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Smartphone-based hierarchical crowdsourcing for weed identification

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ABSTRACT

Weed infestation is a common problem in agriculture that adversely affects crop production. Given severe constraints on the budget of many land-grant universities due to the economic downturn, extension services or agencies responsible for educating farmers and assisting them with the application of advancements in agricultural research, have taken a hit. To adapt to the current economic climate without adversely affecting the quality of programs for weed management, we present a hierarchical system that uses images captured using a smartphone application, a backend image processing algorithm, and two levels of crowdsourcing to identify weed images. The first of the two crowdsourcing levels consist of a non-expert crowd contributed by Amazon Mechanical Turk (AMT) and the second level consists of a crowd composed of experts such as county extension agents. We present a probabilistic decision engine to determine the suitability of two levels of crowdsourcing for identifying the weed image. We have evaluated the designed system using test weed images and we show that 80% of the weeds in our test set can be identified using the low cost AMT crowd while incurring a maximum latency of 3 h. Our system can help reduce the loses caused by the delay in identifying weeds, and hence, lead to quick remedial control practices applied to contain weed infestations.

1. Introduction

Weeds compete with crops for light, water, and nutrients. If left uncontrolled, crop yields are adversely impacted. Methods of weed control and management are constantly being updated, and more efficient practices emerge as a result of research, but farmers can only benefit from these advances if they have access to the most current information. The traditional extension agencys response to disseminate research based information on weed management, that includes weed identification and their control practices, relies on means such as extension publications, county-level meetings and one-on-one consultations. In the fast paced, social media driven connected world, traditional extension approach seems slow as farmers need latest information right there in the field.

To satisfy this demand, extension agencies are required to have access to trained manpower, both subject matter experts and information technology specialists. Economic downturn in the US economy has resulted in budget cuts in several land-grant universities thus, leading to a reduction in trained manpower. Given this reality, it is time to start thinking of innovative approaches for keeping extension and outreach services viable and useful by developing tools that could potentially be customized by extension agencies for use outside a state or a region. In this paper, we use weed management as a test case to propose a novel identification and control system that could be used to augment existing programs. A typical weed identification call from a producer results in field visit by a county extension agent (Maunder et al., 1972).[1] The agent either completes the identification or refers it to a subject matter expert who in turn provides the necessary information. Unfortunately this manual process incurs high latency and increases the burden on extension service agents.

Smartphones have penetrated the rural population both in developing and developed countries. For instance, low-end Android phones that provide basic cellular data plans, a camera, and location information are common devices for farmers and extension agents. In a recent initiative in Arkansas, for example, the extension agents were provided with data plan-enabled iPads. We leverage this observation to design a system that involves the concept of crowdsourcing (van Etten, 2011; Lowry and Fienen,

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[1] Agricultural extension is a general term used for applying research in the field of agriculture through farmer education. The experts who facilitate agricultural extension are called extension agents.

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2013)-using a human network to solve a challenging problem-for developing a modern solution for weed management.

2. Related work

Identifying weeds play a major role in controlling infestations through timely use of herbicides in the crop field. Communicating research-based information on weed control practices, on a timely manner, has potential to result in efficient application thereby reducing environmental contamination and damage to crops. We examined previous efforts on image analysis for weed identification (Hemming and Rath, 2001) and application of crowdsourcing technique (Yan et al., 2010) in unrelated application domains before developing and testing our proposed system.

2.1. Image analysis

Several techniques for identifying weeds using contextual data have been proposed. To augment automated image analysis, for instance, researchers have used contextual data on lighting conditions (Hemming and Rath, 2001), color and shape (Perez et al., 2000), soil conditions, weed's age, and information on the specificity of the crop field (Burgos-Artizzu et al., 2011). Many of the proposed weed identification processes in crop fields use machine vision (Tellaeche et al., 2008; Shearer and Holmes, 1990) systems, but the morphological and texture parameters used in image analysis (Tellaeche et al., 2008; Ishak et al., 2007; Li et al., 2010) can be complicated and computationally expensive (Meyer et al., 1998). These also need to run on dedicated desktop PCs to meet the required computational needs.

