Creating space for biodiversity by planning swath patterns and field margins using accurate geometry

S. de Bruin[1], S. Heijting[1], A. Klompe[2], P. Lerink[3], M. Vonk[4], T. van der Wal[5],

[1] *Wageningen University, Centre for Geo-Information, P.O. Box 47, 6700 AA Wageningen, The Netherlands. Sytze.debruin@wur.nl*
[2] *Stichting H-WodKa, Langeweg 55, 3261 LJ Oud-Beijerland, The Netherlands*
[3] *IB-Lerink, Laan van Moerkerken 85, 3271 AJ Mijnsheerenland, The Netherlands*
[4] *Commissie Hoeksche Waard, P.O. Box 7059, 3286 ZH Klaaswaal, The Netherlands*
[5] *Portolis BV, Spoorbaanweg 23, 3911 CA Rhenen, The Netherlands*

Abstract

Potential benefits of field margins or boundary strips include promotion of biodiversity and farm wildlife, maintaining landscape diversity, exploiting pest predators and parasites and enhancing crop pollinator populations. In this paper we propose and demonstrate a method to relocate areas of sub-efficient machine manoeuvring to boundary strips so as to optimise the use of available space. Accordingly, the boundary strips will have variable rather than fixed widths. The method is being tested in co-operation with seven farmers in the Hoeksche Waard within the province of Zuid Holland, The Netherlands. In a preliminary stage of the project, tests were performed to determine the required accuracy of field geometry. The results confirmed that additional data acquisition using accurate measuring devices is required. In response, a local contracting firm equipped a small all-terrain vehicle (quad) with an RTK-GPS receiver and set up a service for field measurement. Protocols were developed for requesting a field measurement and for the measurement procedure itself. Co-ordinate transformation to a metric system and brute force optimization of swath patterns are achieved using an open source geospatial library (osgeo.ogr) and Python scripting. The optimizer basically tests all orientations and relevant intermediate angles of input field boundaries and tries incremental positional shifts until the most efficient swath pattern is found. Inefficient swaths intersecting boundary areas are deleted to create space for field margins. The optimised pattern can be forwarded to an agricultural navigation system. At the time of the conference, the approach will have been tested on several farm fields.

Keywords: path planning, spatial optimisation, agricultural vehicle guidance

Introduction

Agricultural land has important food production, environmental and societal functions which may seem to compete for available space. However, the premise of this paper is that within agricultural fields the spatial claims of different functions of the land can be optimised by relocating areas of sub-efficient machine manoeuvring to boundary strips (cf. Sparkes et al., 1998). In this work we assume that field operations are performed using some precision guidance system and that the vehicle tracks are planned using a parallel, non-overlapping swathing method (Jin and Tang, 2006; Taïx et al., 2006). Furthermore, in contrast to the common practice of

uniform width boundary strips, field margins are allowed to have variable widths. The rationale for the latter is that cropping patterns in wedge-shaped and other non-rectangular fields lead to inefficient use of agrochemicals and environmental pollution. In case of overlapping swaths, some areas will unnecessarily receive multiple doses of agrochemicals unless individual nozzles can be controlled on the spray boom (cf. Batte and Ehsani (2006)). In the approach here presented such problems are avoided by adhering to a straight non-overlapping swath pattern on the cropped land and by resolving any geometrical irregularities within the field margins. The procedure thus aims for an efficiency gain at the expense of a small reduction of the cropped area, which gets an environmental or societal function. The optimised swath pattern is geo-referenced and can be forwarded to a vehicle navigation system.

Promoted by technological advances and economic developments, automated navigation of agricultural machines has aroused considerable academic and commercial interest over the past decade (Keicher and Seufert, 2000; Reid et al., 2000; Batte and Ehsani, 2006). In contrast to our work, several researchers aim to completely cover fields of potentially any geometrical complexity (Choset, 2001; Oksanen et al., 2005; Taïx et al., 2006). Other work includes or is focussed on routing under vehicular constraints (Gray et al., 2006; Vougioukas et al., 2006; Bochtis et al., 2007). Whilst the abilities to deal with complex field geometry (particularly obstacles within a field) and vehicle routing may be required for fully operational application, they are not covered in the current paper.

