Computers and Electronics in Agriculture 124 (2016) 194–210

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Planning machine paths and row crop patterns on steep surfaces to minimize soil erosion

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ARTICLE INFO

Article history:
Received 19 October 2015
Received in revised form 7 March 2016
Accepted 15 March 2016
Available online 18 April 2016

Keywords:
Path planning
Soil loss
Runoff
Controlled traffic farming
Machine efficiency
GIS

ABSTRACT

Soil erosion in arable fields is intensified on irregular surfaces. Although machine and crop-row patterns following terrain contours reduce runoff and increase water infiltration, these contours are almost never parallel while machine operations always are. In this work, a method is presented to generate patterns of machine paths on sloping land and assess their susceptibility to water erosion. The approach comprises three main process-steps: (1) assembling a comprehensive set of reference tracks and introducing hybrid contour lines; (2) adjust these curved tracks into steerable parallel tracks for agricultural machines; and (3) assess water flow accumulation and susceptibility to soil loss of the corresponding pattern. The methods were implemented in open source software and applied on three case studies concerning sugarcane production in the São Paulo region in Brazil. Our results suggest that soil loss could be reduced fivefold by inserting one single change in the cropping pattern while estimated reductions up to 75% could be obtained by the model when compared to a human-suggested coverage pattern.

1. Introduction

Machine operations are easiest in large, flat and rectangular fields with no obstacles. In these fields, the time spent for manoeuvres at boundaries and for servicing are minimized or easier to be managed. Also, such fields suffer less from coverage problems of operations, inefficient fuel consumption and water erosion. Yet, a large number of agricultural fields are not in such conditions and with increasing complexity of field shapes and irregularity of surfaces, it becomes more difficult to decide intuitively on track orientation of machines and crops that will result in minimal economic and environmental costs.

Within the scope of path planning for agricultural machines (PPAM), geo-information methods were thus developed to generate in advance a large number of different options of in-field driving tracks for machines (Oksanen and Visala, 2009; Hameed et al., 2010). Along the, impacts are retrieved, allowing the least cost solution to be selected. Moreover, two trends are pushing the PPAM development: (1) increasing adoption of the auto steering technology for farm machinery (Holland et al., 2013), which nowadays enables a full geographical route developed in computers to be inserted in a machine's guidance interface; and (2) adoption of the controlled traffic farming (CTF) practice, where machine movement on fields is limited to the same tracks along the years, keeping most of the land free of soil compaction (Tullberg et al., 2007).

To optimize machine efficiency for given field shapes, PPAM has focussed on minimizing overlap in headlands (Palmer et al., 2003; de Bruin et al., 2009); splitting complex fields into convex-shaped subfields for finding efficient driving patterns (Jin and Tang, 2006; Hofstee et al., 2009; Oksanen and Visala, 2009); and combinations of different costs minimizations (Bochtis et al., 2010; Jin and Tang, 2010; Spekken and de Bruin, 2013). Also field robots are being developed and tested using on-field sensors and real time path planning algorithms aiming for collision free paths (Cheein, 2013).

Note that all above listed work considers two spatial dimensions for modelling machine movements on fields. Existing PPAM efforts that take surface irregularities into account have aimed to minimize fuel consumption (Hameed et al., 2013; Hameed, 2014) and to adjust the width of machine tracks so as to avoid skips and overlap of swaths (Hameed et al., 2016). Yet, an important concern when operating heavy machines on steep surfaces is the effect of the field work pattern on soil loss by water erosion. For example,

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http://dx.doi.org/10.1016/j.compag.2016.03.013
0168-1699/

contour farming can substantially reduce runoff of water, thus also can diminish soil erosion and improve water infiltration into the land (Heege, 2013).

Between 1950 and 1990 about one third of the global area of arable land has been lost by water erosion (Pimentel et al., 1995). The awareness of the damages caused by water erosion and the adoption of soil conservation practices are increasing (Triplett and Dick, 2008; Derpsch et al., 2010; Held and Clawson, 2013) and this should be extended to mechanized agriculture on steep and irregular surfaces which are very susceptibility to water erosion.

The practice of contouring, i.e., performing field operations perpendicular to slope direction, significantly reduces water runoff. Carvalho et al. (2009) found that contouring reduced soil loss owing to water erosion by 68.7% compared to crop rows established in the direction of slope. It was also found that the cropping pattern had a higher conservation impact than the type of coverage.

However, since steep surfaces hardly ever have regular slopes, contours are typically non-parallel. This contrasts with machine operations that are performed in parallel passes because of the fixed width of swaths. In a traditional soil conservation procedures, this problem is solved by varying machine and crop orientations over the field within subfields. An implementation of this method is exemplified in Fig. 1, where irregularly shaped infiltration terraces were created using dirt ridges that follow contours at fixed elevation steps.

