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Visual features based boosted classification of weeds for real-time selective herbicide sprayer systems

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ABSTRACT

Recent years have shown enthusiastic research interest in weed classification for selective herbicide sprayer systems which are helpful in eradicating unwanted plants such as weeds from fields, minimizing the side effects of chemicals on the environment and crops. Two commonly found weeds are monocots (thin leaf) and dicots (broad leaf), requiring separate chemical herbicides for eradication. Researchers have used various computer vision-assisted techniques for eradication of these weeds. However, the changing and unpredictive lighting conditions in fields make the process of weed detection and identification very challenging. Therefore, in this paper, we present an efficient weed classification framework for real-time selective herbicide sprayer systems, exploiting boosted visual features of images, containing weeds. The proposed method effectively represents the image using local shape and texture features which are extracted during the leaf growth stage using an efficient method, preserving the discrimination between various weed species. Such effective representation allows accurate recognition at early growth stages. Furthermore, the various illumination problems prior to feature extraction are minimized using an adaptive segmentation algorithm. AdaBoost with Naïve Bayes as a base classifier discriminates the two weed species. The proposed method achieves an overall accuracy 98.40%, with true positive rate of 0.983 and false positive rate of 0.0121 for the original dataset and achieved 94.72% accuracy with the expanded dataset. The execution time of the proposed method is about 35 millisecond per image, which is less than state-of-the-art methods.

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1. Introduction

Elimination of unnecessary plants such as weeds from fields is one of the tedious jobs for farmers on a regular basis. Weeds in fields result in various issues such as competing for water, nutrients, light, and space; reducing crop yields; and affecting the surrounding environment [1]. To eradicate these weeds from fields, chemical herbicides [2] can be effectively used. Herbicides must be applied in a way to successfully eliminate weeds, avoiding their unwanted effects on remaining crops and environment [3,4]. In a recent study, Laursen et al. [4] presented an algorithm to segment and quantify weeds in Maize crops in order to reduce herbicide usage. Their study revealed that the selective application of herbicides reduces its usage by 65%. Weeds may grow in patches or individually, however, applying herbicides equally on all parts of the field is ineffective. In this case, the sprayer system should spray selectively on the concerned regions of the fields only [5]. Computer vision-directed approaches are helpful in this regard to develop smart sprayer systems which can selectively spray herbicides on weeds in the fields. Numerous methods [6–10] have been developed for weed classification but they lack classification accuracy and are not robust to varying field conditions. Hence, the superlative set of features and classification approach is yet to be discovered [1,11].

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The intelligent sprayer systems such as those equipped with visual sensors along with a mechanical sprayer, capture images from the field which are then processed for detecting the existence of weeds [12–15]. The detected weeds are then classified into monocots and dicots and lastly suitable signals are sent to the sprayer system for applying herbicides to the detected weed patches. Visual features such as texture, color, and shape are typically extracted from the captured images. Texture based features have been extensively applied for weed classification [16]. Previous methods of weed classification utilized features such as leaf shape and plant structure [6,17]. Later on, some color and texture based methods [6] were also proposed. Nevertheless, majority of the techniques fail to balance the efficiency and effectiveness of weed classification in terms of processing speed and accuracy. Therefore, the goal is to develop a fast technique which is suitable for real time weed classification, avoiding unnecessary computations, and providing accurate classification under varying field environments.

To achieve such a system, researchers from the last decade have presented various weed classification techniques [1,18]. Ahmad et al. [19] utilized simple statistical features for weeds classification, achieving a low accuracy as the technique utilized too naïve features. To improve the accuracy, Siddiqi et al. [20] explored edge link detector, achieving an accuracy of 93% on a small dataset. The authors in Ref. [8] utilized wavelets by extracting highest 200 coefficients and integrated them with the k-nearest neighbor classifier (K-NN) for classification, achieving an accuracy of 95%. This work was further improved by employing multi-level wavelet decomposition (MWD) based classification by extracting highest coefficients of the wavelet decomposed images, representing weeds. However, the method fails to work effectively under varying field conditions [21]. Faisal et al. [16] incorporated local binary patterns along with template matching and support vector machine (SVM) classifiers for weed classification. But, their technique demands for extra computation due to its feature invariance property. Their technique achieved 89% accuracy in case of template matching and 98% with radial basis function (RBF) kernel based SVM classifier. However, due to exploring expensive texture descriptors for making the method geometric transform invariance, the computational complexity increased, hence making it less suitable for real-time applications.