The aim of this paper is to share our experiences with an elementary method for optimising the spatial configuration of cropped swaths while creating space for field margins. The paper draws on previously published (de Bruin et al., 2008) and unpublished work of the same authors in which the required positional accuracy and input requirements of the method were assessed. We implemented a prototype of the optimisation method using the open source GIS library GDAL/OGR (http://www.osgeo.org/gdal_ogr) and Python (http://www.python.org) scripting. Data were acquired within the project 'Akkerbouw in groen en blauw' (agriculture in green and blue) in the Hoeksche Waard, the Netherlands where farmers support the realization of regional plans concerning biodiversity and societal demands. Farmers are looking for innovative technology to improve the vitality of arable farming while supporting the preservation or enhancement of landscape values. GIS, GPS and remote sensing are being recognized as important tools for targeted management of (intentional) spatial variability, since they can support optimal allocation of field margins, vehicle path planning, variable rate application and other agricultural operations (De Bruin and Hunter, 2007). The polder landscape of the Hoeksche Waard was reclaimed in the fifteenth century and it is characterised by a pattern of mostly non-rectangular fields, streams and dikes.

Methods

Positional accuracy

De Bruin et al (2008) assessed the required positional accuracy of field boundaries for path planning in an error propagation study. They employed the Data Uncertainty Engine (Brown and Heuvelink, 2007; Heuvelink et al., 2007), which is free software that aids the user in defining probability distributions for uncertain spatial objects, and draws random samples from these distributions. An error model was parameterised on measurement scenarios representing (1) special purpose Real Time Kinematic (RTK) GPS surveys; (2) differential GPS-based field checks for verification of area declarations; and (3) the Dutch registry of agricultural fields. Two

types of error were considered in the intersections of reference geometry of an agricultural field and mapped geometry:

1. False inclusions (errors of commission); areas outside the true field that are erroneously mapped as belonging to the field.
2. False exclusions (errors of omission); areas belonging to the reference field that are erroneously excluded from the mapped field.

In the first case, the farmer would plan field operations outside the true field; in the second case, the farmer would sub-utilize the field because part of it is left uncultivated. To assess the effect of measuring techniques (1-3), costs were assigned to both types of error and the distribution of loss associated with each surveying scenario was analysed.

Planning algorithm

In this work, swath pattern optimisation is based on an exhaustive search over a discrete set of potential swath orientations computed from the edges of the field and positional shifts. Position and orientation are optimised so as to achieve minimum costs. Therefore, the following costs are considered:

- loss of net result for uncropped area;
- cost of an additional swath, which includes the cost of turning;
- subsidy (negative cost) received for field margins

The optimisation and required coordinate transformations were implemented using an open source GIS library (osgeo.ogr) and Python scripting. The pseudo code of the optimisation is given below:

```
read field geometry, field margin edges, preferred direction (if any)
extract field boundaries with their orientations (angles)
compute positional shifts
for each orientation to be tested:
  for each incremental shift:
  compute a parallel swath pattern
  for each field boundary:
     if field boundary == field margin edge & angle below threshold:
        delete swaths that overlap the minimum field margin width
     else:
        cut swaths at intersection with boundaries or strips
  compute realized number of swaths, field margins & area loss
  cost = cost(swaths) + cost(area loss) – subsidy(field margins)
  retain design with lowest cost
```

De Bruin et al. (unpublished data) tested the stability of the optimal swathing pattern and economic evaluation of farming alternatives under changes in the cost values used in the objective function.