This procedure was widely adopted in Brazil in a "one-rule-fits-all" fashion but, unfortunately, it disregards soil conservation practices, soil type and the very benefits of the crop-row orientation towards the slope.

Fig. 1b also shows how the divisors hinder operational work of machines by creating a large number of short rows and difficult turns. This results in a large number of within-field manoeuvres, which would either overrun existing crops on headlands or require the existence of an extensive net of roads which reduce the productive area.

Owing to the current high costs, mechanization is incompatible with such soil conservation practices. Spekken et al. (2015) studied the machine costs of boundary manoeuvres and their economic impacts. The authors pointed out that sugarcane-rows of less than 50 m length may be unprofitable.

Hence there is a need for a PPAM approach that optimizes path and row orientations with few pattern changes while reducing water runoff.

Jin and Tang (2011) developed a pioneering algorithm for PPAM seeking to minimize soil loss and machine inefficiency. However, the method still has some limitations:

- By creating parallel passes on field using a single contour as reference, the algorithm produces sharp turns that cannot be steered, leading the machine to skip areas that are thus left uncropped.

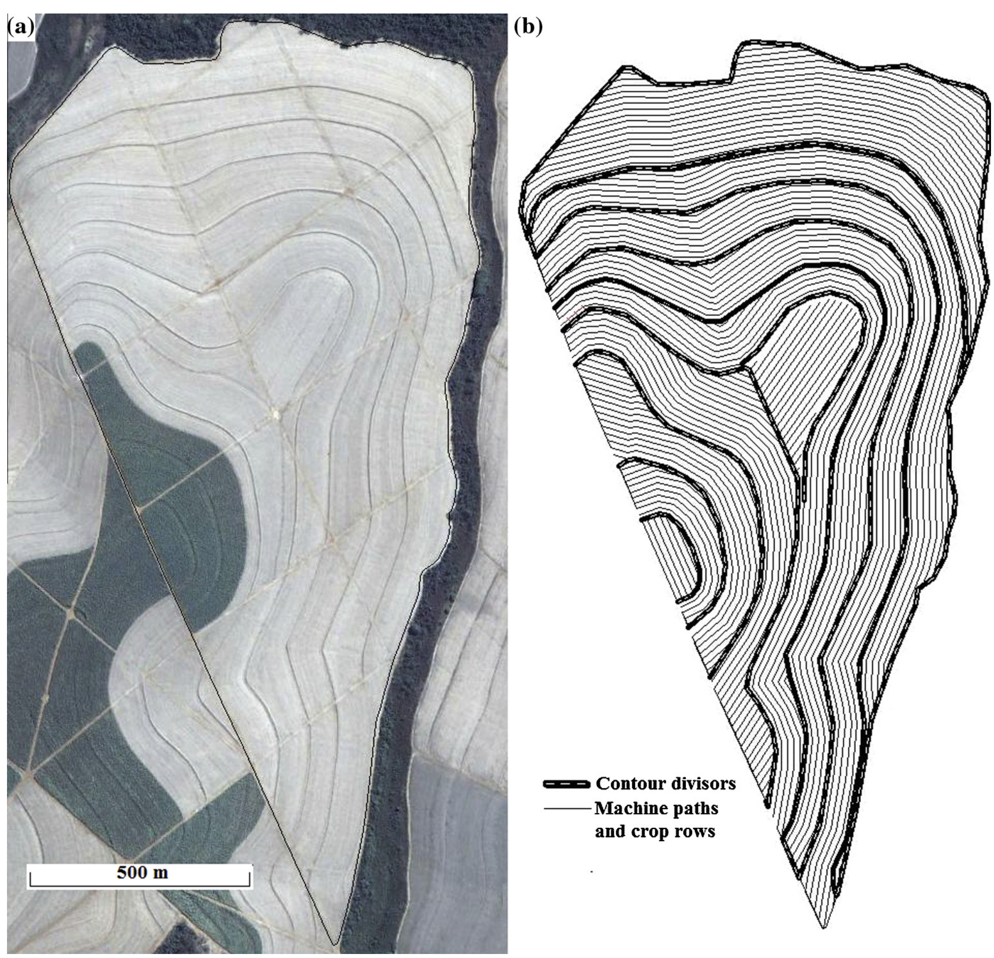

Fig. 1. Sugarcane field in Brazil showing, in (a), terraces at elevation contours, and in (b), its resulting orientation of machine path and crops rows. *Source:* Google Earth.