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Review

A survey of image processing techniques for plant extraction and segmentation in the field

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ABSTRACT

In this review, we present a comprehensive and critical survey on image-based plant segmentation techniques. In this context, "segmentation" refers to the process of classifying an image into plant and non-plant pixels. Good performance in this process is crucial for further analysis of the plant such as plant classification (i.e. identifying the plant as either crop or weed), and effective action based on this analysis, e.g. precision application of herbicides in smart agriculture applications.

The survey briefly discusses pre-processing of images, before focusing on segmentation. The segmentation stage involves the segmentation of plant against the background (identifying plant from a background of soil and other residues). Three primary plant extraction algorithms, namely, (i) colour index-based segmentation, (ii) threshold-based segmentation, (iii) learning-based segmentation are discussed. Based on its prevalence in the literature, this review focuses in particular on colour index-based approaches. Therefore, a detailed discussion of the segmentation performance of colour index-based approaches is presented, based on studies from the literature conducted in the recent past, particularly from 2008 to 2015. Finally, we identify the challenges and some opportunities for future developments in this space.

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1. Introduction

1.1. Background and motivation

Weeds are one of the big challenges in agriculture because they appear everywhere randomly, and compete with the plant for resources. As a result of this competition for resources, crop yields suffer. Yield losses depend on factors such as weed species, population density, and relative time of emergence and distribution as well as on the soil type, soil moisture levels, pH and fertility (Papamichail et al., 2002). Numerous researchers have identified a strong link between weed competition and crop yield loss, with a wide range of crop varieties. For example, according to the study by Stall (2009), an annual loss of 146 million pounds of fresh market sweet corn and 18.5 million pounds of sweet corn for processing occurred in the United States from 1975 to 1979 due to weed competition, which corresponds to revenue losses of $13,165,000 and $9,155,000 respectively. Besides, the dry and head weight of crop yield are measured to evaluate losses. Based on a study carried out in 1996/1997 and repeated in 1997/1998 in central Jordan (Qasem, 2009), it was found that the average reduction in shoot dry weight and head yield were 81% and 89% respectively. An effective and efficient weed management system is necessary to minimise yield losses in valuable crops. The critical period for weed control must be taken into account to enhance weed management strategies (Swanton and Weise, 1991), as the duration of co-existence of weed and crop is an important indicator of yield losses due to weed competition (Kropff et al., 1992).

Zimdahl (1988, 1993) defined the critical period of weed control (CPWC) as "a span of time between that period after seeding or emergence when weed competition does not reduce crop yield and the time after which weed competition will no longer reduce crop yield". A more quantitative definition is as the number of weeks after crop emergence during which a crop must be weed-free in order to prevent yield losses greater than 5% (Hall et al., 1992; Van Acker et al., 1993; Knezevic et al., 1994).

A number of studies have been carried out in many different locations, under different environmental conditions in an attempt to establish the CPWC. The studies are generally conducted by keeping the crop free from weeds for a fixed period of time, and then allowing the weeds to infest. Another approach used is growing weeds with the crop for certain predetermined durations, after which all weeds are removed until the growing season ends (Nieto et al., 1968). Some studies have reported that weeds that emerge at the same time as the crop, or slightly after, cause greater yield loss than weeds emerging later in the growth cycle of the crop (Dew, 1972; O'Donovan et al., 1985; Swanton et al., 1999). Most studies recommended that crops should keep weed-free within the CPWC in order to minimise yield loss (e.g. Karkanis et al., 2012).

Manual methods for weed control include hand weeding and use of simpler hand tools. Hand weeding is a conventional weed removal method that has been successfully used to control weeds for many centuries, before any other methods existed, but is not practical for large scale commercial farms because it is extremely labour intensive, costly, tedious, and time consuming (USDA, 1996).

Mechanical methods for weed control (by tillage or cultivation of the soil) are mostly applied in large areas for row crops such as sugar beet, wheat, and corn for inter-row weed control. A number of studies have been carried out to evaluate the efficacy of mechanical weed control methods. Forcella (2000) reported that rotary hoeing yielded approximately 50% weed control alone without using other weed control methods such as herbicides and manual labour. Donald (2007) found that inter-row mowing systems for controlling both winter annual and summer annual weeds may reduce the use of herbicides by approximately 50%.

Mechanical weeding is particularly suited to organic fields for weed control and can also be helpful in conventional fields. On the other hand, the use of machinery may also have negative effects on crops and the environment by causing damage and erosion (Nelson and Giles, 1986; Eyre et al., 2011). Chemical weeding is the most widely used method for weed control in agriculture since the introduction of synthetic organic chemicals in the late 1940s, and farmers now rely heavily on herbicides for effective weed control in crops (Gianessi and Reigner, 2007; Grichar and Colburn, 1993; Bridges, 1992), particularly on large scale commercial farms. Many studies have documented that the use of herbicides is a more economical method for controlling weeds compared to hand and mechanical weeding. With the help of herbicides, farmers in Mississippi were estimated to have saved $10 million per year compared to the cost of labour (Gianessi and Reigner, 2007). Demand for chemicals by farmers has increased the market size; according to a report carried out in 2014 by BCC Research Chemical Report (2014), the biopesticide and synthetic pesticide market are expected to reach up to $83.7 billion by 2019.

Although herbicides are very effective at controlling weeds, they have negative impacts on both the environment (through pollution) and plant biology (development of resistance). Groundwater and surface water pollution has been reported in many cases in recent decades, and excessive use of herbicide has often been found to be the cause (Liu and O'Connell, 2002; Spliid and Koeppen, 1998). To counteract these catastrophic environmental effects, most European countries have introduced legislative directives to restrict the use of herbicides in agriculture (Lotz et al., 2002). If there are means to accurately detect and identify weed spatial distribution (weed patches), it is possible to limit herbicide quantities by applying them only where weeds are located (e.g. Lindquist et al., 1998; Manh et al., 2001; Berge et al., 2012; Christensen et al., 2009; Jeschke et al., 2011). Heisel et al. (1999) demonstrated a potential herbicide saving of 30–75% through the use of appropriate spraying technology and a decision support system for precision application of herbicides. This drives the need for systems for more accurate identification of weed patches, and has provided one motivation for development of image processing methods for identification of weeds. Colour-index based segmentation methods have demonstrated a particular utility for weed identification, and hence are a particular focus of this paper.

Besides identification of weeds to permit precision weeding, plant segmentation is also useful for other proposes, and applied in several applications such as plant species recognition (Lei et al., 2008), growing phase determination (Kataoka et al., 2003), and plant disease detection (Camargo and Smith, 2009). While weeding remains the most important motivator at present, these other applications are growing in importance with increasing interest in smart agriculture.