Field experiment

The approach was tested with farmers in de Hoeksche Waard. Figure 1 shows the workflow of activities used in the experiment. It mainly involved (1) selection of fields and indication in Google Earth, (2) measurement with RTK-GPS equipment, (3) specification of machine properties (e.g. width) etc., (4) the optimisation itself and (5) communication with vehicle

navigation equipment. A contracting firm equipped a small all-terrain vehicle (quad) with an RTK-GPS receiver and set up a service for field measurement.
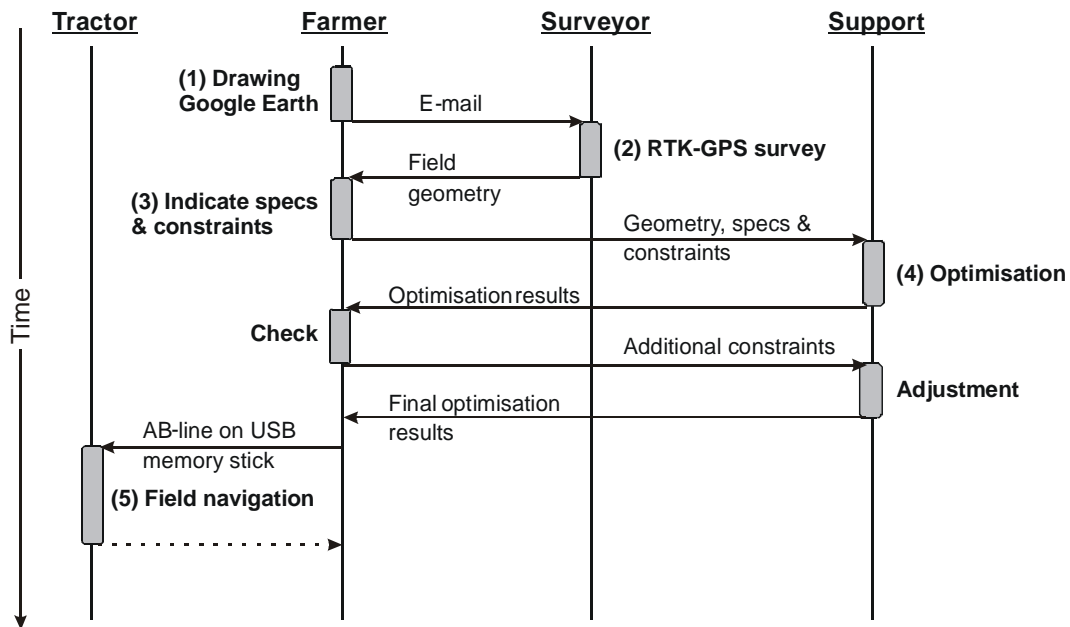

Figure 1. Work and data flow of swath pattern optimisation experiment in the Hoeksche Waard. Numbers are referred to in the text.

Results and discussion

Positional accuracy

Table 1 (after De Bruin et al., 2008) lists summary statistics of the financial losses suffered by a farmer in a single year if measured field geometry was used to plan and execute field operations for a potato crop on a field of 15 ha. If, for example, the farmer of the case study had a manually digitised map of his field, the cut-off point at which an RTK-GPS survey would become cost-effective was €442 in a single crop year. The expected losses for the DGPS scenarios varied between €100 and €160 and the losses for the RTK-GPS scenarios were virtually negligible. Note that the GPS survey would not need to be conducted every year while benefits may persist for several years (as long as field geometry does not change). Another example: after some manipulation of the table entries it becomes apparent that there was over 99% chance that a farmer owning a manually digitised/rigid object map of the field would benefit from a map made under the EGNOS-JRC scenario.
It is important to note that the risks considered in these examples concern only the crop inputs and the yields. Other risks associated with errors of commission, such as damage to equipment and infrastructure (e.g. the risk of hitting obstacles in the field by machinery) and externalities (e.g. environmental effects) are not considered here. However, these may considerably increase the benefits of accurate mapping.

Table 1. Summary statistics of financial loss (€) with respect to error-free geometry under various measurement scenarios.

