observed that there is no generalized system for identification of different kind of insects. Besides that, no work was found regarding the automated systems for identification of RPW.

In order to develop a wireless automated system for RPW identification and control, the first step is the identification of RPW using digital image processing techniques. From the literature review, it is found that software has been developed for identification of Pecan Weevil insect which uses digital image processing techniques (Ashaghathra, 2008). In this research work, five different recognition methods were used based on template matching for recognizing Pecan Weevil. These methods were Normalized Cross Correlation, Fourier Descriptors, Zernike Moments, String Matching and Regional Properties. It was found that none of the method gave 100% accurate result but Zernike Moments method was found to be the best among the five studied methods. In order to improve the efficiency of the proposed identification system in terms of recognition and processing time as described in (Ashaghathra, 2008), Zernike Moments and Region Properties methods were used simultaneously for the identification of Pecan Weevil.

The objective of our research is to develop an algorithm for recognition of Red Palm Weevil and it needs to discriminate RPW from other insects which are normally found in or near palm trees. This research will play a pivotal role in later research studies which will involve designing and developing a wireless automated system for identification and control of RPW. The proposed algorithm is a first step towards developing this system. This step is considered pivotal because instead of visual observance of field staff, an imaging sensor mounted in traps, should take the images of insects. After taking the images, the wireless sensor network motes should process the images and then forwards the information to the server which may raise the level of threat if RPW is detected or vice versa.

MATERIALS AND METHODS

Recognition methods: The objective of this research is to develop software that can recognize RPW among different insects which are usually found in or around palm trees. The challenges in developing such an application are indefinite number of body sizes of RPW and orientation of the insect in the acquired image. Thus, such a technique is required which can recognize the targeted insect in all possible situations.

This research started by using two region based methods for identification of RPW. These methods are Zernike Moments and Region Properties. These methods were already working efficiently in identification of other type of weevils found in North America (Ashaghathra, 2008).

Zernike moments method: This method is a very efficient method due to its invariance in rotation, efficiency in expression, noise robustness, fast computing and representation of multi-levels for describing various shapes of patterns (Kim and Kim, 2000). In this method, a set of complex polynomials are introduced which form an orthogonal set over interior of a circle. The Zernike Moments computation comprises of three steps:

- Radial polynomials computation
- Zernike basis function computation and
- Zernike moments computation by projecting the image on to the basis function, as mentioned by (Hwang and Kim, 2006)

The form of these polynomials is presented below in Eq. 1:

$$V_{nm}(x,y) = Vnm(\rho,\theta) = R_{nm}(\rho)\exp(jm\theta) \qquad (1)$$

Where:
N = Order
M = Positive and negative integer (known as "repetition") with constraint
V = Length of vector from origin to pixel
Θ = Angle between vector and axis in counter-clockwise direction
R = Radial polynomial and it defined below in Eq. 2:

$$R_{nm} = \sum_{s=0}^{(n-m)/2} \frac{(-1)^s\left[(n-s)!\right]\rho^{n-2s}}{s!\left(\frac{n+|m|}{2}-s\right)!\left(\frac{n-|m|}{2}-s\right)!} \qquad (2)$$

These polynomials satisfy the orthogonality properties and are orthogonal:

$$\iint_{x^2+y^2\le 1}\left[V_{nm}(x,y)\right]V_{pq}\ (x,y)dxdy = \frac{\pi}{n+1}\delta_{np}\delta_{mq} \qquad (3)$$

Where:

$$\delta = \begin{cases} 1 & (a=b) \\ 0 & (\text{otherwise}) \end{cases}$$

Zernike moments of order with repetition for a continuous image function *f(x, y)* outside the unit circle is presented below in Eq. 4:

$$A_{mn} = \frac{n+1}{\pi}\iint_{x^2+y^2\le 1} f(x,y)\left[V_{nm}(\rho,\theta)\right]dxdy \qquad (4)$$

Integral may be replaced in Eq. 4 by summations, as all the images are digital:

$$A_{mn} = \frac{n+1}{\pi}\sum_x\sum_y f(x,y)\left[V_{nm}(\rho,\theta)\right] \quad \text{where } x^2+y^2\le 1 \qquad (5)$$

The center of the image is taken as origin and coordinates of pixel are mapped to the unit circle's range for purpose of computation of Zernike Moments. The pixels outside the unit circle are discarded. The orthogonal properties ensure that there is no redundancy or overlapping of information between moments with different orders and repetition (Kim and Kim, 2000).