In an attempt to reduce complexity, image morphology features along with neural network classifier (ANN) have also been used for classification of weed images, taken from outdoor fields. Illumination invariant segmentation procedure helped in achieving an overall accuracy of 95.1% with ANN classifier [10]. Seven hue moments and six shape features were extracted from weed images to classify them into monocots and dicots with an accuracy of 85% [6]. The images used during the experiments contained very little weeds. It was not difficult to analyze the individual leaves. However, in many cases, high infestations of weed are found throughout the fields and analyzing individual leaves become impractical. Therefore, in high weed infestations these methods would fail to perform. A similar study was conducted in Ref. [9], employing seven hue moments for weed classification. This method also failed to cope with high weed densities. Giselsson et al. [22] utilized close contour shape features to distinguish between two classes of plant seedling. They achieved 97.5% accuracy with Legendre Polynomial feature set while classifying nighshade and cornflower. Siddiqi et al. [23] explored a new wavelets family for features extraction from weeds images which were later on minimized based on step-wise linear discriminant analysis, making them linearly separable. Classification was performed by SVM achieving an accuracy of 98.1% with symlet wavelet features. To increase the accuracy, a mixture of features were used by authors in Ref. [24], including co-occurrence matrix, Haralick features, shape analysis, and histogram features, classifying weeds from captured field images while achieving an average accuracy of 97.6% for both types of weeds. However, these methods were evaluated on noise-free, blur-free images, and without taking into consideration the illumination changes being faced in the field. Furthermore, their method was computationally expensive, requiring 0.35 s for classifying an image.

The aforementioned methods exploited various features and classifiers for weed classification. However, none of the methods produce satisfactory results when coping with intense field conditions such as illumination variations, motion blur, and noise. Some of the methods achieved high accuracies but with huge computational complexity, making them unsuitable for real-time applications [16,20]. Other techniques were computationally efficient but lack acceptable accuracy, decreasing its applicability in various areas of interest [8]. Furthermore, some of the existing methods fail to cope with various lighting conditions which further limit their accuracy [1]. Therefore, it is very important to exploit a method for weed classification, maintaining the balance between accuracy, efficiency, and robustness.

In this paper, we propose a fusion based weed classification framework for overcoming the problems of existing methods in terms of classification accuracy, resilience against various lighting conditions, and efficiency. The major contributions of this research work are as follows.

i An efficient fusion based framework is proposed for effective weed classification, maintaining a balance between classification accuracy and efficiency, hence making it more suitable for real-time applications such as selective herbicide sprayer systems.
ii The proposed framework utilizes boosted visual features, incorporating both shape and texture information and are extracted using an efficient method, preserving the discrimination between various weed species and crops, hence results in satisfactory performance.
iii The proposed framework uses an adaptive segmentation algorithm prior to feature extraction, minimizing the various illumination, noise, and motion blurring problems, hence making it more suitable for weed classification.
iv A hybrid classifier AdaBoost ensemble of Naïve Bayes [25,26] was used for classification, increasing the accuracy of current state-of-the-art weed classification methods.

The rest of this paper is structured as follows. Section 2 explains the detail of the proposed weed classification system. Section 3 explores experimental results and discussion. Section 4 concludes the paper and suggests future research directions.

2. Materials and methods

In this section, we describe the details of the proposed weed classification system. The proposed system comprises of two main phases: an offline training phase and a real-time classification phase. During the training phase, the main objective is the construction of a robust classifier model, having the capability to efficiently distinguish between two weed species in the presence of noise, illumination variation, and motion blurring. This objective is achieved by incorporating three steps in the proposed system. Firstly, an adaptive segmentation algorithm is used to handle the undesirable effects of noise, motion blur, and illumination during image acquisition. Secondly, visual features are extracted, incorporating both texture and shape, hence effectively drawing the boundaries between the two weed species. Finally, the AdaBoost along with Naïve Bayes classifier is used to train the classifier, resulting in the required classifier. During the testing phase, the same features are extracted from captured images and the

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