Measurement scenario	Mean	SD	Percentile	
			P_{10}	P_{90}
WU – RTK	1.24	0.19	1.06	1.45
06-GPS – RTK	2.37	0.85	1.53	3.48
OmniSTAR–VBS (DGPS)	120.36	53.17	65.27	196.99
WU – EGNOS (DGPS)	103.19	39.92	62.22	164.36
JRC – EGNOS (DGPS)	151.18	56.50	84.56	220.27
Manual digitizing	443.69	86.66	343.21	565.20

(after De Bruin et al., 2008)

Planning algorithm and field experiment

Figure 2 shows an example of an optimised swath pattern where the farmer chose to avoid headlands and rather put field margins along a waterway in the south under an environmental scheme. The pushpins in Figure 2 were e-mailed by the farmer and hold tags with information on potential field margins to be realised. Optimisation required several iterations between farmer and GIS expert.
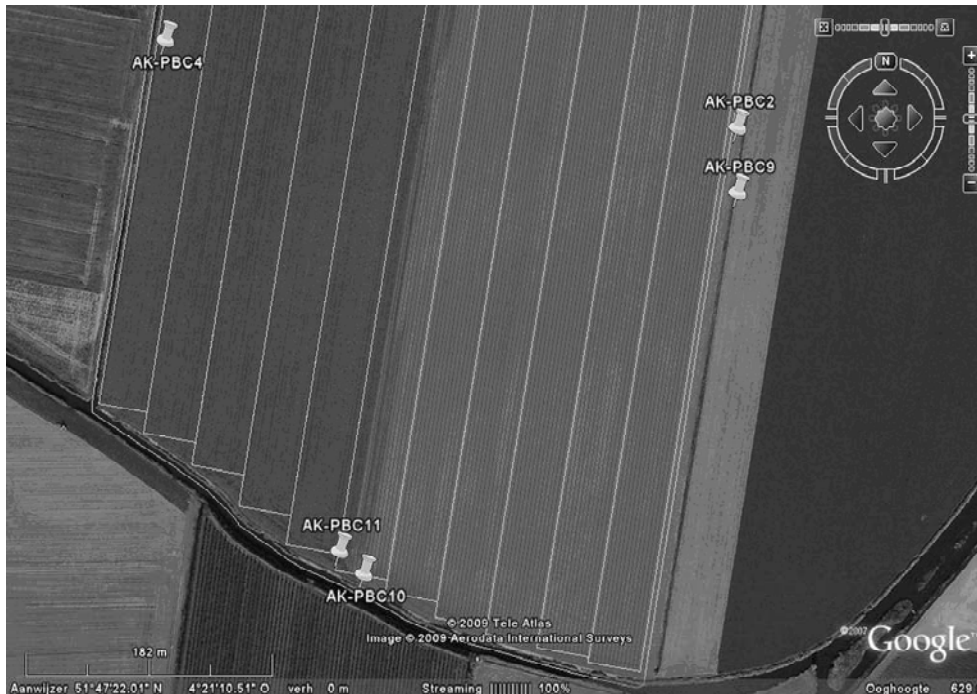

Figure 2. Example of an optimised swath pattern. Thick grey lines indicate spray swaths; faint gray lines within the spraying swaths correspond to plant swaths.

De Bruin et al. (unpublished data) found that given a choice for either compulsory buffer strips or voluntary field margins, the spatial designs of swaths and margins generated by the algorithm were stable under considerably different cost ratios. This is a favourable feature because it may be difficult to obtain accurate estimates for the costs and benefits of swaths and uncropped land. On the other hand, an economic evaluation between the options of narrow compulsory buffer strips and wider voluntary field margins does require accurate estimates of the costs and adequate compensation for area loss. Only in scenarios with the lowest costs assigned to area loss, the costs of designs with field boundaries were lower than those of designs without, but otherwise the opposite was the case (not shown here). In the majority of the scenarios considered, efficiency gains did not outweigh the costs associated with loss of cultivated area. Of course this result is highly dependent on the costs and benefits used in the computations.

Figure 3 shows the quad equipped with RTK GPS equipment that was used successfully to acquire field geometry (3a) and an experimental set-up for testing communication with several brands of farm equipment (3b). The results of the latter will be presented at the JIAC conference.

(a)   **(b)**

Figure 3. Precision positioning used to acquire field geometry (a) and to check communication with farm equipment (b).