Thus, each moment will be unique and independent representation of a specific image. The outperformance of Zernike Moments is already observed in many comparative studies such as (Belkasim *et al*., 1991; Ezer *et al*., 1994; Liao and Pawlak, 1996; Lin and Chou, 2003; Padilla-Vivanco *et al*., 2007; Park and Kim, 2005; The and Chin, 1998; Zhang and Lu, 2004).

Regional properties method: As the name mentions, this method is one of the techniques which use regional descriptors of the object. Instead of the boundary of the object in the image, it deals with the region of the image. This simple technique describes pivotal properties of regions of image e.g., area, orientation, centroid.

It has been observed that there are many insects which are similar to Red Palm Weevil in shape and size, but there is a feature of RPW, which distinguishes it from other insects i.e., its rostrum. The length of both of head and rostrum makes one third of the length of RPW (Al-Ajlan, 2008). It was observed that RPW is the only insect to have a rostrum among the insects found in or around palm tree habitat, so different regional characteristics are considered for the Regional Properties method.

To form the unique representation of RPW, lengths of major and minor axis and area of the region of RPW are used. The region is selected by considering the number of connected pixels in the image. The length of major axis and minor axis are taken as length (in pixels) and width (in pixel) of the considered region (ellipse) in the image respectively that has the same second moments as the region (Gonzalez *et al*., 2004).

Euclidean distance: Euclidean distance is implemented to measure the degree of similarity of the corresponding descriptors of an acquired insect image and the image of RPW existing in database. The Euclidean Distance's equation can be written as follows:

$$D = \sqrt{\sum_{i=1}^{n} \left(g(i) - h(i)\right)^2} \quad (6)$$

Using the descriptors of Zernike and Regional Properties methods, a threshold value of Euclidean Distance is determined for each method after conducting the experiments and examining the results to discriminate between the RPW and other insects. A tested image is recognized as RPW if the value of Euclidean Distance is not greater than the threshold value.

Collection of insects: The RPW were collected from two infested farms in Al-Kharaj, Saudi Arabia. During the visit, live palm trees were inspected and it was found that some of the trees were infested. In few worst affected trees, the sound of chewing of pupae was also observed. The trunk of the palm trees were cut and RPW were found belonging to all stages of its lifecycle inside the trunks of the trees. The adult RPW were flying in the range of 3-4 meters in an attempt to escape. Few adult RPW were collected and were placed in jars containing alcohol. The RPW died as soon as they were placed in the alcoholic jars.

Overall, 390 different adult RPW were collected. Later, 64 of them were rejected due to the damage done to their body shapes while collecting. The selected 326 RPW insects included both males and females genders. They also varied in size and age.

The source of other insects is the Kind Saud University's museum for insects. 93 insects of 20 different types were collected. The selected other insects are usually found in or around the palm trees while few of them also resemble to RPW in its features. The names of insects used in the experiment and their number of replicates are presented in Table 1.

Table 1: Other Insects for experiments

Scientific name (family/order)	Quantity
Calosoma Chlorostictum (Carabidae/Coleoptera)	5
Gryllus Bimaculatus (Gryllidae/Orthoptera)	10
Conocephalus Conocephalus (Tettigoniidae/Orthoptera)	5
Gryllotalpa Gryllotalpa (Gryllotalpidae/Orthoptera)	3
Gryllotalpa Africana (Gryllotalpidae/Orthoptera)	5
Oryctes Nasicornis (Scarabaeidae/Coleoptera)	13
Cybister Tripunctatus Africana (Dytiscidae/Coleoptera)	5
Scarites Eurytus (Carabidae/Coleoptera)	3
Lanelater Motodenta (Elateroidea/Coleoptera)	5
Mlabri Tenebrosa (Meloidae/Coleoptera)	3
Hyles Lineata Livornica (Sphingidae/Lepidoptera)	5
Coccotrypes advena (Curculionidae/Coleoptera)	3
Gnopholeon Sp. (Myrmeleontidae/Neuroptera)	3
Blepharopsis Mindica (Mantidae/Mantodea)	2
Anax Sp. (Aeshnidae/Odonata)	3
Xylocopa Hottentota (Anthophoridae/Hymenoptera)	5
Poikiloderma (Pamphiliidae/Orthoptera)	4
Lophyra Sp. (Carabidae/Coleoptera)	5
Scarabaens Sp. (Scarabaeidae/Coleoptera)	3
Cerceris Rybyensis (Sphecidae/Hymenoptra)	3

Fig. 4: Imaging System used in lab

Image acquisition: In such type of template-based applications, set of large number of template images play a pivotal role in matching and recognition. To acquire this, large number of insects were collected. The collected RPW samples were taken out of alcoholic jars in the lab and were dried thoroughly. In order to take images of the RPW, their legs were stretched out to resemble body orientation of the normal living RPW. After preparation, the images were taken by imaging system.