In addition to using contextual data, research has been performed in the field of weed sensing in order to discriminate between weeds and plants for specific species like tomato seedlings (Tian et al., 2000), using shape features of crops (Guyer et al., 1993, 1986; Franz et al., 1991; Zhang and Chaisattapagon, 1995; Woebbecke et al., 1993, 1995), spectral analysis (Franz et al., 1991; Zhang and Chaisattapagon, 1995), fractal analysis of leaf shapes (Critten, 1996; Dave and Runtz, 1995) using Fourier transforms, Hadamard transformation and wavelet (Bossu et al., 2009), Hough transformation to find weeds between two rows of crops, and texture of images from a canopy (Dave and Runtz, 1995; Zhang and Chaisattapagon, 1995; Shearer and Holmes, 1990). However, most of these techniques have not been deployed in actual farms. As we show in our evaluation, image analysis alone is not reliable enough to detect weeds accurately.

2.2. Crowdsourcing techniques

Although computer vision and image analysis are powerful techniques for identifying weeds and crops, they have several limitations and cannot guarantee identifying weeds accurately. For instance, it is difficult for automated algorithms to identify weeds at different stages of growth, or when using images taken at different angles and lighting conditions. Moreover, it is impossible to identify weed species that have mutated or are new. Image processing using a human crowd of experts and non-experts has been shown to be more powerful (Sinha et al., 2006) than computer vision for several application. Popularly termed as crowdsourcing, a network of humans can be used to solve challenging and computationally expensive problems that machine intelligence cannot accurately solve. The pioneer work of Luis Von Ahn on reCaptcha (Von Ahn et al., 2008), for instance, uses humans to digitize old books that augments optical character recognition algorithms. Extra Sensory Perception (ESP) games (Von Ahn and Dabbish, 2004; Schmeidler, 1969) also use humans for determining descriptive labels for images. Image searches using crowdsourcing can be tuned to have high accuracy and low cost (Yan et al., 2010).

3. Design goals

The goal for our weed identification system is to provide a low cost, low latency, accurate, and highly usable system to automate the weed detection and mitigation problem. We strictly adhere to the following design goals while implementing our system:

- Reduce the weed identification burden for extension agents and experts and provide high accuracy weed identification.
- Easy to use end-user applications: The adoption of the weed identification system is predicated on creating intuitive smartphone interfaces for both the farmer and the expert. To this end, we have designed our application interface using feedback from extension agents, farmers, and crop boards.

4. System architecture and methods

Our weed identification system architecture is illustrated in Fig. 1. The system uses a combination of hierarchical crowdsourcing based on Amazon Mechanical Turk and experts, augmented with automated image processing, to accurately identify weeds and provide control practice recommendations to farmers. Interacting with this backend are the client-side mobile applications. We next describe our smartphone applications and the backend image processing logic.

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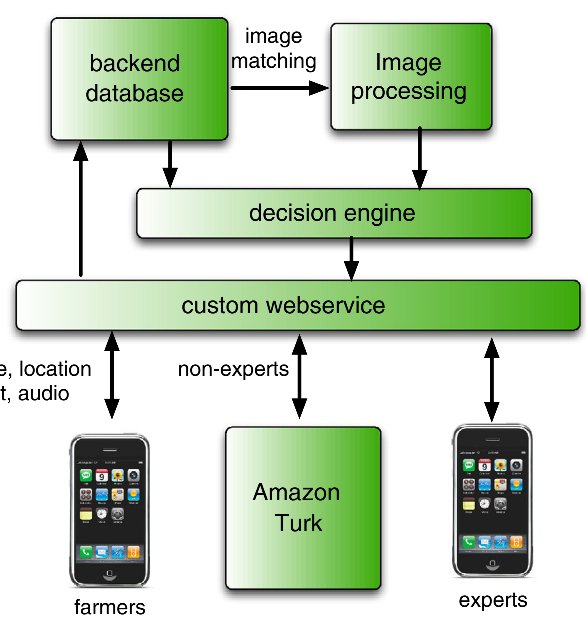

Fig. 1. System architecture for our crowdsourcing-based weed management system. The system uses smart phone applications, automated image processing, and hierarchical crowdsourcing for weed identification and low latency dissemination of control practices to farmers.