Conclusions

If the decision to participate in a field margin programme has been made, our algorithm enables optimisation of the spatial configuration of a single swath pattern while it simultaneously creates space for field margins. Although the method requires accurate data on field geometry, the generated patterns were not influenced by considerable changes in the costs of additional swaths and uncropped areas. We therefore conclude that for solving the spatial configuration problem of swaths and field margins, the cost elements only need to be roughly known. Conversely,

economic evaluations *between* the options of narrow compulsory buffer strips and wider voluntary field margins do require accurate cost estimates. With regards to the required positional accuracy of boundaries, we referred to an operational procedure for measuring field geometry. We have noticed that even for experienced farmers working on nearly rectangular fields it may be quite a challenge to fit a complete final swath when reaching the opposite side of their land. The approach here presented helps to achieve this while it also allows minimizing losses with more irregular field boundaries. For this reason it may appeal to contractors and farmers who rent foreign land e.g. for potato farming. Most benefits, however, can be expected when used for landscape management purposes. In the Hoeksche Waard, for example, the method is being used to support the realization of regional plans concerning biodiversity and societal demands at a local level. Anticipated additional benefits of the approach are potential integration with tracking and tracing systems and reduced soil compaction if field traffic is restricted to predetermined paths.

The research in the Hoeksche Waard was conducted in a unique cooperation between farmers, local administration, businesses and scientists.

References

Batte, M.T. and Ehsani, M.R., 2006. The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers. Computers and Electronics in Agriculture 53: 28-44.

Bochtis, D., Vougioukas, S., Tsatsarelis, C. and Ampatzidis, Y., 2007. Optimal dynamic motion sequence generation for multiple harvesters. Agricultural Engineering International (CIGR EJournal) 9: ATOE 07 001

Brown, J.D. and Heuvelink, G.B.M., 2007. The Data Uncertainty Engine (DUE): A software tool for assessing and simulating uncertain environmental variables. Computers and Geosciences 33: 172-190.

Choset, H., 2001. Coverage for robotics - A survey of recent results. Annals of Mathematics and Artificial Intelligence 31: 113-126.

De Bruin, S. and Hunter, G.J., 2007. Beyond spatial data quality - Assessing the requirements and usability of geo-information products. GEOinformatics April/May 2007: 34-36.

De Bruin, S., Heuvelink, G.B.M. and Brown, J.D., 2008. Propagation of positional measurement errors to agricultural field boundaries and associated costs. Computers and Electronics in Agriculture 63: 245-256.

Gray, S.A., Hansen, S.L. and Flann, N.S., 2006. Path planner and a method for planning a path of a work vehicle. United States Patent 7010425 B2. Deere & Company, Moline, IL.

Heuvelink, G.B.M., Brown, J.D. and Van Loon, E.E., 2007. A probabilistic framework for representing and simulating uncertain environmental variables. International Journal of Geographical Information Science 21: 497-513.

Jin, J. and Tang, L., 2006. Optimal path planning for arable farming. 2006 ASABE Annual International Meeting, Portland, Oregon, American Society of Agricultural Engineers.

Keicher, R. and Seufert, H., 2000. Automatic guidance for agricultural vehicles in Europe. Computers and Electronics in Agriculture 25: 169-194.

Oksanen, T., Kosonen, S. and Visala, A., 2005. Path planning algorithm for field traffic. 2005 ASAE Annual Meeting. American Society of Agricultural and Biological Engineers, Tampa, Florida.

Reid, J.F., Zhang, Q., Noguchi, N. and Dickson, M., 2000. Agricultural automatic guidance research in North America. Computers and Electronics in Agriculture 25: 155-167.

Sparkes, D.L., Jaggard, K.W., Ramsden, S.J. and Scott, R.K., 1998. The effect of field margins on the yield of sugar beet and cereal crops. Annals of Applied Biology 132: 129-142.

Taïx, M., Souères, P., Frayssinet, H. and Cordesses, L., 2006. Path planning for complete coverage with agricultural machines. In: Siciliano, B., Khatib, O., Groen, F. (Eds.), Field and Service Robotics. Springer, Berlin, pp. 549-558.

Vougioukas, S., Blackmore, S., Nielsen, J. and Fountas, S., 2006. A two-stage optimal motion planner for autonomous agricultural vehicles. Precision Agriculture 7: 361-377.