Imaging system: The imaging system used in lab is presented in Fig. 4. It consists of Sony Cyber-shot DSC-HX1 camera which can shoot at 10 frames per second and equipped with 9.1 megapixel resolution and 20x optical zoom. Images of insects taken were of the size of 3456 X 2592 pixels.

The lighting system was designed and built in workshop of the department. The lamp housing dimensions were 67 cm (Length) ×46 cm (Breadth) ×25 cm (Height). It had 3 Philips TL RS 20W/54-765 lamps. On top of the lighting box, an opaque white-glass cover of thickness 0.31 cm was placed.

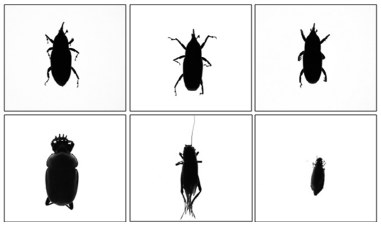

Fig. 5: Sample pictures of Red Palm Weevils (1st row) and other insects (2nd row) by the imaging system

For performing the simulations, Dell Optiplex 780 computer having Intel Core 2 Duo E8400 3.0 GHz processor and 4 GB RAM was used. The software used was MATLAB® Version 7.9.0.529 (R2006a). Some pictures of the insects snapped by the imaging system are presented in Fig. 5.

Errors: In this research, Error is defined as a case when RPW is falsely recognized as other insect or other insect is falsely recognized as RPW. The error in recognizing RPW can be categorized in two types:

- Type-I Error: When other insect is recognized as RPW
- Type-II Error: When RPW is recognized as other insect

In our research, if there is false alarm due to Type-I Error then this means that system is more sensitive to RPW while if system misses to alert because it does not recognize RPW then it is an inefficiency of the system. Thus, for our research, Type-II Error is of more critical nature as compared to the Type-I Error.

Threshold value: In literature relevant to Computer Vision, finding a threshold value is considered by some scientists as "Black Art" (Faugeras, 1993) while others proposed some techniques such as Fixed Thresholding (Savakis, 1998), Optimal Thresholding (Snyder *et al*., 1990), Otsu's Thresholding (Otsu, 1979). But none of these threshold finding techniques can be used as general techniques to find threshold value for all applications.

In this research, in order to keep the Type-II error low, threshold value is taken as a cut-off value where 85% of the RPW images are correctly identified.

RESULTS AND DISCUSSION

Using zernike moment method: Firstly, the method of Zernike Moments was implemented on all images for recognizing Red Palm Weevil and other insects.

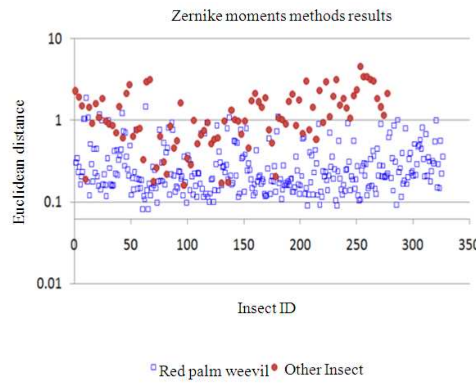

Fig. 6: Euclidean Distance (Degree of Similarity) distribution using Zernike Moment method

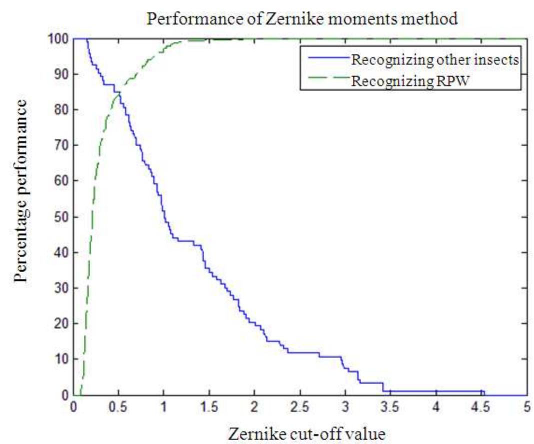

Fig. 7: Performance of Zernike moment method

The degree of similarity found for each image is shown in Fig. 6. The Zernike Moments method was used in different orders ranging from 2 to 8 and was showing the similar pattern of results. The Zernike Moments for order 5 is chosen due to its optimal processing speed and performance.

It can be observed from Fig. 6 that degree of similarity for all insects are distributed over a certain range. The degree of similarity for RPW usually remains low while it is higher for other insects except some exceptional scenarios. It can be seen in Fig. 6 that there is no clear boundary or threshold value that can separate RPW from other insects. The performance of correctly identifying RPW and other insects vary and depend upon the chosen cut-off value. The change in performance for identifying RPW and other insects with respect to change in cut-off value is shown in Fig. 7. The Threshold Value is obtained to be 0.53 where 85% of RPW are correctly identified.

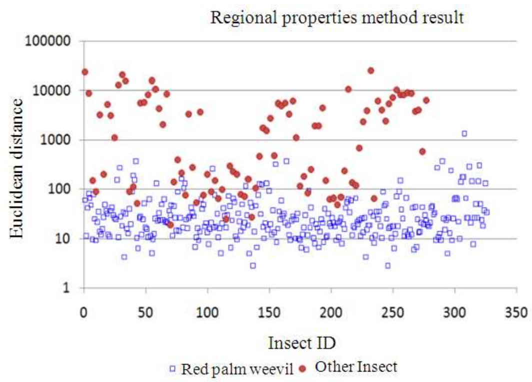

Fig. 8: Euclidean distance (degree of similarity) distribution using regional properties method

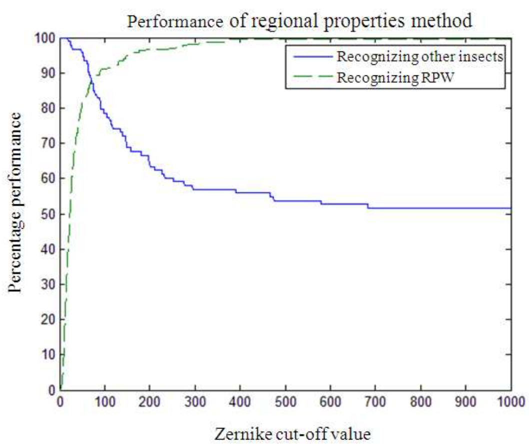

Fig. 9: Performance of Regional Properties method

Using regional properties method: The second method that has been adopted is Regional Properties. It was used in different variances by using major axis, minor axis and area. The best result was obtained when all the three mentioned characteristics of Regional Properties were used. The degree of similarity for each image is shown in Fig. 8.

It can be observed from Fig. 8 that degree of similarity for images of RPW usually have lower value as compared to images of other insects. The distribution of degree of similarity is better as compared to distribution by Zernike Moments method. The performance graph shown in Fig. 9 supports the above comparative statement. The Threshold Value obtained is 64 where 85% of RPW images are correctly recognized.

Using both Zernike moments and regional properties methods: Earlier, both the methods of Zernike Moment and Regional Properties were implemented separately for recognizing the RPW.

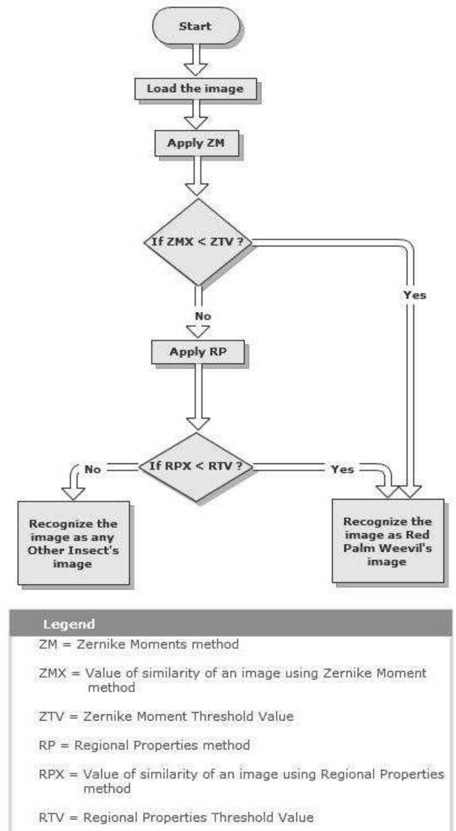

Fig. 10: Flow chart of proposed algorithm

During the thorough investigation of the results, it was observed that some images were correctly recognized by one method but not by the other method. Thus, in order to improve the efficiency, both the methods were used together in the proposed algorithm, shown in Fig. 10.

In the flowchart presented in Fig. 10, a new image is loaded into the system and degree of similarity using Zernike Moments method of order 5 is calculated for that image. If the calculated degree of similarity is smaller than Zernike threshold value, then the image will be classified as Red Palm Weevil. If the calculated degree of similarity is equal to or greater than the Zernike threshold value, then the new degree of similarity for the same image will be calculated using Regional Properties method. If recently calculated degree of similarity is greater than Regional Properties' threshold value then the image is recognized as Red Palm Weevil else it will be considered as image of other insect.

The result obtained shows that the proposed algorithm has improved the performance of identifying RPW to 97%. Besides that, 66% of other insects are also correctly identified.

1. Load an image of insect
2. Align the image and subtract the background from the image
3. Crop the image to the size of insect
4. Find the length of major axis of the image
5. Crop the head portion (including rostrum) of the image
6. Slice the image (extracted in 5) to extract rostrum and head of an insect
7. Compare both the images extracted in 6
8. If rostrum is detected then it is recognized as Red Palm Weevil
9. If rostrum is not detected then it is recognized as Other Insect

Fig. 11: Algorithm of rostrum analysis

Fig. 12: Image of RPW and its one-third of total size which includes head and rostrum

During the thorough analysis of results, it was observed that there are few insects such as *Orycetus Masicornis*, *Cybister Tripunctatus Africanus* are usually detected as RPW by both Zernike and Regional Properties. These insect is similar in shape to RPW but does not have rostrum. So, in order to improve the results further, a new technique to detect the rostrum of the insect in an image is proposed.

Using rostrum analysis: Rostrum Analysis is proposed as an advanced image processing technique to detect the rostrum of the insect from an image. It is one of the major features of RPW which can distinguish it from other insects. The algorithm of Rostrum Analysis is shown in Fig. 11.

As mentioned earlier, it is found in literature that head and rostrum makes one third of the total body size of Red Palm Weevil. During the analysis, it is observed that length of head is approximately equal to the length of the rostrum of the RPW if it is properly extended in forwarded direction, as mentioned in Fig. 12.

Using these features and Image processing techniques, the areas of the both head and rostrum are calculated. The ratio of the area of head to area of rostrum is found to be approximately equal to 4:1. As the position of head and rostrum are different as well as the position of its fore legs, so this ratio does not remain the same and changes according to position of rostrum and four legs. Thus in algorithm, the ratio of the area of head to the area of rostrum is not taken as actual but is taken as 5:2 for the detection of rostrum. In case, the ratio is greater from this value then the image of insect is considered to not to have a rostrum. All the calculations are done in ratios instead of exact or range of values because the size of the RPW varies with respect to gender and age and so as the size of rostrum and head of RPW:

The results obtained by using Rostrum Analysis are highly promising with 100% correct detection for the RPW. This high success rate is accompanied by the 72% correct detection of other insects.

It is observed in the case of Rostrum Analysis that all other insects which were wrongly detected as RPW had small rostrum or antennas on their head. Thus in order to improve the efficiency of the Rostrum Analysis, a new advanced algorithm is proposed which include all the image processing techniques discussed above.

Advanced algorithm: To reduce errors and improve the performance of detection of RPW, the advanced digital image processing techniques were used and an advanced algorithm is proposed which analyze the image using Rostrum Analysis before submitting the image for the analysis by Regional Properties or Zernike Moments methods. The flowchart of proposed advanced algorithm is presented in Fig. 13.

The advanced algorithm has three main stages which are:

- Rostrum analysis
- Zernike moments analysis and
- Regional properties analysis

The detail working of all the above sections has already been discussed earlier. When the new image is uploaded into the system, Rostrum Analysis tries to detect the rostrum in the uploaded image. After categorization of Rostrum Analysis, Zernike Moments method verifies the result of the Rostrum Analysis. In case the result of Zernike Moments method is similar to Rostrum Analysis then the result is finalized and image is counted in that particular category. In case of the other scenario, if the result of Zernike Moments method is different than the Rostrum Analysis, then uploaded image is taken up for Regional Properties Analysis. If the result of Regional Properties Analysis is similar to the result of Rostrum Analysis then the result of Rostrum Analysis is finalized otherwise if the result of

Regional Properties Analysis is similar to the result of Zernike Moment Analysis (which is already contradicting the result of Rostrum Analysis) then the result of Regional Properties and Zernike Moments Analyses is finalized and image is counted in that particular category.

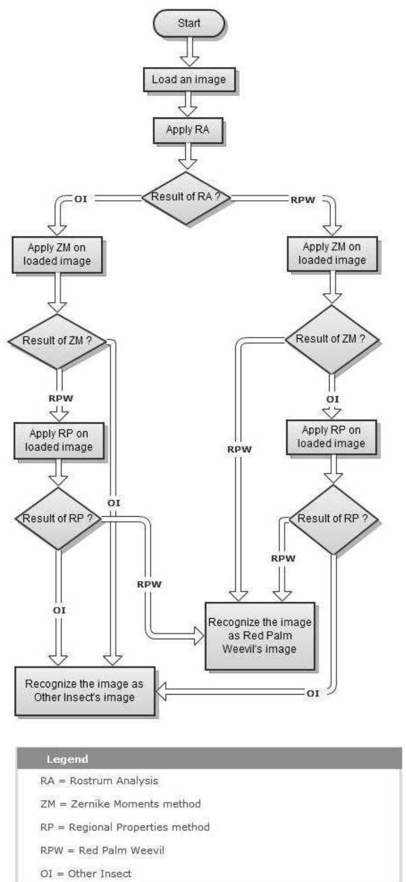

Fig. 13: Flowchart of Proposed Advanced Algorithm

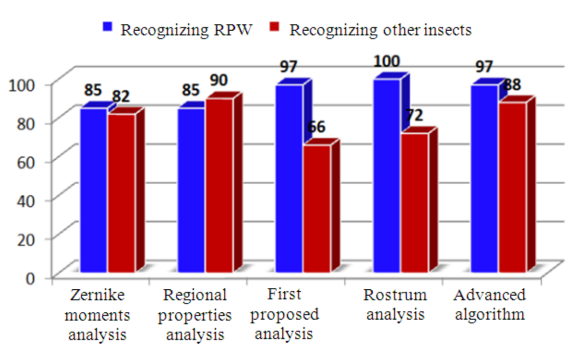

Fig. 14: Comparative graphs for all techniques

Overall, the result of Rostrum Analysis has been given more weight than the result of Zernike Moments Analysis and Regional Properties Analysis. The result of Rostrum Analysis is only reverted if both the Zernike Moments Analysis and Regional Properties Analysis results are contradicting with the result of Rostrum Analysis otherwise the result of Rostrum Analysis is upheld and finalized.

The results mentions that with this advanced algorithm, the RPW are correctly detected 97% of the time while other insects are correctly detected 88% of the time. The maximum time taken by the entire algorithm to process an image is 0.47 sec. It may take lesser time because all images shall not be analyzed by Regional Properties method.

Comparing all the result in Fig. 14, it can be observed that Advanced Algorithm is providing the best overall performance as compared to other used techniques. Consequently, the Type-I and Type-II errors are lesser using Advanced Algorithm. Due to its efficiency, this algorithm is probably be used in the wireless automated red palm weevil monitoring and control system.

CONCLUSION

It can be easily concluded that well known image recognition techniques of Zernike and Regional Properties are not highly efficient individually in recognizing RPW. Besides that, their combination is providing better results in recognizing RPW than individual results of both. The feature of rostrum in RPW is exploited and a new technique for recognizing rostrum of an insect is developed. Thereafter, combination of newly developed Rostrum Analysis and earlier discussed techniques are combined to have an efficient and reliable recognition system. The proposed system is efficient in recognizing and discriminating RPW from other insects and vice versa. The huge sample data of 326 RPW and 93 other insects' images was used for testing and verifying the results. The results exemplify the efficiency of proposed algorithm which can recognize 97% of RPW and 88% of other insects correctly.

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